To meet the challenges of energy security and climate change as well as the growing energy needs of the developing world, a global energy technology revolution is essential. This was the key message of the 2008 edition of Energy Technology Perspectives (ETP). But is this fundamental transformation happening? What are the key technologies that can play a role? What are the costs and benefits? And what policies do we need?

The new ETP 2010 explores such questions and many others, drawing on the extensive expertise of the International Energy Agency (IEA) and its energy technology network.

ETP 2010 presents updated scenarios from the present to 2050 that show which new technologies will be most important in key sectors and in different regions of the world. It highlights the importance of finance to achieve change, examines the implications of the scenarios for energy security and looks at how to accelerate the deployment of low-carbon technologies in major developing countries. It presents roadmaps and transition pathways for spurring deployment of the most important clean technologies and for overcoming existing barriers.

With extensive data, projections and analysis, Energy Technology Perspectives 2010 provides decision makers with the detailed information and insights needed to accelerate the switch to a more secure, low-carbon energy future.
Scenarios & Strategies to 2050
The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its mandate is two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply and to advise member countries on sound energy policy.

The IEA carries out a comprehensive programme of energy co-operation among 28 advanced economies, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency aims to:

- Secure member countries’ access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.

IEA member countries:

Australia
Austria
Belgium
Canada
Czech Republic
Denmark
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Japan
Korea (Republic of)
Luxembourg
Netherlands
New Zealand
Norway
Poland
Portugal
Slovak Republic
Spain
Sweden
Switzerland
Turkey
United Kingdom
United States

The European Commission also participates in the work of the IEA.
The previous edition of *Energy Technology Perspectives* (ETP), published in summer 2008, called for an energy technology revolution to tackle the undesirable consequences of our current patterns of energy supply and use. It also highlighted that, if we did not alter course, concerns about energy security and the threat of dangerous climate change would only become much worse. So what – if any – progress have we made over the last two years in meeting these challenges?

At first sight, it may seem as though not much has changed. Countries are still discussing what a long-term climate change framework should look like, while greenhouse-gas emissions go on rising. Concerns about energy security are still with us and oil prices remain high and prone to further volatility.

However, I believe that in fact we may be witnessing the early signs of the historic transition that we so badly need: high oil prices and the global financial crisis may have changed the demand structure for energy. We may indeed see an “oil-less recovery” in OECD countries, in which our economies return to positive growth without a notable pick-up in oil demand. We are also seeing some promising signs of accelerated deployment for a number of important low-carbon technologies, particularly in renewable energy, energy efficiency and advanced vehicle technologies. Funding for clean energy research, development and demonstration is increasing again after more than two decades of decline and stagnation, and many countries have committed to spend even more in the future.

But we still have formidable challenges before us. Tackling climate change and enhancing energy security require a massive decarbonisation of the energy system leading to a new age of electrification. We need to break the historic link between CO$_2$ emissions and economic output; and do this not just for a few years, but from now on. *ETP 2010* shows how this can be achieved. It identifies the technologies that we require and the policies that we will need to stimulate the necessary investment. Importantly, it also clearly demonstrates the benefits in terms not only of reduced CO$_2$ emissions, but also of fossil fuel savings.

We also need to think about what a low-carbon energy mix will mean for comprehensive energy security. On the one hand, reduced dependence on imported fossil fuels and broader development of alternative energy sources can help alleviate some of the current concerns around security of supply for these fuels. Yet as the demand for decarbonised electricity and also for biofuels increases, so new challenges will no doubt emerge requiring innovative policies to ensure that we have the affordable and reliable energy supplies that we need.

*ETP 2010* also shows how efforts to tackle climate change will need to include all major economies and so require truly global co-operation. We at the IEA acutely recognise this challenge, with our member states now representing a decreasing share of the world’s energy demand, production and CO$_2$ emissions. In the face of this, the IEA and its members must create ever stronger ties with key non-member countries such as China, India, Russia and many other countries. The newly proposed international low-carbon energy technology platform is one way in which we are doing this. The platform, which was endorsed by the IEA Ministerial meeting
in October 2009, will bring together policy makers, business representatives and technology experts to discuss how best to encourage the spread of clean energy technologies and, we hope, will usher in a new era of broader, heightened and proactive collaboration.

By working together we can and must meet the global energy challenges we now face. There simply is no alternative. ETP 2010 shows us what we have to do. Let us make that revolutionary future a reality together.

This publication has been produced under my authority as Executive Director of the IEA. The views expressed do not necessarily reflect the views or policies of individual IEA member countries.

Nobuo Tanaka
Executive Director
ACKNOWLEDGEMENTS

This publication was prepared by the International Energy Agency’s Directorate of Sustainable Energy Policy and Technology, under the leadership of Bo Diczfalusy, and in co-operation with other divisions of the Agency. Peter Taylor, Head of the Energy Technology Policy Division, was the project manager and had overall responsibility for the design and implementation of the study. The other main authors were Pierpaolo Cazzola, François Cuenot, Joana Chiavari, David Elzinga, Lew Fulton, Ben Gibson, Tom Kerr, Steven Lee, Uwe Remme, Cecilia Tam, Michael Taylor, Paul Tepes and Nathalie Trudeau.

Many other IEA colleagues have provided important contributions, in particular Brendan Beck, Barbara Buchner (now with the Climate Policy Initiative), Keith Burnard, Kat Cheung, Hugo Chandler, Zuzana Dobrotkova, Paolo Frankl, Dagmar Graczyk, Yuichi Ikeda, Andrea Nour, Sara Pasquier, Cédric Philibert, Carrie Pottinger, Jonathan Sinton and Jayen Veerapen. Helpful advice and support were also received from Sun Joo Ahn, Richard Baron, Marco Baroni, Fatih Birol, Jean-Yves Garnier, Didier Houssin, Julie Jiang, Nigel Jollands, Samantha Ölz, Roberta Quadrelli and Sylvie Stephan. Martin Taylor of the Organisation for Economic Development (OECD) Nuclear Energy Agency was a main author of the nuclear roadmap. The cement roadmap was jointly authored with the World Business Council for Sustainable Development (WBCSD) Cement Sustainability Initiative.

A number of external experts have contributed significantly to different parts of the publication. Heather Haydock (AEA Technology) helped co-ordinate the study and contributed to the chapter on policies to accelerate a low-carbon technology transition. Bloomberg New Energy Finance contributed to the finance chapter. Karen Ehrhardt-Martinez (Human Dimensions Research Associates) helped write the chapter on technology choices and behaviour. Modelling and other support for the United States and OECD Europe chapters was provided respectively by Tom Alfstad (US Department of Energy [US DOE] Brookhaven National Laboratory), and Markus Blesl and Tom Kober (University of Stuttgart). Contributors to the China chapter included Wenyi Chen (Tsinghua University), Libo Wu (Fudan University) and Yufeng Yang (Energy Research Institute), and their colleagues.

The IEA is grateful for the contribution of the India Energy Technology Perspectives Expert Group, chaired by S.M. Dhiman, Member (Planning), Central Electricity Authority; I.C.P. Keshari, Joint Secretary, Ministry of Power, chairman of the power sub-group; Dr. Ajay Mathur, Director General, Bureau of Energy Efficiency, chairman of the buildings sub-group; V. Raghuraman, Chief Adviser, Jaguar Overseas Ltd, chairman of the industry sub-group; Dilip Chenoy, Director General, SIAM, chairman of the transportation sub-group, as well as all participants at the Joint IEA-India Workshop on Regional Analysis of India who provided valuable comments and feedback on the India analysis.

Gillian Balitrand, Annette Hardcastle, Catherine Smith and Colette Davidson helped to prepare the manuscript. Rob Wright (Wrighthand Ltd) carried editorial responsibility.
Production assistance was provided by the IEA Communication and Information Office: Jane Barbière, Madeleine Barry, Viviane Consoli, Muriel Custodio, Rebecca Gaghen, Delphine Grandrieux, Corinne Hayworth, Bertrand Sadin and Marilyn Smith helped to improve and clarify content and managed the layout and graphic design.

Special thanks go to Pieter Boot and Dolf Gielen, former IEA colleagues, for their input and support during the early stages of the project and later expert review.

The work was guided by the members of the IEA Committee on Energy Research and Technology (CERT) who helped to improve substantially the policy relevance of this document. The Standing-Group on Long-Term Co-operation, the Working Party on Energy End-Use Technologies, the Working Party on Renewable Energy Technologies and the Working Party on Fossil Fuels also provided helpful inputs and suggestions.

IEA Implementing Agreements

The technology analysis in this book draws extensively upon the unique IEA international network for collaboration on energy technology. Numerous experts from many of the 42 IEA Implementing Agreements have contributed with data, suggestions and expert review. Some of these experts are listed below:

Advanced Transport Materials
Stephen Hsu

Demand Side Management
Hans Nilsson
Seppo Kärkkäinen

District Heating and Cooling
Robin Wiltshire

Efficient Electrical Equipment
Hans-Paul Siderius

Electricity Networks Analysis, Research and Development
Lars Audun Fodstad
Rainer Bacher
John Baker
Otto Bernsen
Minnesh Bipath
Michele DeNigris
Stig Goethe
Eric Lightner
Ian Welch

Energy Conservation through Energy Storage
Andreas Hauer
Astrid Wille
Heat Pumping Technologies
Monica Axell
Jerry Groff
Roger Nordman
Shogo Tokura

Hybrid and Electric Vehicle Technologies and Programmes
Urs Muntwyler
Martijn Van Walwijk

High-Temperature Superconductivity
Guy Deutscher

Hydrogen
Mary-Rose de Valladares

IEA Clean Coal Centre
Paul Baruya
Colin Henderson
John Kessels
John Topper

IEA Greenhouse Gas RD Programme
John Davison

Renewable Energy Technology Deployment
Ryan Katofsky
Kristian Petrick
Matthew Stanberry

Solar Heating and Cooling
Esther Rojas

Wind Energy Systems
Hannele Holttinen

Expert reviewers

A large number of reviewers provided valuable feedback and input to the analysis presented in this book:

Rosemary Albinson, Castrol, United Kingdom; Roy Antink, Skanska AB, Sweden; Robert Arnot, Natural Resources Canada (NRCan), Canada; Paul Arwas, independent consultant, United Kingdom; Zafer Ates, Permanent Delegation of Turkey to the OECD, France; Quan Bai, Energy Research Institute (ERI), China; Françoise Bartaux, Université Catholique de Louvain, Belgium; Matthew Bateson, WBCSD, Switzerland; Barbara Bauman Tyran, Electric Power Research Institute (EPRI), United States; Georg Bäuml, Volkswagen, Germany; Chris Bayliss, International Aluminium Institute (IAI), United Kingdom; Morgan Bazilian, United Nations Industrial Development Organization (UNIDO), Austria; David Beauvais, NRCan, Canada; Martina Beitke, European Chemical Industry Council (CEFIC),
Belgium; Ron Benioff, National Renewable Energy Laboratory (NREL), United States; Kamel Bennaceur, Schlumberger, France; Alissa Boardley, Environment Canada, Canada; Inger Rihl Byriel, Energinet, Denmark; Terry Carrington, Department of Energy and Climate Change (DECC), United Kingdom; Satish Chander, The Fertiliser Association of India, India; Ian Christmas, Worldsteel, Belgium; Robert Clover, HSBC, United Kingdom; Jonathan Coony, World Bank, United States; Karlynn Cory, NREL, United States; Sean Cuthbert, Lloyd's Register Group Services Ltd., United Kingdom; Pradeep Kumar Dadhich, The Energy and Resources Institute (TERI), India; Francois Dassa, EDF, France; Pedro Dias, European Solar Thermal Industry Federation, Belgium; Carmen Difiglio, US DOE, United States; Rick Duke, US DOE, United States; George Eads, Consultant, United States; Andrew Eil, International Finance Corporation (IFC), United States; Eric J. ten Elshof, Ministry of Economic Affairs, the Netherlands; Craig Erdrich, US DOE, United States; Robert Falzon, Goldman Sachs, United Kingdom; Nicolas Fichaux, European Wind Energy Association, Belgium; Michel Folliet, IFC, United States; Timothy Foxon, University of Leeds, United Kingdom; Jim Fritz, UTC, United States; Eamon Geraghty, International Building Materials Group (CRH), Ireland; Doug Grano, United States Environmental Protection Agency (US EPA), United States; Sallie Greenberg, Illinois State Geological Survey, United States; Jake Handelsman, American Forest and Paper Association (AF&PA), United States; Atsushi Hatano, Nissan, Japan; Ruth Herbert, DECC, United Kingdom; Andrew Higham, United Nations Framework Convention on Climate Change (UNFCCC) Secretariat, Germany; Neil Hirst, Imperial College, United Kingdom; Volker Hoenig, VZD, Germany; Bazmi Hussain, ABB, Switzerland; Tomoya Ichimura, New Energy and Industrial Technology Development Organization, Japan; Kejun Jiang, ERI, China; Nakhun Jung, Ministry of Knowledge Economy, Korea; Birte Holst Jorgensen, Technical University of Denmark, Denmark; Mitsuru Kaihori, Japan Paper Association, Japan; Larry Kavanagh, American Iron and Steel Institute, United States; Ron Knapp, IAI, United Kingdom; Steve Kidd, World Nuclear Association, United Kingdom; Joris Knigge, Enexis, Netherlands; Bernhard Kohl, Eurofer, Belgium; Joachim Krüger, CEFIC, Belgium; Martyna Kurcz-Jenn, Alstom, Belgium; Skip Laitner, American Council for an Energy-Efficient Economy, United States; Paul Lansbergen, Forest Products Association of Canada, Canada; Erin Laws, Energy Efficiency and Conservation Authority (EECA), New Zealand; Jean Le Cocguic, OECD, France; Henry Lee, Harvard University, United States; Yongpil Lee, Ministry of Knowledge Economy, Korea; Xavier Leflaive, OECD, France; Alan Meier, Lawrence Berkeley Laboratory, United States; Maria Mendiluce, WBCSD, Switzerland; Gilles Mercier, NRCan, Canada; Andy Miller, US EPA; United States; Marco Mensink, Confederation of European Paper Industries, Belgium; Motomi Miyashita, Japan Gas Association, Japan; Fuad Mohamed Siala, Organization of Petroleum Exporting Countries, Austria; Danielle H. Monosson, US State Department, United States; David Mora, University of Flensburg, Denmark; Ben Muirhead, International Fertilizer Industry Association (IFA), France; Denise Mulholland, US EPA, United States; S. Nand, The Fertiliser Association of India, India; Nakano Naokazu, Japan Iron and Steel Federation, Japan; Thomas Nowak, European Heat Pump Association, Belgium; Nils-Olof Nylund, VTT, Finland; Stathis Peteves, European Commission Joint Research Centre, the Netherlands; Dirk Pilat, OECD, France; Sean Plasynski, US DOE National Energy Technology Laboratory, United States; Thomas Pregger, German Aerospace Center, Germany; Shuba V. Raghavan, Center for Study of
Science, Technology and Policy (CSTEP), India; Wayne Richardson, independent consultant, Canada; Nick Robins, HSBC, United Kingdom; Hans-Holger Rogner, International Atomic Energy Agency (IAEA), Vienna; Sea Ratmann, EECA, New Zealand; Claes Rytoft, ABB, Switzerland; Steve Sawyer, Global Wind Energy Council, Belgium; Laurent Schmitt, Alstom, France; Elizabeth Shove, Lancaster University, United Kingdom; William Sisions, UTC, United States; Rebecca Smith-Kevern, US DOE, United States; Erik Kjær Soerensen, Vestas Wind Systems A/S, Denmark; Ravi Srivastava, EPA, United States; Garry Staunton, Carbon Trust, United Kingdom; Helga Stenseth, Ministry of Foreign Affairs, Norway; Paul Stern, National Academy of Sciences, United States; Didier Stevens, Toyota, Europe; Gary Siegel, US DOE- NETL, United States; Ulrik Stridbæk, Dong Energy, Denmark; Hiroyuki Takahashi, Tokyo Electric Power Company Inc. (TEPCO), Japan; Wanna Tanunchaiwatana, UNFCCC Secretariat, Germany; Martin Taylor, OECD Nuclear Energy Agency, France; Shogo Tokura, Heat Pump and Thermal Storage Center for Japan, Japan; Ferenc L. Toth, IAEA, Vienna; Franz Trieb, German Aerospace Center, Germany; Caroline Twigg, WBCSD Cement Sustainability Initiative, Switzerland; Alice Tyne, Bloomberg New Energy Finance, United Kingdom; Fridtjof Unander, Research Council of Norway, Norway; Diana Úrge-Vorsatz, Central European University, Hungary; Rob van der Meer, Heidelberg Cement, Netherlands; Charles Vlek, University of Groningen, Netherlands; Michael Wang, Argonne National Laboratory, United States; Shannon Wang, REN21 Secretariat, France; Yanjia Wang, Tsinghua University, China; Masaaki Watanabe, TEPCO, Japan; Wolfgang Weber, BASF, Germany; Anthony White, B W Energy, United Kingdom; Michael Whitfield, Department of Resources, Energy and Tourism, Australia; Mark Winskel, University of Edinburgh, United Kingdom; Bartosz Wojszczycz, General Electric, United States; Jacqueline Wong, US DOE, United States; Casey Zils, European Climate Exchange, United Kingdom.

Workshops

A number of workshops and meetings were held in the framework of this study and the development of the technology roadmaps. The workshop participants have contributed valuable new insights, data and feedback for this analysis:

- Enhancing International Technology Collaboration, 12-13 November 2008, Washington, DC;
- Energy Technology Transition Project Launch Workshop, 13-14 June 2009, Beijing;
First IEA-Indian ETP Expert Group Workshop, 20 October 2009, Delhi;

From Roadmaps to Implementation, 2-3 November 2009, Paris;

Workshop on Regional Analysis for the Energy Technology Perspectives 2010, 19 January 2010, Beijing;

Energy Technology Roadmap Workshop, 20 January 2010, Beijing;

Joint IEA-India Workshop on Regional Analysis of India in the Energy Technology Perspective 2010, 29 January 2010, New Delhi;

Chief Technology Officer Roundtable, 2 February, 2010;

Energy Efficient and Low-Carbon Buildings: Heating and Cooling. Workshops were held on heat pumps (9 November, 2009); thermal energy storage (9 December, 2009); solar thermal (2 February, 2010); CHP (3 February, 2010) and policy and finance issues (6-7 May, 2010).

This study has been supported by voluntary contributions and in-kind support from many IEA governments, including Australia, Canada, Denmark, Germany, Japan, the Netherlands, Norway, Switzerland, the United Kingdom and the United States.

The individuals and organisations that contributed to this study are not responsible for any opinions or judgements contained in this study. Any errors and omissions are solely the responsibility of the IEA.

Comments and questions are welcome and should be addressed to:

Peter Taylor
Head, Energy Technology Policy Division
International Energy Agency
9, Rue de la Fédération
75739 Paris Cedex 15
France

Email: peter.taylor@iea.org

©OECD/IEA, 2010
TABLE OF CONTENTS

PART 1

TECHNOLOGY AND
THE GLOBAL ENERGY ECONOMY TO 2050

PART 2

THE TRANSITION
FROM PRESENT TO 2050
Foreword ................................................. 3
Acknowledgements ....................................... 5
Table of contents ......................................... 11
List of figures ................................................. 25
List of tables .................................................. 36
List of boxes .................................................. 42
Executive summary ...................................... 45

Chapter 1 Introduction ................................. 61
The political context ..................................... 62
The purpose and scope of this study .................. 63

PART 1 Technology and the Global Energy Economy to 2050

Chapter 2 Overview of scenarios ................. 67
Scenario characteristics ............................... 68
Energy and CO₂ emission trends .................... 72
Technologies for reducing CO₂ emissions ......... 74
Energy efficiency ....................................... 77
Power sector ........................................... 79
Fuel switching in end-use sectors .................. 80
Carbon capture and storage ......................... 81
Investment costs and fuel savings .................. 82
Regional and country-level trends ................. 83
Sectoral trends .......................................... 88
Energy trends ........................................... 90
Coal .................................................. 91
Liquid fuel ........................................... 92
Natural gas ........................................... 94
## TABLE OF CONTENTS

- Electricity 96
- Biomass 96
- **Going beyond the BLUE scenarios** 98

### Chapter 3
#### Electricity generation 101

- **Introduction** 102
- **Recent trends** 103
  - Generation mix by fuel 103
  - Efficiency of electricity generation 104
  - CO$_2$ emissions 105
- **Future scenarios** 106
  - Baseline scenario 106
  - BLUE Map scenario 107
  - BLUE scenario variants 111
- **Fossil fuel power plants** 113
  - Overview 113
  - Technology status and prospects 115
  - Costs 118
- **Carbon capture and storage** 119
  - Overview 119
  - Technology status and prospects 120
  - Costs 123
- **Renewable energy** 124
  - Overview 124
  - Technology status and prospects 126
  - Costs 133
- **Nuclear power** 134
  - Overview 134
  - Technology status and prospects 136
  - Costs 138

### Chapter 4
#### Electricity networks 141

- **Introduction** 142
- History of the grid 142
**Electricity demand** .................................................. 143
  Electricity demand by region .......................... 143
  Electricity demand by sector ......................... 144
  Demand profiles ..................................................... 145

**Electricity generation** ............................................. 147

**Power system flexibility** ................................. 149

**Electricity network losses** ................................. 149

**Vision for the grid of the future** .................... 150
  Smart grid technology ........................................ 151
  Benefits of smart grids ...................................... 152
  Smart grid CO\textsubscript{2} emissions reduction .... 153
  Benefits for developing countries .................... 154
  Storage technology ............................................. 154
  Analysis of electricity storage needs ............. 155
  How much does the grid of the future cost? .... 156

**Barriers to electricity grid investment** ............ 156

**Priorities for next steps** ................................. 157
  Regional assessment of grid needs ................. 157
  Technology research, development and demonstration (RD&D) needs 158
  Markets ............................................................. 158
  Regulatory and policy needs ......................... 159
  Public education and public engagement ........ 159
  Human resources .................................................. 159

---

**Industry** .......................................................... 161

**Introduction** .................................................... 162

**Industrial energy use and CO\textsubscript{2} emissions** .......... 162

**Energy and CO\textsubscript{2} scenarios** ...................... 166
  Scenario assumptions .................................... 166
  Scenario results .................................................. 167
  Carbon capture and storage ......................... 172
  Industrial electrification ............................... 173
  Recycling .......................................................... 174
  Sectoral results .................................................. 175
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron and steel</td>
<td>176</td>
</tr>
<tr>
<td>Energy efficiency and CO₂ reduction potentials</td>
<td>176</td>
</tr>
<tr>
<td>Scenario results</td>
<td>177</td>
</tr>
<tr>
<td>Technology options</td>
<td>179</td>
</tr>
<tr>
<td>Investment costs</td>
<td>181</td>
</tr>
<tr>
<td>Cement</td>
<td>181</td>
</tr>
<tr>
<td>Energy efficiency and CO₂ reduction potentials</td>
<td>181</td>
</tr>
<tr>
<td>Scenario results</td>
<td>182</td>
</tr>
<tr>
<td>Technology options</td>
<td>183</td>
</tr>
<tr>
<td>Investment costs</td>
<td>185</td>
</tr>
<tr>
<td>Chemicals</td>
<td>185</td>
</tr>
<tr>
<td>Energy efficiency and CO₂ reduction potentials</td>
<td>185</td>
</tr>
<tr>
<td>Scenario results</td>
<td>186</td>
</tr>
<tr>
<td>Technology options</td>
<td>187</td>
</tr>
<tr>
<td>Investment costs</td>
<td>189</td>
</tr>
<tr>
<td>Pulp and paper</td>
<td>189</td>
</tr>
<tr>
<td>Energy efficiency and CO₂ reduction potentials</td>
<td>190</td>
</tr>
<tr>
<td>Scenario results</td>
<td>191</td>
</tr>
<tr>
<td>Technology options</td>
<td>192</td>
</tr>
<tr>
<td>Investment costs</td>
<td>193</td>
</tr>
<tr>
<td>Aluminium</td>
<td>194</td>
</tr>
<tr>
<td>Energy efficiency and CO₂ reduction potentials</td>
<td>194</td>
</tr>
<tr>
<td>Scenario results</td>
<td>195</td>
</tr>
<tr>
<td>Technology options</td>
<td>196</td>
</tr>
<tr>
<td>Investment costs</td>
<td>197</td>
</tr>
<tr>
<td>Industry-wide regional implications.</td>
<td>198</td>
</tr>
<tr>
<td>Investment costs</td>
<td>199</td>
</tr>
<tr>
<td>Policy changes needed to support technology transition in industry</td>
<td>201</td>
</tr>
<tr>
<td>From sectoral agreements to global emissions trading</td>
<td>201</td>
</tr>
<tr>
<td>Improving industrial data coverage should be a priority</td>
<td>202</td>
</tr>
<tr>
<td>Pathway to the next Industrial Revolution</td>
<td>202</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>205</td>
</tr>
<tr>
<td>Buildings</td>
<td>205</td>
</tr>
<tr>
<td>Overview of the residential and service sectors</td>
<td>206</td>
</tr>
<tr>
<td>Building stock turnover and heating and cooling</td>
<td>207</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Current building stock and energy consumption</td>
<td>207</td>
</tr>
<tr>
<td>Households: the residential building stock and its characteristics</td>
<td>207</td>
</tr>
<tr>
<td>The service sector building stock</td>
<td>210</td>
</tr>
<tr>
<td>Global trends in buildings sector energy consumption</td>
<td>211</td>
</tr>
<tr>
<td>Residential sector</td>
<td>211</td>
</tr>
<tr>
<td>The service sector</td>
<td>212</td>
</tr>
<tr>
<td>Buildings sector CO₂ emissions</td>
<td>213</td>
</tr>
<tr>
<td>Demand drivers in the scenario analysis</td>
<td>214</td>
</tr>
<tr>
<td>The Baseline scenario</td>
<td>215</td>
</tr>
<tr>
<td>Energy consumption by fuel and by sector</td>
<td>215</td>
</tr>
<tr>
<td>Energy consumption and CO₂ emissions by region and by sector</td>
<td>216</td>
</tr>
<tr>
<td>The BLUE Map scenario</td>
<td>218</td>
</tr>
<tr>
<td>Energy consumption in the BLUE Map scenario</td>
<td>220</td>
</tr>
<tr>
<td>Investment requirements in the BLUE Map scenario</td>
<td>227</td>
</tr>
<tr>
<td>BLUE scenario variants</td>
<td>229</td>
</tr>
<tr>
<td>Technology options in the BLUE Map scenario</td>
<td>230</td>
</tr>
<tr>
<td>The building envelope and good design</td>
<td>231</td>
</tr>
<tr>
<td>Heat pumps for heating and cooling</td>
<td>235</td>
</tr>
<tr>
<td>Combined heat and power in buildings</td>
<td>241</td>
</tr>
<tr>
<td>Solar thermal heating and cooling</td>
<td>246</td>
</tr>
<tr>
<td>Lighting and appliances</td>
<td>250</td>
</tr>
<tr>
<td>Transport</td>
<td>255</td>
</tr>
<tr>
<td>Introduction</td>
<td>256</td>
</tr>
<tr>
<td>Energy efficiency by mode</td>
<td>260</td>
</tr>
<tr>
<td>Transport scenarios</td>
<td>263</td>
</tr>
<tr>
<td>Scenario results</td>
<td>264</td>
</tr>
<tr>
<td>Transport technologies and policies</td>
<td>278</td>
</tr>
<tr>
<td>Fuels</td>
<td>278</td>
</tr>
<tr>
<td>Light-duty vehicles</td>
<td>281</td>
</tr>
<tr>
<td>Advanced technology vehicles</td>
<td>282</td>
</tr>
<tr>
<td>Trucking and rail freight</td>
<td>288</td>
</tr>
<tr>
<td>Aviation</td>
<td>290</td>
</tr>
<tr>
<td>Shipping</td>
<td>293</td>
</tr>
</tbody>
</table>
## OECD Europe

### Regional description

- 298

### Recent trends in energy and CO₂ emissions

- 298
  - Energy production and supply
  - Energy consumption
  - End-use efficiency improvement
  - Carbon dioxide emissions

### Overall energy policy framework

- 302
  - Current status of energy policies and climate change initiatives

### Overview of scenarios and CO₂ abatement options

- 307
  - Energy and CO₂ emission scenarios
  - Carbon dioxide abatement options

### Sectoral results

- 310
  - Power sector
  - Industry sector
  - Buildings sector
  - Transport sector

### Investment needs in the BLUE Map scenario

- 331

### Transition to a low-carbon energy future

- 332
  - Future technology priorities
  - Future policy priorities

## United States

### Regional description

- 338

### Recent trends in energy and CO₂ emissions

- 338
  - Energy production and supply
  - Energy consumption
  - End-use efficiency improvement
  - Carbon dioxide emissions

### Overall energy policy framework

- 341
  - Current status of energy policies and climate change initiatives

### Overview of scenarios and CO₂ abatement options

- 345
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy and CO₂ emission scenarios</td>
<td>345</td>
</tr>
<tr>
<td>Carbon dioxide abatement options</td>
<td>346</td>
</tr>
<tr>
<td><strong>Sectoral results</strong></td>
<td>347</td>
</tr>
<tr>
<td>Power sector</td>
<td>347</td>
</tr>
<tr>
<td>Industry sector</td>
<td>355</td>
</tr>
<tr>
<td>Buildings sector</td>
<td>358</td>
</tr>
<tr>
<td>Transport sector</td>
<td>363</td>
</tr>
<tr>
<td><strong>Investment needs in the BLUE Map scenario</strong></td>
<td>368</td>
</tr>
<tr>
<td><strong>Transition to a low-carbon energy future</strong></td>
<td>369</td>
</tr>
<tr>
<td>Future technology priorities</td>
<td>369</td>
</tr>
<tr>
<td>Future policy priorities</td>
<td>370</td>
</tr>
<tr>
<td><strong>Chapter 10: China</strong></td>
<td>373</td>
</tr>
<tr>
<td><strong>Regional description</strong></td>
<td>374</td>
</tr>
<tr>
<td><strong>Recent trends in energy and CO₂ emissions</strong></td>
<td>374</td>
</tr>
<tr>
<td>Energy production and supply</td>
<td>375</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>377</td>
</tr>
<tr>
<td>End-use efficiency improvement</td>
<td>378</td>
</tr>
<tr>
<td>Carbon dioxide emissions</td>
<td>378</td>
</tr>
<tr>
<td><strong>Overall energy policy framework</strong></td>
<td>378</td>
</tr>
<tr>
<td>Current status of energy policies and climate change initiatives</td>
<td>380</td>
</tr>
<tr>
<td><strong>Overview of scenarios and CO₂ abatement options</strong></td>
<td>381</td>
</tr>
<tr>
<td>Energy and CO₂ emission scenarios</td>
<td>382</td>
</tr>
<tr>
<td>Carbon dioxide abatement options</td>
<td>383</td>
</tr>
<tr>
<td><strong>Sectoral results</strong></td>
<td>384</td>
</tr>
<tr>
<td>Power sector</td>
<td>384</td>
</tr>
<tr>
<td>Industry sector</td>
<td>391</td>
</tr>
<tr>
<td>Buildings sector</td>
<td>397</td>
</tr>
<tr>
<td>Transport sector</td>
<td>402</td>
</tr>
<tr>
<td><strong>Investment needs in the BLUE Map scenario</strong></td>
<td>409</td>
</tr>
<tr>
<td><strong>Transition to a low-carbon energy future</strong></td>
<td>411</td>
</tr>
<tr>
<td>Future technology and policy priorities</td>
<td>411</td>
</tr>
</tbody>
</table>
Chapter 11  India  415

Regional description  416

Recent trends in energy and CO₂ emissions  417
   Energy production and supply  417
   Energy consumption  419
   End-use efficiency improvement  420
   Carbon dioxide emissions  421

Overall energy policy framework  421
   Current status of energy policies and climate change initiatives  422

Overview of scenarios and CO₂ abatement options  424
   Energy and CO₂ emission scenarios  425
   Carbon dioxide abatement options  426

Sectoral results  427
   Power sector  427
   Industry sector  433
   Buildings sector  438
   Transport sector  444

Investment needs in the BLUE Map scenario  450

Transition to a low-carbon energy future  452

PART 2  The Transition from Present to 2050

Chapter 12  Policies to accelerate a low-carbon technology transition  459

Introduction  460

The need for energy technology policies  463
   Tailoring policies to the stage of technology development  464
   Enabling actions: addressing the business and human aspects of a low-carbon technology revolution  469

Energy technology research, development and demonstration  476
   Current public-sector low-carbon RD&D expenditure  476
Private-sector RD&D spending 478
Assessing the gap: global low-carbon energy technology RD&D needs 479
Accelerating energy technology RD&D 481

Chapter 13 Technology roadmaps 489

A portfolio of technologies is needed 489
The role of roadmaps 492
Roadmaps 493
Roadmap summaries 493
Carbon capture and storage roadmap 494
Cement sector roadmap 498
Concentrating solar power roadmap 502
Electric and plug-in hybrid vehicles roadmap 506
Nuclear energy roadmap 510
Solar photovoltaic power roadmap 514
Wind energy roadmap 518

Chapter 14 Finance 523

Investment needs 524
Baseline scenario 524
BLUE Map scenario 525
Fuel savings 529
Current trends in financing of low-carbon technologies and global energy asset finance 530
International financing mechanisms 535
Financing technology deployment in non-OECD countries 535
Financing options for an energy technology revolution 544
Public finance mechanisms 550
Risk and returns 552
Cost of debt and equity 552
Risk versus return 552
Policy needs 555
### Chapter 15: Accelerating the diffusion of low-carbon technologies in emerging economies

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>566</td>
</tr>
<tr>
<td>Background</td>
<td>568</td>
</tr>
<tr>
<td>Non-OECD countries’ contribution to CO₂ emissions reduction in</td>
<td>568</td>
</tr>
<tr>
<td>the Baseline and BLUE Map scenarios</td>
<td></td>
</tr>
<tr>
<td>Investment needs in emerging economies in the BLUE Map scenario</td>
<td>570</td>
</tr>
<tr>
<td>Diffusion of low-carbon technologies in emerging economies</td>
<td>571</td>
</tr>
<tr>
<td>Low-carbon technology flows</td>
<td>573</td>
</tr>
<tr>
<td>Trade flows</td>
<td>576</td>
</tr>
<tr>
<td>International financial flows of low-carbon energy technologies</td>
<td>577</td>
</tr>
<tr>
<td>Private flows</td>
<td>578</td>
</tr>
<tr>
<td>Official flows</td>
<td>579</td>
</tr>
<tr>
<td>Flows under the UNFCCC and the Kyoto Protocol</td>
<td>582</td>
</tr>
<tr>
<td>Summary of international financial flows for diffusion of low-carbon</td>
<td>583</td>
</tr>
<tr>
<td>technologies</td>
<td></td>
</tr>
<tr>
<td>Enhancing technology diffusion</td>
<td>584</td>
</tr>
<tr>
<td>Strengthening low-carbon technological capacity in emerging economies</td>
<td>588</td>
</tr>
<tr>
<td>The way forward</td>
<td>592</td>
</tr>
</tbody>
</table>

### Chapter 16: Technology choices and behaviour

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>596</td>
</tr>
<tr>
<td>The potential contribution of behaviour</td>
<td>596</td>
</tr>
<tr>
<td>Social and behavioural frameworks</td>
<td>597</td>
</tr>
<tr>
<td>Extensions and alternatives to the techno-economic model</td>
<td>599</td>
</tr>
<tr>
<td>Chapter 17</td>
<td>Environmental co-impacts of emerging energy technologies</td>
</tr>
<tr>
<td>------------</td>
<td>----------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Introduction ..................................................................</td>
</tr>
<tr>
<td></td>
<td>Objective and scope ...................................................</td>
</tr>
<tr>
<td></td>
<td>Co-impacts in context ................................................</td>
</tr>
<tr>
<td></td>
<td>Impact areas ...................................................................</td>
</tr>
<tr>
<td></td>
<td>Co-impacts in the electricity sector ............................</td>
</tr>
<tr>
<td></td>
<td>Technologies assessed ..................................................</td>
</tr>
<tr>
<td></td>
<td>Baseline case: USC coal combustion ................................</td>
</tr>
<tr>
<td></td>
<td>Biomass co-combustion ..................................................</td>
</tr>
<tr>
<td></td>
<td>Carbon capture and storage ............................................</td>
</tr>
<tr>
<td></td>
<td>Integrated gasification combined cycle .............................</td>
</tr>
<tr>
<td></td>
<td>Natural gas combined cycle ............................................</td>
</tr>
<tr>
<td></td>
<td>Nuclear: Generation-III ..................................................</td>
</tr>
<tr>
<td></td>
<td>Solar: concentrating solar power ......................................</td>
</tr>
<tr>
<td></td>
<td>Solar: photovoltaic power ...............................................</td>
</tr>
<tr>
<td></td>
<td>Wind .............................................................................</td>
</tr>
<tr>
<td></td>
<td>Quantitative results from the electricity sector .................</td>
</tr>
<tr>
<td></td>
<td>Overall results relative to the coal baseline .....................</td>
</tr>
<tr>
<td></td>
<td>Transport co-impacts: passenger light-duty vehicles ..............</td>
</tr>
<tr>
<td></td>
<td>Technologies assessed ..................................................</td>
</tr>
<tr>
<td></td>
<td>Air impacts .....................................................................</td>
</tr>
<tr>
<td></td>
<td>Water impacts ..................................................................</td>
</tr>
<tr>
<td></td>
<td>Land impacts ...................................................................</td>
</tr>
<tr>
<td></td>
<td>Other considerations ......................................................</td>
</tr>
<tr>
<td></td>
<td>Recommendations for next steps ........................................</td>
</tr>
</tbody>
</table>
Annex A Framework assumptions 651
Annex B IEA Energy Technology Collaboration Programme 655
Annex C Acronyms 663
Annex D Definitions, abbreviations and units 669
Annex E References 677

LIST OF FIGURES

Executive summary

Figure ES.1 Key technologies for reducing CO₂ emissions under the BLUE Map scenario 47
Figure ES.2 Policies for supporting low-carbon technologies 50
Figure ES.3 Global CO₂ emissions in the Baseline and BLUE Map scenarios 54

Chapter Overview scenarios

Figure 2.1 Global CO₂ emissions in the Baseline and BLUE Map scenarios 73
Figure 2.2 Key technologies for reducing CO₂ emissions under the BLUE Map scenario 75
Figure 2.3 CO₂ emissions reductions in the BLUE Map scenario by sector 76
Figure 2.4 CO₂ emissions reductions by technology area in 2050 in the BLUE Map scenario 76
Figure 2.5 Long-term energy savings from improvements in energy efficiency, OECD-11 78
Figure 2.6 Historical and projected changes in final energy consumption per unit of GDP 79
Figure 2.7 Use of carbon capture and storage in the BLUE Map scenario, 2050 82
Figure 2.8 Shares of primary energy use by fuel and final energy use by sector, 2007 83
Figure 2.9 CO₂ emissions by region/country in the Baseline and BLUE Map scenarios 85
Figure 2.10 Contribution of technologies to CO₂ emissions abatement in the BLUE Map scenario for different countries and regions, 2050 86
Figure 2.11 Energy use by sector in the Baseline scenario 88
Figure 2.12 Final energy use by sector 89
| Figure 2.13 | World total primary energy supply | 90 |
| Figure 2.14 | Primary energy demand by fuel and by scenario | 91 |
| Figure 2.15 | World coal demand by scenario | 92 |
| Figure 2.16 | World liquid fuel supply by scenario | 93 |
| Figure 2.17 | Reduction in oil demand by sector in the BLUE Map scenario, 2050 | 94 |
| Figure 2.18 | World natural gas demand by scenario | 95 |
| Figure 2.19 | World electricity demand by scenario | 96 |
| Figure 2.20 | World biomass use by scenario | 97 |

**Chapter 3 Technology roadmaps**

| Figure 3.1 | Historical trends in global electricity production | 103 |
| Figure 3.2 | Efficiency of electricity production from fossil fuels | 104 |
| Figure 3.3 | CO₂ emissions from global electricity generation | 105 |
| Figure 3.4 | Global electricity production by energy source and by scenario | 106 |
| Figure 3.5 | CO₂ intensity of electricity production by scenario | 107 |
| Figure 3.6 | The contribution of different power sector technologies to reductions in CO₂ emissions in the BLUE Map scenario | 108 |
| Figure 3.7 | Growth of renewable power generation in the BLUE Map scenario | 109 |
| Figure 3.8 | Net electricity generation efficiencies of fossil-fuelled power plants by scenario | 109 |
| Figure 3.9 | Global deployment of CCS and CO₂ captured in the power sector in the BLUE Map scenario in 2050 | 110 |
| Figure 3.10 | Share of fossil-fuelled electricity generation in selected countries and regions, 2007 | 114 |
| Figure 3.11 | Electricity generation from fossil fuels by technology type and by scenario, 2050 | 114 |
| Figure 3.12 | Regional deployment of CCS in power generation under the BLUE Map scenario | 119 |
| Figure 3.13 | Composition of renewable power generation, 2007 | 124 |
| Figure 3.14 | Renewable electricity generation in the BLUE Map scenario for key countries and regions in 2050 | 125 |
| Figure 3.15 | World nuclear generating capacity | 135 |

**Chapter 4 Electricity networks**

<p>| Figure 4.1 | Global electricity demand by sector | 144 |
| Figure 4.2 | Load duration curves for several countries in 2008 | 146 |</p>
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 4.3</td>
<td>Daily average residential electricity demand in a sample of homes in Florida, United States with a high penetration of central air-conditioning load</td>
<td>146</td>
</tr>
<tr>
<td>Figure 4.4</td>
<td>Global electricity generation mix</td>
<td>148</td>
</tr>
<tr>
<td>Figure 4.5</td>
<td>Regional generation mix in 2050, BLUE Map scenario</td>
<td>148</td>
</tr>
<tr>
<td>Figure 4.6</td>
<td>A smart grid</td>
<td>151</td>
</tr>
<tr>
<td>Figure 4.7</td>
<td>Smart grid CO$_2$ reductions in 2050 in the BLUE Map scenario compared to the Baseline scenario</td>
<td>153</td>
</tr>
<tr>
<td>Figure 4.8</td>
<td>Barriers to electricity grid investment</td>
<td>157</td>
</tr>
</tbody>
</table>

**Chapter 5: Industry**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 5.1</td>
<td>World industrial energy use by sector</td>
<td>163</td>
</tr>
<tr>
<td>Figure 5.2</td>
<td>Industrial energy use by region and by fuel, 2007</td>
<td>164</td>
</tr>
<tr>
<td>Figure 5.3</td>
<td>Direct CO$_2$ emissions in industry by sector and by region, 2007</td>
<td>166</td>
</tr>
<tr>
<td>Figure 5.4</td>
<td>Materials production under the Baseline and BLUE scenarios</td>
<td>168</td>
</tr>
<tr>
<td>Figure 5.5</td>
<td>Total industry CO$_2$ emissions in the Baseline and BLUE scenarios</td>
<td>169</td>
</tr>
<tr>
<td>Figure 5.6</td>
<td>Contribution to total direct and indirect CO$_2$ emissions reductions in the industry sector in the BLUE scenarios compared to Baseline scenarios</td>
<td>169</td>
</tr>
<tr>
<td>Figure 5.7</td>
<td>Share of industrial energy use by fuel in the Baseline and BLUE scenarios</td>
<td>170</td>
</tr>
<tr>
<td>Figure 5.8</td>
<td>Use of biomass and waste in the industrial sector</td>
<td>171</td>
</tr>
<tr>
<td>Figure 5.9</td>
<td>Industrial CO$_2$ emissions reductions from CCS compared to the Baseline equivalent scenarios by sector, 2050</td>
<td>172</td>
</tr>
<tr>
<td>Figure 5.10</td>
<td>Direct energy and process CO$_2$ emissions in industry by sector</td>
<td>175</td>
</tr>
<tr>
<td>Figure 5.11</td>
<td>Energy savings potential in 2007 for iron and steel, based on BATs</td>
<td>177</td>
</tr>
<tr>
<td>Figure 5.12</td>
<td>Direct emissions reduction by technology option for iron and steel</td>
<td>178</td>
</tr>
<tr>
<td>Figure 5.13</td>
<td>Energy savings potential in 2007 for cement, based on BATs</td>
<td>182</td>
</tr>
<tr>
<td>Figure 5.14</td>
<td>Direct emissions reduction by technology option for cement</td>
<td>183</td>
</tr>
<tr>
<td>Figure 5.15</td>
<td>Energy savings potential in 2007 for chemicals, based on BPT</td>
<td>186</td>
</tr>
<tr>
<td>Figure 5.16</td>
<td>Direct emissions reduction by technology option for chemicals and petrochemicals</td>
<td>187</td>
</tr>
<tr>
<td>Figure 5.17</td>
<td>Energy savings potential in the paper and pulp sector in 2007, based on BATs</td>
<td>190</td>
</tr>
<tr>
<td>Figure 5.18</td>
<td>Direct emissions reduction by technology option for pulp and paper, 2007-50</td>
<td>192</td>
</tr>
<tr>
<td>Figure 5.19</td>
<td>Energy savings potential in 2007 in the aluminium sector, based on BATs</td>
<td>194</td>
</tr>
</tbody>
</table>
Chapter 6  Buildings

Figure 6.1  Economic life spans of energy-consuming equipment and infrastructure 209
Figure 6.2  Share of residential building stock in selected countries by vintage 209
Figure 6.3  Service sector value added by country 210
Figure 6.4  Global energy consumption of buildings by sector 211
Figure 6.5  Household energy use by energy commodity 212
Figure 6.6  Service sector energy use by energy commodity 213
Figure 6.7  Buildings sector energy consumption in the Baseline scenario by sector and by energy commodity 215
Figure 6.8  Residential sector energy consumption by fuel and by region in the Baseline scenario 217
Figure 6.9  Service sector energy consumption by fuel and by region in the Baseline scenario 217
Figure 6.10  Buildings sector energy consumption by fuel and by scenario 221
Figure 6.11  Buildings sector energy consumption by fuel, by scenario and by region 222
Figure 6.12  Change in residential sector energy demand by end use in the BLUE Map scenario compared to the Baseline scenario, 2050 223
Figure 6.13  Change in service sector energy demand by end use in the BLUE Map scenario compared to the Baseline scenario, 2050 224
Figure 6.14  Buildings sector energy savings by sector and by end use, 2050 224
Figure 6.15  Buildings sector CO₂ emissions by scenario and by fuel 225
Figure 6.16  Contribution of CO₂ emissions reduction options 227
Figure 6.17  Incremental investment needs in the buildings sector in the BLUE Map scenario 228
Figure 6.18  Incremental investment needs in the residential and service sectors in the BLUE Map scenario, 2007-50 228
Figure 6.19  Direct CO₂ emissions reduction below the Baseline scenario in the buildings sector BLUE Map scenario variants, 2050 230
Figure 6.20  Yearly primary space heating use per dwelling in selected European countries 232
Figure 6.21  CO₂ abatement costs for heat pumps in heating applications 240
Figure 6.22  CO₂ abatement costs for CHP in the buildings sector by technology, 2015 246
Figure 6.23  Selected appliance ownership by country 251

Chapter 7  Transport

Figure 7.1  World transport final energy use by mode 257
Figure 7.2  Transport sector energy use by region, 2007 258
Figure 7.3  Motorised passenger travel by mode, 2007 259
Figure 7.4  Freight activity trends by region 260
Figure 7.5  Greenhouse-gas efficiency of different modes, freight and passenger, 2007 261
Figure 7.6  New LDV tested fuel economy in various OECD countries 262
Figure 7.7  Evolution of energy use by fuel type, worldwide 265
Figure 7.8  Energy use by transport mode and by region 266
Figure 7.9  Well-to-wheel passenger mobility greenhouse-gas emissions by mode 267
Figure 7.10  Well-to-wheel freight mobility greenhouse-gas emissions by mode 268
Figure 7.11  Sources of greenhouse-gas emissions reduction, transport sector 270
Figure 7.12  Well-to-wheel transport CO₂-equivalent emissions by region and by scenario 270
Figure 7.13  Transport vehicle investment costs and fuel costs, 2010-50 272
Figure 7.14  Passenger and freight mobility by mode, by year and by scenario 273
Figure 7.15  Passenger LDV ownership rates versus GDP per capita in three scenarios 275
Figure 7.16  Evolution of passenger LDV sales by technology type in the Baseline and BLUE Map scenarios 276
Figure 7.17  Evolution of the greenhouse-gas intensity of passenger transport modes 278
Figure 7.18  Incremental cost of alternative fuels as a function of their CO₂-equivalent saving potentials (at USD 120/bbl) 280
Figure 7.19  Lifetime incremental cost of vehicle and fuel pathways as a function of CO₂-equivalent savings 286
Figure 7.20  Cost per tonne of CO₂-equivalent saved over the vehicle’s life, oil price at USD 120/bbl 287
Figure 7.21  Road and rail freight energy use by fuel, by scenario and by year 289
Figure 7.22  Average energy intensity of aircraft by region 291
Figure 7.23  Aircraft greenhouse-gas emission projections by scenario 292
Figure 7.24  Trends in maritime transport volumes and related CO₂-equivalent emissions 293
### TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.25</td>
<td>International shipping activity, energy intensity and energy use by scenario</td>
<td>294</td>
</tr>
<tr>
<td>7.26</td>
<td>Shipping energy use by scenario</td>
<td>295</td>
</tr>
</tbody>
</table>

### Chapter OECD Europe

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1</td>
<td>Total primary energy supply in OECD Europe</td>
<td>300</td>
</tr>
<tr>
<td>8.2</td>
<td>Energy production, imports and exports by fuel for OECD Europe</td>
<td>300</td>
</tr>
<tr>
<td>8.3</td>
<td>Final energy consumption by fuel and by sector in OECD Europe</td>
<td>301</td>
</tr>
<tr>
<td>8.4</td>
<td>Total primary energy supply by fuel for OECD Europe, Baseline and BLUE Map scenarios</td>
<td>308</td>
</tr>
<tr>
<td>8.5</td>
<td>Contributions to emissions reductions in OECD Europe</td>
<td>310</td>
</tr>
<tr>
<td>8.6</td>
<td>Electricity generating capacity and generation for OECD Europe, 2007</td>
<td>311</td>
</tr>
<tr>
<td>8.7</td>
<td>Electricity generation mix, OECD Europe, 2007</td>
<td>312</td>
</tr>
<tr>
<td>8.8</td>
<td>Power generation mix in major European electricity producing countries in BLUE Map scenario, 2050</td>
<td>315</td>
</tr>
<tr>
<td>8.9</td>
<td>Industrial final energy mix in OECD Europe and the world, 2007</td>
<td>317</td>
</tr>
<tr>
<td>8.10</td>
<td>Materials production in OECD Europe in the BLUE low-demand and high-demand scenarios</td>
<td>318</td>
</tr>
<tr>
<td>8.11</td>
<td>Options for reducing direct CO\textsubscript{2} emissions from European industry</td>
<td>319</td>
</tr>
<tr>
<td>8.12</td>
<td>Residential and service sectors’ energy consumption by fuel, OECD Europe, 2007</td>
<td>320</td>
</tr>
<tr>
<td>8.13</td>
<td>Commercial and services value added for OECD Europe</td>
<td>321</td>
</tr>
<tr>
<td>8.14</td>
<td>Residential and service sectors’ energy consumption by end-use in OECD Europe, 2006/07</td>
<td>322</td>
</tr>
<tr>
<td>8.15</td>
<td>Residential building stock in selected countries by vintage</td>
<td>323</td>
</tr>
<tr>
<td>8.16</td>
<td>Energy use in the buildings sector in the Baseline and BLUE Map scenarios for OECD Europe</td>
<td>324</td>
</tr>
<tr>
<td>8.17</td>
<td>Contribution to reductions in CO\textsubscript{2} emissions in the buildings sector in OECD Europe under the BLUE Map scenario</td>
<td>325</td>
</tr>
<tr>
<td>8.18</td>
<td>Transport sector final energy use by mode in OECD Europe and the world, 2007</td>
<td>326</td>
</tr>
<tr>
<td>8.19</td>
<td>Transport energy use by fuel in the Baseline and BLUE scenarios in OECD Europe</td>
<td>328</td>
</tr>
<tr>
<td>8.20</td>
<td>OECD Europe's greenhouse-gas emissions evolution by transport mode</td>
<td>330</td>
</tr>
<tr>
<td>8.21</td>
<td>Passenger light-duty vehicles sales by technology type in OECD Europe</td>
<td>331</td>
</tr>
<tr>
<td>Figure Number</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>---------------</td>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>8.22</td>
<td>Additional investment needs and fuel cost savings for OECD Europe</td>
<td>332</td>
</tr>
<tr>
<td>8.23</td>
<td>CO₂ emissions reductions by technology area in the BLUE Map scenario in OECD Europe, 2050</td>
<td>333</td>
</tr>
<tr>
<td>9.1</td>
<td>Total primary energy supply in the United States</td>
<td>339</td>
</tr>
<tr>
<td>9.2</td>
<td>United States energy production, imports and exports</td>
<td>340</td>
</tr>
<tr>
<td>9.3</td>
<td>Final energy consumption by fuel and by sector in the United States</td>
<td>341</td>
</tr>
<tr>
<td>9.4</td>
<td>Total primary energy supply by fuel for the United States, Baseline and BLUE Map scenarios</td>
<td>346</td>
</tr>
<tr>
<td>9.5</td>
<td>Contributions to emissions reduction in the United States</td>
<td>346</td>
</tr>
<tr>
<td>9.6</td>
<td>Electricity generating capacity and generation in the United States, 2007</td>
<td>348</td>
</tr>
<tr>
<td>9.7</td>
<td>Renewable power generation mix by region in the United States, 2007</td>
<td>353</td>
</tr>
<tr>
<td>9.8</td>
<td>Power generation mix by region in the United States in the BLUE Map scenario, 2050</td>
<td>354</td>
</tr>
<tr>
<td>9.9</td>
<td>Industrial final energy mix in the United States and the world, 2007</td>
<td>355</td>
</tr>
<tr>
<td>9.10</td>
<td>Industrial energy use in the United States, Baseline and BLUE scenarios</td>
<td>357</td>
</tr>
<tr>
<td>9.11</td>
<td>Options for reducing direct CO₂ emissions from United States industry</td>
<td>357</td>
</tr>
<tr>
<td>9.12</td>
<td>Residential and service sectors’ energy consumption by fuel in the United States</td>
<td>359</td>
</tr>
<tr>
<td>9.13</td>
<td>Residential and service sectors’ energy consumption by end-use in the United States, 2007</td>
<td>360</td>
</tr>
<tr>
<td>9.14</td>
<td>Energy use in the buildings sector in the Baseline and BLUE Map scenarios in the United States</td>
<td>361</td>
</tr>
<tr>
<td>9.15</td>
<td>Contribution to reductions in CO₂ emissions in the buildings sector in the United States in the BLUE Map scenario</td>
<td>363</td>
</tr>
<tr>
<td>9.16</td>
<td>Transport sector final energy use by mode in the United States and in the world, 2007</td>
<td>364</td>
</tr>
<tr>
<td>9.17</td>
<td>United States transport energy use by fuel in the Baseline and BLUE scenarios</td>
<td>365</td>
</tr>
<tr>
<td>9.18</td>
<td>Passenger light-duty vehicles sales by technology in the United States in the Baseline and BLUE Map scenarios</td>
<td>366</td>
</tr>
<tr>
<td>9.19</td>
<td>United States greenhouse-gas emissions by mode for passenger travel in the Baseline and BLUE scenarios</td>
<td>367</td>
</tr>
</tbody>
</table>
Chapter 10 China

Figure 10.1 Total primary energy supply in China 375
Figure 10.2 Energy production, imports and exports for China 376
Figure 10.3 Final energy consumption by fuel and by sector for China 377
Figure 10.4 Total primary energy supply, Baseline and BLUE Map scenarios by fuel for China 383
Figure 10.5 Contributions to emissions reduction in China 384
Figure 10.6 Electricity generating capacity and generation for China, 2007 385
Figure 10.7 Commissioning of new generation capacity for China 386
Figure 10.8 Electricity generation by region for China, 2007 (TWh) 387
Figure 10.9 Development of transmission network, and transmission and distribution losses for China 388
Figure 10.10 Regional electricity generation in the BLUE Map scenario for China 2050 390
Figure 10.11 Industrial final energy mix in China and in the world, 2007 392
Figure 10.12 Materials production in China in the BLUE low-demand and high-demand scenarios 394
Figure 10.13 Energy use in industry by fuel type in the Baseline and BLUE scenarios for China 394
Figure 10.14 Options for reducing direct CO$_2$ emissions from Chinese industry 396
Figure 10.15 Residential and service sectors’ energy consumption by fuel for China 397
Figure 10.16 Residential and service sectors’ energy consumption by end use for China, 2007 398
Figure 10.17 Energy use in the buildings sector in the Baseline and BLUE Map scenarios for China 400
Figure 10.18 Contribution to reductions in energy use in the BLUE Map scenario for China 401
Figure 10.19 Contribution to reductions in CO$_2$ emissions in the building sector in the BLUE Map scenario, China 402
Figure 10.20 Transport sector final energy mix in China and the world, 2007 402
Figure 10.21 China’s transport energy demand and greenhouse-gas emissions 405
Figure 10.22 Passenger LDV sales by technology in the Baseline and BLUE Map scenarios for China, 2050 407
Figure 10.23 High-speed rail corridors in China, 2009 408
Figure 10.24 Additional investment needs and fuel savings for China 410
| Figure 10.25 | CO$_2$ emissions reduction by technology area in the BLUE Map scenario for China, 2050 | 412 |
| Chapter 11 | India |
| Figure 11.1 | Total primary energy supply in India | 418 |
| Figure 11.2 | Energy production, imports and exports for India | 419 |
| Figure 11.3 | Final energy consumption by fuel and by sector for India | 420 |
| Figure 11.4 | Total primary energy supply, Baseline and BLUE Map scenarios by fuel for India | 426 |
| Figure 11.5 | Contributions to emissions reduction in India | 427 |
| Figure 11.6 | Electricity generating capacity and generation for India, 2007/08 | 428 |
| Figure 11.7 | Development of transmission network, and transmission and distribution losses for India | 430 |
| Figure 11.8 | Regional power capacity and electricity demand in the BLUE Map scenario for India, 2050 | 433 |
| Figure 11.9 | Industrial final energy mix in India and in the world, 2007 | 434 |
| Figure 11.10 | Materials production in India in the BLUE low-demand and high-demand scenarios | 436 |
| Figure 11.11 | Energy use in industry by fuel type in the Baseline and BLUE scenarios for India | 436 |
| Figure 11.12 | Options for reducing direct CO$_2$ emissions from Indian industry | 437 |
| Figure 11.13 | Residential and service sectors’ energy consumption by fuel in India, 2007 | 439 |
| Figure 11.14 | Residential and service sectors’ energy consumption by end use for India, 2007 | 441 |
| Figure 11.15 | Energy use in the buildings sector in the Baseline and BLUE Map scenarios for India | 443 |
| Figure 11.16 | Contribution to reductions in energy use in the buildings sector in the BLUE Map scenario for India, 2050 | 444 |
| Figure 11.17 | Contribution to reductions in CO$_2$ emissions in the buildings sector in the BLUE Map scenario for India, 2050 | 444 |
| Figure 11.18 | Transport sector final energy use by mode in India and in the world, 2007 | 445 |
| Figure 11.19 | Transport sector final energy mix in India and in the world, 2007 | 445 |
| Figure 11.20 | Transport energy use by fuel in the Baseline and BLUE scenarios for India | 447 |
| Figure 11.21 | Transport energy use by mode in the Baseline and BLUE scenarios for India | 448 |
### Table of Contents

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.5</td>
<td>Share of investments in low-carbon technologies by technology</td>
<td>532</td>
</tr>
<tr>
<td>14.6</td>
<td>Low-carbon energy investments by region (USD billions)</td>
<td>533</td>
</tr>
<tr>
<td>14.7</td>
<td>Additional investment needs in the BLUE Map scenario compared to the Baseline scenario by region and sector</td>
<td>537</td>
</tr>
<tr>
<td>14.8</td>
<td>The development of the carbon market</td>
<td>539</td>
</tr>
<tr>
<td>14.9</td>
<td>Funding options for different stages of technology development</td>
<td>545</td>
</tr>
<tr>
<td>14.10</td>
<td>Global assets, 2008</td>
<td>546</td>
</tr>
<tr>
<td>14.11</td>
<td>Interest rates on government bonds (at 6 April 2010)</td>
<td>554</td>
</tr>
</tbody>
</table>

#### Chapter 15 Accelerating the diffusion of low-carbon technologies in emerging economies

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.1</td>
<td>OECD and non-OECD primary energy demand in the Baseline scenario</td>
<td>569</td>
</tr>
<tr>
<td>15.2</td>
<td>World energy-related CO₂ emission abatement by region</td>
<td>569</td>
</tr>
<tr>
<td>15.3</td>
<td>International trends in technology diffusion</td>
<td>573</td>
</tr>
</tbody>
</table>

#### Chapter 16 Technology choices and behaviour

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.1</td>
<td>The techno-economic model of energy efficiency</td>
<td>598</td>
</tr>
<tr>
<td>16.2</td>
<td>Policy instruments and behavioural drivers</td>
<td>599</td>
</tr>
<tr>
<td>16.3</td>
<td>Theory of planned behaviour</td>
<td>600</td>
</tr>
<tr>
<td>16.4</td>
<td>Household behaviours associated with energy consumption, efficiency and conservation</td>
<td>601</td>
</tr>
<tr>
<td>16.5</td>
<td>Impact of policies on different costs relating to technology choices</td>
<td>602</td>
</tr>
<tr>
<td>16.6</td>
<td>Transport greenhouse-gas reductions by scenario and source of reduction</td>
<td>606</td>
</tr>
<tr>
<td>16.7</td>
<td>Fuel cost per kilometre by vehicle technology, 2050</td>
<td>609</td>
</tr>
</tbody>
</table>

#### Chapter 17 Environmental co-impacts of emerging energy technologies

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.1</td>
<td>Energy use has indirect effects on human health and the environment</td>
<td>620</td>
</tr>
<tr>
<td>17.2</td>
<td>NOₓ and SO₂ emissions from energy technologies in the electricity sector</td>
<td>633</td>
</tr>
<tr>
<td>17.3</td>
<td>Water demands of energy technologies in the electricity sector</td>
<td>634</td>
</tr>
<tr>
<td>17.4</td>
<td>Direct land use from energy technologies in the electricity sector</td>
<td>635</td>
</tr>
<tr>
<td>17.5</td>
<td>Leaded petrol phase-out: global status as of March 2010</td>
<td>638</td>
</tr>
<tr>
<td>17.6</td>
<td>Lifetime emissions from a gasoline, diesel and electric vehicle</td>
<td>641</td>
</tr>
</tbody>
</table>
**LIST OF TABLES**

**Executive summary**

| Table ES.1 | Energy and emission trends under the Baseline and BLUE Map scenarios: 2050 compared to 2007 | 48 |

**Chapter 1 Introduction**

| Table 1.1 | The relationship between CO₂ emissions and climate change | 61 |

**Chapter 2 Overview scenarios**

| Table 2.1 | High-level energy indicators for the world and four countries or regions, 2007 | 84 |
| Table 2.2 | CO₂ emissions reduction by sector in the BLUE Map scenario, 2050 | 89 |

**Chapter 3 Technology roadmaps**

| Table 3.1 | Global electricity production by energy source and by scenario | 112 |
| Table 3.2 | Cost assumptions for hard coal- and natural gas-fired electricity generation | 118 |
| Table 3.3 | Cost assumptions for fossil electricity generation with CCS | 123 |
| Table 3.4 | Cost assumptions for renewable electricity generation | 134 |
| Table 3.5 | Cost assumptions for nuclear electricity generation technologies | 139 |

**Chapter 4 Electricity networks**

| Table 4.1 | Regional electricity demand and future growth | 144 |
| Table 4.2 | Regional electricity system use and loss of electricity, 2007 | 150 |
Chapter 5 Industry

Table 5.1 Potential savings from adopting BATs in industry 165
Table 5.2 Energy and CO₂ emissions reduction from heat pump application in the food and beverage sector 174
Table 5.3 Technology options for the iron and steel industry 180
Table 5.4 Additional investment needs in the iron and steel sector to 2050: BLUE scenarios compared to Baseline scenarios 181
Table 5.5 Technology options for the cement industry 184
Table 5.6 Additional investment needs in the cement sector to 2050: BLUE scenarios compared to Baseline scenarios 185
Table 5.7 Technology options for the chemical industry 189
Table 5.8 Additional investment needs in the chemical sector to 2050: BLUE scenarios compared to Baseline scenarios 189
Table 5.9 Technology options for the pulp and paper industry 193
Table 5.10 Additional investment needs in the pulp and paper sector to 2050: BLUE scenarios compared to Baseline scenarios 193
Table 5.11 Technology options for the aluminium industry 197
Table 5.12 Additional investment needs in the aluminium sector to 2050: BLUE scenarios compared to Baseline scenarios 197
Table 5.13 Direct CO₂ reductions in industry by region in the Baseline and BLUE low-demand scenarios 199
Table 5.14 Investment needs in industry in the Baseline and BLUE scenarios 200

Chapter 6 Buildings

Table 6.1 Priority policy actions needed to deliver the outcomes in the BLUE Map scenario 219
Table 6.2 Buildings sector energy consumption by fuel in the Baseline and BLUE Map scenarios 221
Table 6.3 Technology and cost characteristics of heat pumps for heating and cooling, 2007 239
Table 6.4 Technology and cost characteristics of CHP technologies 245
Table 6.5 Solar thermal system characteristics and costs for OECD Europe, North America and the Pacific, 2006-50 249
Chapter 7  Transport

Table 7.1  Scenario descriptions, assumptions and key results 264
Table 7.2  Fuels and their production processes 279
Table 7.3  A rough guide to energy-saving measures for truck and rail freight transport 290

Chapter 8  OECD Europe

Table 8.1  Proven energy reserves in OECD Europe and the world 299
Table 8.2  High-level indicators for OECD Europe 308
Table 8.3  OECD Europe’s absolute and relative CO₂ emissions reduction by sector in the BLUE Map scenario 309
Table 8.4  Current and projected final electricity demand for OECD Europe by end-use sector 313
Table 8.5  OECD Europe’s power generation mix and capacity, Baseline and BLUE Map scenarios, 2050 314
Table 8.6  Industrial production, energy use and CO₂ emissions in OECD Europe, 2007 317
Table 8.7  Direct energy and process CO₂ emissions by industry sector in OECD Europe 319
Table 8.8  Transport energy indicators in OECD Europe, 2007 327
Table 8.9  Transport CO₂ indicators in OECD Europe, 2007 327

Chapter 9  United States

Table 9.1  Proven energy reserves in the United States and the world 339
Table 9.2  United States clean energy spending by category 344
Table 9.3  High-level indicators for the United States 345
Table 9.4  Current and projected final electricity demand in the United States by end-use sector 352
Table 9.5  United States power generation mix and capacity in the Baseline and BLUE Map scenarios, 2050 352
Table 9.6  Industrial production, energy use and CO₂ emissions in United States, 2007 355
Table 9.7  Direct energy and process CO₂ emissions by industry in the United States 357
Table 9.8  Transport energy and CO₂ indicators in the United States, 2007 364
Chapter 10  China

Table 10.1 Proven energy reserves in China and the world 375
Table 10.2 Responsibilities of China’s National Energy Administration departments 380
Table 10.3 High-level indicators for China 382
Table 10.4 Current and projected final electricity demand for China by end-use sector 389
Table 10.5 China’s power generation capacity in the Baseline and BLUE Map scenarios, 2050 389
Table 10.6 Industrial production, energy use and CO₂ emissions for China, 2007 392
Table 10.7 Direct energy and process CO₂ emissions by industry sector, China 395
Table 10.8 Transport energy and CO₂ indicators in China, 2007 403
Table 10.9 Mass transit in Chinese cities, 2009 409
Table 10.10 China’s current energy technology priorities 412

Chapter 11  India

Table 11.1 Proven energy reserves in India and in the world, 2008 417
Table 11.2 High-level indicators for India 425
Table 11.3 Indian renewable power generation capacities, status at 31 March 2008 429
Table 11.4 Current and projected final electricity demand for India by end-use sector 431
Table 11.5 India’s power generation capacity in the Baseline and BLUE Map scenarios, 2050 432
Table 11.6 Industrial production, energy use and CO₂ emissions for India, 2007 435
Table 11.7 Direct energy and process CO₂ emissions by industry sector in India 437
Table 11.8 Indian industry status and options for reducing energy use and CO₂ emissions in the BLUE scenarios 438
Table 11.9 Residential energy use in India 440
Table 11.10 Transport energy and CO₂ indicators in India, 2007 446

Chapter 12  Policies to accelerate a low-carbon technology transition

Table 12.1 Examples of public engagement projects 474
Table 12.2 Estimated public-sector low-carbon energy technology current spending, needs and gap to achieve BLUE Map outcomes in 2050 480
Chapter 13 **Technology roadmaps**

Table 13.1 CO₂ emissions reductions and RDD&D spending needs in the BLUE Map scenario 491

Chapter 14 **Finance**

Table 14.1 Average annual investment by sector in the Baseline and BLUE Map scenarios 524

Table 14.2 Total investment needs for LDVs 526

Table 14.3 Incremental investment needs in the buildings sector for BLUE Map scenario compared to the Baseline scenario, 2010-50 528

Table 14.4 Investment needs in industry in the Baseline and BLUE Map scenarios 529

Table 14.5 Investments by the 25 largest companies in oil and gas, power and coal mining sectors, 2008 (USD billions) 534

Table 14.6 Possible funding mechanisms for meeting the additional cost of energy technology transition 536

Table 14.7 Multilateral and bilateral funding for low-carbon technologies 538

Table 14.8 The carbon market (USD billions) 540

Table 14.9 Conventional investment assets, 2007 548

Table 14.10 Largest ten sovereign wealth funds by assets under management, October 2009 549

Table 14.11 Examples of public finance mechanisms used to support investments in clean technologies 550

Table 14.12 Factors affecting perceived risk for various power generation projects 553

Table 14.13 Observed discount rates by project type 553

Table 14.14 Funding options to bridge the commercial gap for early CCS demonstration 560

Chapter 15 **Accelerating the diffusion of low-carbon technologies in emerging economies**

Table 15.1 Examples of incremental investment costs for selected low-carbon technologies in non-OECD countries in 2010-50 in the BLUE Map scenario (USD billions) 570

Table 15.2 Top 10 countries in renewable energy capacity, 2009 574

Table 15.3 Net exports in BRIC countries related to renewable energy technologies (USD billion) 577
Table 15.4 Sources of investment in gross fixed capital formation in non-OECD countries, 2000

Table 15.5 Bilateral ODA expenditure to developing countries and a selection of emerging economies in 2008 for eight low-carbon technologies (USD million)

Table 15.6 Multilateral ODA expenditure to developing countries and to a selection of emerging economies in 2008 for eight low-carbon technologies (USD million)

Table 15.7 Financing for diffusion of low-carbon technologies in developing countries by financing source

Table 15.8 National clean energy policies implemented in emerging economies

Table 15.9 Enabling environments for technology diffusion, examples of implementation measures and main actors involved

Table 15.10 Averages of the share of world climate innovations for selected countries, 2000-05

Table 15.11 R&D priorities, policies and expenditure for clean energy in BRICS countries

Chapter 16 Technology choices and behaviour

Table 16.1 Potential impact of behaviour on United States household energy use

Chapter 17 Environmental co-impacts of emerging energy technologies

Table 17.1 Estimated life-years (in millions) lost due to exposure to PM$_{2.5}$ emissions

Table 17.2 Energy technology co-impacts in the electricity sector relative to a USC coal baseline

Table 17.3 Lifetime emissions from different light-duty vehicle technologies

Annex Framework assumptions

Table A.1 Population projections (millions)

Table A.2 GDP projections (% per year, based on purchasing power parity)

Table A.3 Oil, gas and coal price projections for the Baseline scenarios (in 2008 USD per unit)

Table A.4 Oil, gas and coal price projections for the BLUE scenarios (in 2008 USD per unit)
## LIST OF BOXES

### Executive summary
- Box ES.1 Messages from the models 49
- Box ES.2 IEA technology roadmaps 52
- Box ES.3 Regional differences 58

### Chapter 2 Overview scenarios
- Box 2.1 Scenarios in ETP 2010 69
- Box 2.2 Substantial CO₂ reductions will require a global effort 71
- Box 2.3 Economic impacts of the BLUE Map scenario 77
- Box 2.4 Oil supply prospects 93
- Box 2.5 Gas supply prospects 95

### Chapter 3 Technology roadmaps
- Box 3.1 Recent developments in CCS 121
- Box 3.2 CCS retrofit and capture-ready plants: avoiding lock-in of non-CCS plants 122
- Box 3.3 Recent developments in renewable electricity generation 133
- Box 3.4 Recent developments in nuclear power 137
- Box 3.5 Nuclear fusion 138

### Chapter 4 Electricity networks
- Box 4.1 What is a smart grid? 151

### Chapter 5 Industry
- Box 5.1 Heat pump applications in industry 173
- Box 5.2 Impacts of gas availability on use of gas-based direct reduced iron 179

### Chapter 6 Buildings
- Box 6.1 Recent trends in low-carbon technologies for buildings 220
Chapter 7  Transport

Box 7.1  Advanced technology vehicles in the BLUE Map scenario 277
Box 7.2  Natural gas for transport: the role of biogas and bio-synthetic gas 280

Chapter 9  United States

Box 9.1  Clean energy investment under the 2009 Recovery Act 344

Chapter 10  China

Box 10.1  Unconventional gas in China 376

Chapter 11  India

Box 11.1  Data for the buildings sector in India 439
Box 11.2  Energy efficiency actions taken by the Government of India 441
Box 11.3  India’s technology innovation targets 453

Chapter 12  Policies to accelerate a low-carbon technology transition

Box 12.1  Wind energy technologies span development categories 466
Box 12.2  Examples of policies to support promising but not yet mature technologies 466
Box 12.3  Accelerating technology developments through public-private collaboration and innovation 470
Box 12.4  Examples of low-carbon training programmes 472
Box 12.5  Quality and availability of RD&D spending data 481
Box 12.6  Examples of recent funding announcements for basic science in the area of energy 486

Chapter 13  Technology roadmaps

Box 13.1  What is a low-carbon energy technology roadmap? 492

Chapter 14  Finance

Box 14.1  New funding commitments in the Copenhagen Accord 538
Box 14.2  Debt financing options 545
Box 14.3  Investment profiles for different classes of equity investor 547
Chapter 15  Accelerating the diffusion of low-carbon technologies in emerging economies

Box 15.1 Developing countries and emerging economies: a changing definition 566
Box 15.2 An urgent priority: low-carbon development in the least-developed countries 567
Box 15.3 Technology transfer: history and initiatives 571
Box 15.4 Tracing international technology flows: precision of the data and the need for more certainty 572
Box 15.5 Examples of South-South technology transfer 574
Box 15.6 Acquisition of foreign technologies through merger and acquisition 575
Box 15.7 Climate Investment Funds (CIFs) 581
Box 15.8 Barriers to trade in low-carbon energy technologies 586
Box 15.9 Rationale for intellectual property rights 587

Chapter 17  Environmental co-impacts of emerging energy technologies

Box 17.1 Major studies assessing the co-impacts of energy technologies 618
Box 17.2 Energy efficiency in buildings 621
Box 17.3 Noise pollution 637
Box 17.4 Lead emissions from gasoline 638
EXECUTIVE SUMMARY

Throughout energy circles, the threat of climate change has held the spotlight in recent years. Meanwhile, two other concerns have re-emerged from the shadows. The financial crisis of 2008/09, which some analysts link with volatile oil prices, reinforced the concern that high energy prices can cripple economic growth. Headlines announcing gas supply cuts to the Ukraine, oil tanker hijackings along the coast of Somalia, pipeline bombings in Nigeria, and hurricanes destroying oil rigs in the Gulf of Mexico showed that threats to energy security arise in many forms and unexpected places. For several years, the IEA has been presenting the case that an energy revolution, based on widespread deployment of low-carbon technologies, is needed to tackle the climate change challenge. Energy Technology Perspectives 2010 (ETP 2010) demonstrates that a low-carbon future is also a powerful tool for enhancing energy security and economic development.

Equally important, ETP 2010 highlights early signs that such an energy technology revolution is under way. Investment in renewable energy, led by wind and solar, is increasing substantially. A number of countries are considering building new nuclear power stations. The rate of energy efficiency improvement in OECD countries is starting to accelerate again, after many years of modest gains. Public investment is increasing for low-carbon technology research, development and demonstration (RD&D). In transport, major car companies are adding hybrid and full-electric vehicles to their product lines and many governments have launched plans to encourage consumers to buy these vehicles. Yet these encouraging developments represent but the first small, fragmented steps on a long journey towards transforming the way we supply and use energy. The trends that drive growth in energy demand and carbon dioxide (CO₂) emissions associated with climate change continue to surge forward at an unrelenting pace.

Current energy and CO₂ trends run directly counter to the repeated warnings sent by the United Nations Intergovernmental Panel on Climate Change (IPCC), which concludes that reductions of at least 50% in global CO₂ emissions compared to 2000 levels will need to be achieved by 2050 to limit the long-term global average temperature rise to between 2.0°C and 2.4°C. Recent studies suggest that climate change is occurring even faster than previously expected and that even the “50% by 2050” goal may be inadequate to prevent dangerous climate change.

Efforts to forge a long-term policy framework for tackling climate change are continuing, but the 15th Conference of the Parties (COP 15) to the UN Framework Convention on Climate Change demonstrated the difficulty of reaching agreement on “top-down” legally binding targets. Nonetheless, COP 15 did make progress on some crucial issues. The Copenhagen Accord, while not formally adopted at COP 15, reflected a large degree of consensus on a number of vital elements, including: limiting the increase in global temperature to less than 2.0°C; achieving deep cuts in global greenhouse-gas emissions by 2050; the role of technology in meeting these goals; and the need for additional funding for developing countries. Many governments are already backing up their support for the Accord’s principles.
EXECUTIVE SUMMARY

through increased funding for low-carbon energy research and development, new and more effective policies, and national emissions reduction targets.

ETP 2010 feeds into this momentum by providing an IEA perspective on how low-carbon energy technologies can contribute to deep CO₂ emissions reduction targets. Using a techno-economic approach that assesses costs and benefits, the book examines least-cost pathways for meeting energy policy goals while also proposing measures to overcome technical and policy barriers. Specifically, ETP 2010 examines the future fuel and technology options available for electricity generation and for the key end-use sectors of industry, buildings and transport. For the first time, this edition includes an analysis of OECD Europe, the United States, China and India, which together account for about 56% of today’s global primary energy demand. It then sets out the technology transitions needed to move to a sustainable energy future, and provides a series of technology roadmaps to chart the path. Other new elements of ETP 2010 include chapters on financing, behavioural change, the diffusion of technologies amongst developed and emerging economies, and a discussion of the environmental impacts of key energy technologies.

It is clear that, at present, the energy technology revolution is coming from the “bottom up”. In many ways, this is a healthy sign: many energy challenges have the greatest impact on local populations – and those populations need to find solutions that work for their local contexts. Ultimately, the scale of the challenge demands a global strategy, not least because globalisation makes major economies increasingly interdependent in terms of trade, investment and the spread of technology. Another striking development is that many of these efforts already reflect stronger engagement between government, industry and civil society. ETP 2010 highlights innovative policies and actions that warrant thoughtful consideration and broader application.

The next decade is critical. If emissions do not peak by around 2020 and decline steadily thereafter, achieving the needed 50% reduction by 2050 will become much more costly. In fact, the opportunity may be lost completely. Attempting to regain a 50% reduction path at a later point in time would require much greater CO₂ reductions, entailing much more drastic action on a shorter time scale and significantly higher costs than may be politically acceptable.

Concern about energy security, the threat of climate change and the need to meet growing energy demand (particularly in the developing world) all pose major challenges to energy decision makers. Advancing the low-carbon technology revolution will involve millions of choices by a myriad of stakeholders – all individuals acting in personal or professional spheres. Yet choice, in itself, can be a barrier: wading through the reams of information to arrive at the best choice can be quite paralysing. This book demonstrates that a portfolio of existing and new technologies will be needed to address these challenges, and lays out both the priority areas for action and the mechanisms that can help deliver change. This approach is designed to help decision makers from all spheres identify which combinations of technologies and policies will be most effective in their specific situations. By incorporating detailed roadmaps to facilitate technology deployment, ETP 2010 hopes to prompt two aspects of the energy revolution: the necessary
step change in the rate of progress and broader engagement of the full range of countries, sectors and stakeholders.

**ETP scenarios present options rather than forecasts**

*ETP 2010* analyses and compares various scenarios. This approach does not aim to forecast what will happen, but rather to demonstrate the many opportunities to create a more secure and sustainable energy future.

The *ETP 2010* Baseline scenario follows the Reference scenario to 2030 outlined in the *World Energy Outlook 2009*, and then extends it to 2050. It assumes governments introduce no new energy and climate policies. In contrast, the BLUE Map scenario (with several variants) is target-oriented: it sets the goal of halving global energy-related CO₂ emissions by 2050 (compared to 2005 levels) and examines the least-cost means of achieving that goal through the deployment of existing and new low-carbon technologies (Figure ES.1). The BLUE scenarios also enhance energy security (e.g. by reducing dependence on fossil fuels) and bring other benefits that contribute to economic development (e.g. improved health due to lower air pollution). A quick comparison of *ETP 2010* scenario results demonstrates that low-carbon technologies can deliver a dramatically different future (Table ES.1).

![Figure ES.1](image-url)

**Key technologies for reducing CO₂ emissions under the BLUE Map scenario**

- **Baseline emissions**: 57 Gt
- **BLUE Map emissions**: 14 Gt

**Key point**

*A wide range of technologies will be necessary to reduce energy-related CO₂ emissions substantially.*
### Table ES.1 Energy and emission trends under the Baseline and BLUE Map scenarios: 2050 compared to 2007

<table>
<thead>
<tr>
<th>Baseline scenario</th>
<th>BLUE Map scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Energy-related CO₂ emissions roughly double</td>
<td>• Energy-related CO₂ emissions reduced by 50%</td>
</tr>
<tr>
<td>• Primary energy use rises by 84%; carbon intensity of energy use increases by 7%</td>
<td>• Primary energy use rises by 32%; carbon intensity of energy use falls by 64%</td>
</tr>
<tr>
<td>• Liquid fuel demand rises by 57% requiring significant use of unconventional oil and synthetic fuels; primary coal demand increases by 138%; gas demand is 85% higher</td>
<td>• Liquid fuel demand falls by 4% and biofuels meet 20% of total; coal demand drops by 36%; natural gas falls by 12%; renewables provide almost 40% of primary energy supply</td>
</tr>
<tr>
<td>• CO₂ emissions from power generation more than double; CO₂ intensity of power generation declines slightly to 459 g/kWh</td>
<td>• CO₂ emissions from power generation are cut by 76%; its CO₂ intensity falls to 67 g/kWh</td>
</tr>
<tr>
<td>• Fossil fuels supply more than two-thirds of power generation; the share of renewable energy increases slightly to 22%</td>
<td>• Renewables account for 48% of power generation; nuclear provides 24% and plants equipped with CCS 17%</td>
</tr>
<tr>
<td>• Carbon capture and storage (CCS) is not commercially deployed</td>
<td>• CCS is used to capture 9.4 Gt of CO₂ from plants in power generation (55%), industry (21%) and fuel transformation (24%)</td>
</tr>
<tr>
<td>• CO₂ emissions in the buildings sector, including those associated with electricity use, nearly double</td>
<td>• CO₂ emissions in buildings are reduced by two-thirds through low-carbon electricity, energy efficiency and the switch to low- and zero-carbon technologies (solar heating and cooling, heat pumps and CHP)</td>
</tr>
<tr>
<td>• Almost 80% of light-duty vehicles (LDVs) sales rely on conventional gasoline or diesel technology; petroleum products meet more than 90% of transport energy demand</td>
<td>• Almost 80% of LDVs sales are plug-in hybrid, electric or fuel-cell vehicles; the share of petroleum products in final transport demand falls to 50%</td>
</tr>
<tr>
<td>• CO₂ emissions in industry grow by almost half, as industrial production increases</td>
<td>• CO₂ emissions in industry fall by around a quarter mainly thanks to energy efficiency, fuel switching, recycling, energy recovery and CCS</td>
</tr>
<tr>
<td>• Total investment in energy supply and use totals USD 270 trillion</td>
<td>• Investment is USD 46 trillion (17%) more than in Baseline; cumulative fuel savings are USD 112 trillion higher than in Baseline</td>
</tr>
<tr>
<td>• Non-OECD countries are responsible for almost 90% of growth in energy demand and account for nearly three-quarters of global CO₂ emissions</td>
<td>• Non-OECD countries achieve CO₂ emissions reduction of around 30% compared to 2007; OECD countries account for less than one-quarter of global CO₂ emissions, having reduced emissions by 70% to 80% below 2007 levels</td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

Box ES.1 Messages from the models

The findings of ETP 2010 reinforce conclusions from previous editions while also serving as a reminder that, since the first edition was released in 2006, the world has continued to move – and even at an accelerated pace – in the wrong direction. From 1990 to 2000, global CO₂ emissions increased by an average of 1.1% per year. Over the following seven years, the annual growth rate in emissions jumped to 3.0%. Two main factors are evident: rising energy demand in coal-based economies; and an increase in coal-fired power generation in response to higher oil and gas prices. The rate of increase in emissions from coal use rose from 0.6% per year (between 1990 and 2000) to 4.8% per year (between 2000 and 2007).

The most important message remains unchanged: current trends – as illustrated by the Baseline scenario – are patently unsustainable in relation to the environment, energy security and economic development. Ongoing dependence on fossil fuels (especially coal) continues to drive up both CO₂ emissions and the price of fossil fuels. Oil prices, for example, are assumed to reach USD 120 per barrel (in 2008 prices) by 2050.

But this carbon-intensive future is not a given. Using a combination of existing and new technologies, as envisaged in the BLUE scenarios, it is possible to halve worldwide energy-related CO₂ emissions by 2050. Achieving this will be challenging, and will require significant investment. But the benefits in terms of environmental outcomes, improved energy security and reduced energy bills will also be large. Oil prices in these scenarios are assumed to be only USD 70 per barrel (in 2008 prices) by 2050.

- A portfolio of low-carbon technologies, with costs of up to USD 175/tCO₂ when fully commercialised, will be necessary to halve CO₂ emissions by 2050. No one technology or small group of technologies can deliver the magnitude of change required.

- Widespread deployment of low-carbon technologies can reduce global oil, coal and gas demand below current levels by 2050. Even so, fossil fuels will remain an important element of the world’s energy supply for the foreseeable future.

- Increasing energy efficiency, much of which can be achieved through low-cost options, offers the greatest potential for reducing CO₂ emissions over the period to 2050. It should be the highest priority in the short term.

- Decarbonising the power sector, the second-largest source of emissions reductions, is crucial and must involve dramatically increasing the shares of renewables and nuclear power, and adding carbon capture and storage (CCS) to generation from fossil fuels.

- A decarbonised electricity supply offers substantial opportunities to reduce emissions in end-use sectors through electrification (for example, switching from internal combustion engine vehicles to electric vehicles (EVs) and plug-in hybrids (PHEVs), or from fossil fuel heating to efficient heat pumps).

- New low-carbon technologies will be needed to sustain emissions reductions beyond 2030, particularly in end-use sectors such as transport, industry and buildings.

The future is inherently uncertain and always will be. Trends in economic growth (and therefore energy use and emissions) and technology development are difficult to predict. A portfolio approach to low-carbon technology development and deployment can help deal with this uncertainty.
Technology policy

Many of the most promising low-carbon technologies currently have higher costs than the fossil-fuel incumbents. It is only through technology learning from research, development, demonstration and deployment (RDD&D) that these costs can be reduced and the technologies become economic. Thus, governments and industry need to pursue energy technology innovation through a number of parallel and interrelated pathways. Most new technologies will require, at some stage, both the “push” of RD&D and the “pull” of market deployment.

The role of governments in developing effective technology policy is crucial: policy establishes a solid foundation and framework on which other stakeholders, including industry, can build. Where appropriate, policies will need to span the entire spectrum of RDD&D. In this way, governments can reduce the risk for other actors in the early phases of technology development and then gradually expose the technology to greater competition, while allowing participants to realise reasonable returns on their investments as a low-carbon economy takes hold.

Governments will need to intervene on an unprecedented level in the next decade to avoid the lock-in of high-emitting, inefficient technologies. They must take

Figure ES.2 Policies for supporting low-carbon technologies

Note: The figure includes generalised technology classifications; in most cases, technologies will fall in more than one category at any given time.

**Key point**

Government support policies need to be appropriately tailored to the stage(s) of development of a technology.
swift action to implement a range of technology policies that target the cost-competitiveness gap while also fairly reflecting the maturity and competitiveness of individual technologies and markets (Figure ES.2). The overriding objectives should be to reduce risk, stimulate deployment and bring down costs. Evidence suggests that a large proportion of breakthrough innovations come from new firms that challenge existing business models. Thus, government steps to remove barriers to the entry and growth of new firms may have an important part to play in low-carbon energy technology development.

In recent years, much attention has been given to the importance of policies that put a price on carbon emissions as a way of stimulating the clean technology development and deployment needed to deliver an energy revolution. The Copenhagen Accord acknowledges market approaches as a means to enhance cost-effectiveness. While such policies (e.g., carbon trading) are likely to be an important driver of change, they are not necessarily the most effective way to deliver short-term investment in the more costly technologies that have longer-term emissions reduction benefits. Moreover, a truly global carbon market is likely to be many years away. Governments can draw upon a wide variety of other tools to help create markets for the technologies that meet national policy objectives, including regulations, tax breaks, voluntary programmes, subsidies and information campaigns. But they also need to have exit routes: the level of government support should decrease over time and be removed altogether as technologies become competitive – or indeed, if it becomes clear that they are unlikely to do so.

*ETP 2010* estimates that to achieve the 50% $\text{CO}_2$ emissions reduction, government funding for RD&D in low-carbon technologies will need to be two to five times higher than current levels. This message is being taken seriously by many countries. Governments of both the Major Economies Forum and the IEA have agreed to dramatically increase and co-ordinate public-sector investments in low-carbon RD&D, with a view to doubling such investments by 2015. Simply increasing funding will not, however, be sufficient to deliver the necessary low-carbon technologies. Current government RD&D programmes and policies need to be improved by adopting best practices in design and implementation. This includes the design of strategic programmes to fit national policy priorities and resource availability; the rigorous evaluation of results and adjusting support if needed; and the increase of linkages between government and industry, and between the basic science and applied energy research communities to accelerate innovation.

Reducing $\text{CO}_2$ emissions ultimately depends on the uptake of low-carbon technologies by industry, businesses and individual consumers. To date, efforts to encourage the adoption of energy-efficient and low-carbon technologies have focused primarily on overcoming technological and economic barriers. In fact, research suggests that consumer choices are more heavily influenced by social and behavioural factors. Improved understanding of the human dimensions of energy consumption, particularly in the residential and commercial sectors and in personal transport, will help policy makers to catalyse and amplify technology-based savings. A sampling of successful programmes highlighted in *ETP 2010* indicates that policy strategies to influence consumer choices should target, inform, motivate and empower consumers.
Governments also have an important role in encouraging others to take the lead in relevant areas. Industry can demonstrate leadership through active involvement in public-private partnerships. Universities can expand training and education to develop and deploy the human capacity needed to exploit the innovative energy technologies. Non-governmental organisations can help engage the public and communicate the urgency of the need to deploy new energy technologies on a large scale, including the costs and benefits of doing so. Finally, all stakeholders must work together to strengthen international technology collaboration to accelerate RDD&D, diffusion and investment. Technology roadmaps can be an effective tool to help this process.

**Box ES.2**  ▶ IEA technology roadmaps

At the request of G8 Ministers, the IEA is developing roadmaps to support accelerated development and deployment of the most important low-carbon technologies. Each roadmap sets out a shared vision to 2050 and charts the actions required, at international and national levels, by relevant stakeholders. This collective approach is vital to maximising the net benefit of investment in the RDD&D of new technologies. The roadmaps also address several cross-cutting issues, on the international and regional levels, that will underpin the successful exploitation of these technologies.

Many of the IEA technology roadmaps recommend private-sector partnerships to accelerate innovation and the transition from demonstration to commercial deployment. Such partnerships may be particularly appropriate for technologies such as CCS and electric vehicles, both of which will depend on establishing new business models for industries and technologies.

**Increasing international technology diffusion**

All of the scenarios used in *ETP 2010* confirm a somewhat startling fact: nearly all of the future growth in energy demand and in emissions comes from non-OECD countries. Accelerating the spread of low-carbon technologies to non-OECD countries is therefore a critical challenge, particularly for the largest, fast-growing economies such as Brazil, China, India, the Russian Federation and South Africa.

Non-OECD countries have traditionally been assumed to access new technologies as a result of technology transfer from industrialised countries, presupposing a general trend that technological knowledge flows from countries with higher technological capacities to those with lower capacities. The situation is, however, becoming more complex, with an increasing multi-directional flow of technologies among and between OECD and non-OECD countries, and emerging economies establishing strong manufacturing bases and becoming exporters in their own right.

To be successful, a low-carbon economy should be based on market principles in which energy technologies spread primarily through commercial transactions. The challenge is to reorient these transactions to support the transfer of low-carbon technologies while also helping emerging countries to become technology
developers and market players. Careful consideration must be given to the capacity of countries to absorb new technologies. Some emerging economies, led by China, are rapidly improving their capability to develop and deploy key low-carbon technologies. Given their economic growth rates, they must advance at an even more rapid pace to decouple CO₂ emissions from economic activity.

**Financing and returns on investment**

**ETP 2010** shows that a very considerable investment will be needed to meet the world’s growing energy needs. The Baseline scenario estimates a total investment, between 2010 and 2050, of USD 270 trillion.¹ Most of this (USD 240 trillion or almost 90%) reflects demand-side investments that will be made by energy consumers for capital equipment that uses energy, including vehicles, electric appliances and plants in heavy industry.

Meeting energy demand growth in a way that supports the “50% by 2050” goal will be considerably more expensive: the BLUE Map scenario projects investment requirements of USD 316 trillion, a further increase of 17% (USD 46 trillion).

Over the past three years, annual investments in low-carbon energy technologies averaged approximately USD 165 billion. Implementing the BLUE Map scenario will require investments to reach approximately USD 750 billion per year by 2030 and rise to over USD 1.6 trillion per year from 2030 to 2050. The level of investment doubles in the latter period as a result of increased demand for cars and other consumer products, which rises alongside incomes in emerging and developing countries.

The flip side is that the energy technology revolution holds significant potential for very positive returns on investment. For example, the low-carbon economy will lead to substantial fuel savings due to efficiency improvements and as lower fuel demand drives down prices. **ETP 2010** calculates that the additional USD 46 trillion investment needs in the BLUE Map scenario will yield, over the period from 2010 to 2050, cumulative fuel savings equal to USD 112 trillion. Even if both the investments and fuel savings over the period to 2050 are discounted back to their present values using a 10% discount rate, the net savings amount to USD 8 trillion.

Moreover, the energy revolution offers substantial opportunities to business. Forward-looking companies recognise the enormous potential for developing and deploying – on a global scale – a wide range of new breakthrough and emerging technologies, as well as the possibility to make use of mechanisms that facilitate investment in non-OECD countries (e.g. in return for carbon credits). The role of governments in setting stable policy frameworks and providing some direct funding for RDD&D has already been stated. A second point is the need for increased dialogue between government and the investment community to improve understanding and establish appropriate boundaries to their unique but complementary spheres of activity.

**ETP 2010** also examines the wider economic, social and environmental impacts (referred to as “co-impacts” because of the degree to which they are interrelated) of

---

¹. Excluding upstream investments in the production and transportation of coal, oil and gas.
low-carbon technologies. The analysis focuses primarily on issues that, particularly in developing countries, may be more immediate political and social priorities than reducing CO₂ emissions, namely: air quality and related impacts on human health; water quality and availability; and land use. Reducing air pollution through low-carbon technologies, for example, delivers other energy-related environmental benefits and reduces negative health impacts on local populations.

Further work is needed to refine the estimates in this assessment, including ways to leverage potential co-benefits and to ensure that any negative co-impacts are understood, quantified and, where possible, mitigated. It is equally important to assess co-benefits and potential conflicts at regional, national and local levels, as many will be setting-specific.

**Sectoral findings**

About 84% of current CO₂ emissions are energy-related and about 65% of all greenhouse-gas emissions can be attributed to energy supply and energy use. All sectors will need to reduce dramatically their CO₂ intensity if global CO₂ emissions are to be halved. However, this does not mean that every sector needs to cut its own emissions by 50% (Figure ES.3). Each sector has different growth prospects under the Baseline scenario and a different range of low-carbon options that can be deployed to reduce emissions. *ETP 2010* examines in detail each sector's potential to contribute to a cost-optimal low-carbon future, including the technologies and policies that will be needed.

For advancing deployment of both existing and new technologies across all sectors, a key message is the need for rapid action that takes account of long-term goals. Without a long-range perspective, there is a risk that inappropriate and costly capital investments made in the near term could undermine future emissions reduction targets or will need to be scrapped well in advance of their normal life cycles.

![Figure ES.3](image-url) **Global CO₂ emissions in the Baseline and BLUE Map scenarios**

---

The BLUE Map scenario implies deep emission cuts across all sectors.
Power sector

It bears repeating that decarbonising the power sector will be at the heart of efforts to make deep cuts in global CO₂ emissions. The power sector currently accounts for 41% of energy-related CO₂ emissions. The Baseline scenario projects a doubling of these emissions over the period to 2050, because of continued reliance on fossil fuels. By contrast, the BLUE Map scenario achieves almost a 90% reduction (compared to 2007 levels) in the carbon intensity of electricity generation, with renewables accounting for almost half of global production and nuclear for slightly less than one-quarter. The other key change is that most remaining electricity production from fossil fuels has much lower CO₂ emissions thanks to widespread adoption of CCS.

Significant policy change is needed to break the current dependence on fossil fuels in the power sector, as is significant investment. The BLUE Map scenario requires investment of USD 32.8 trillion (40% more than the USD 23.5 trillion needed in the Baseline scenario), more than half directed towards new power generation plants. A key challenge is that, at present, many low-carbon alternatives are considerably more expensive than traditional fossil-based technologies. In addition to expanding RD&D support and creating market mechanisms to foster technological innovation, governments should adopt policies that encourage the earliest possible closure of the dirtiest and least efficient plants. All low-carbon generation options need to be pursued: excluding any one option could significantly increase the costs of achieving CO₂ emissions reductions from the sector.

Some low-carbon generation technologies raise unique challenges. For example, system integration will be needed to support large quantities of variable renewables (such as wind, solar PV, run-of-river hydropower, and wave and tidal power). There is also an urgent need to accelerate the demonstration of CCS in the power sector and to develop comprehensive regulatory approaches to enable its large-scale commercial deployment. Nuclear power requires further progress on building and operating disposal facilities for radioactive waste.

Achieving a near zero-carbon electricity supply creates opportunities to reduce CO₂ emissions in all end-use sectors by shifting energy consumption from fossil fuels to electricity. For example, from internal combustion engine (ICE) cars running on diesel or gasoline to EVs and PHEVs, or from fossil-fuel heating to efficient heat pumps.

There are some signs that the necessary changes in power generation are starting to happen. Investment in renewable energy, led by wind and solar, reached an all-time high in 2008 and stayed at similar levels in 2009 despite the economic downturn. In 2009, more wind power was installed in Europe than any other electricity-generating technology. Similar developments have been seen in other parts of the world; in terms of global installed renewable capacity, China now ranks second and India fifth. There is also evidence that nuclear power is undergoing a renaissance. Major expansions of nuclear capacity are planned in China, India and Russia. Several other countries with existing nuclear plants but where no new construction has been launched in recent years are also actively considering new nuclear capacity.
Electricity networks

Changing profiles for demand and generation will require modifications in the design, operation and deployment of electricity networks, with regional characteristics becoming more important in determining network configurations.

Although system-scale demonstration is still needed, the flexibility of smart grids (which integrate both electricity and thermal storage technologies) appears to support balancing of variable generation and demand, better management of peak loads and delivery of energy efficiency programmes. Smart grids can contribute to reducing CO₂ emissions from both electricity generation and use. In developing countries, smart grids will facilitate expansion of electricity services, and show significant potential to reduce transmission and distribution losses.

Industry

Over recent decades, industrial energy efficiency has improved and CO₂ intensity has declined in many sectors. However, this progress has been more than offset by growing industrial production worldwide. Direct emissions from industry account for around 20% of current CO₂ emissions. Achieving deep cuts in CO₂ emissions will require the widespread adoption of current best available technology, as well as the development and deployment of a range of new technologies (such as CCS, smelting reduction, separation membranes and black liquor gasification).

Successful application of CCS in a number of energy-intensive industrial sectors (e.g. iron and steel, cement, chemical and petrochemical, and pulp and paper) represents potentially the most important new technology option for reducing direct emissions in industry. To fulfil its promise, the large-scale demonstration of CO₂ capture technologies in industry should be undertaken in parallel with demonstration projects planned for the power sector. Fuel and feedstock substitution with biomass and waste represents another important option but as the resource will be fairly limited, competition could drive up prices and make industrial applications less attractive. A decarbonised power sector will offer new opportunities to reduce the CO₂ intensity through electrification of industrial processes.

Clear, stable, long-term policies that support carbon pricing will be needed to stimulate the technology transition in industry. The current situation, in which only developed countries are subject to emission constraints, gives rise to legitimate concerns about competitiveness and carbon leakage. A global system of emissions trading may eventually be most effective; in the meantime, international agreements covering specific energy-intensive sectors may be a practical first step. Government intervention will be needed to establish standards, incentives and regulatory reforms. Removing energy price subsidies should be a priority in countries where they persist.

Buildings

Direct emissions from buildings account for around 10% of global CO₂ emissions; including indirect emissions from the use of electricity in the sector increases this
EXECUTIVE SUMMARY

share to almost 30%. From an energy perspective, buildings are complex systems consisting of the building envelope and its insulation, space heating and cooling systems, water heating systems, lighting, appliances and consumer products, and business equipment.

Most buildings have long life spans, meaning that more than half of the current global building stock will still be standing in 2050. The low retirement rate of buildings in the OECD and in economies in transition, combined with relatively modest growth, means that most of the energy and CO\textsubscript{2} savings potential lies in retrofitting and purchasing new technologies for the existing building stock. In developing countries, where new building growth will be very rapid, opportunities exist to secure significant energy savings (rather quickly and strongly) through improved efficiency standards for new buildings.

The implementation of currently available, low-cost energy-efficient and low-carbon options is essential to achieve cost-effective CO\textsubscript{2} emissions reductions in the short run. This will buy time to develop and deploy less mature and currently more expensive technologies that can play an important role in the longer term. For space and water heating, these include highly efficient heat pumps, solar thermal systems, and combined heat and power (CHP) systems with hydrogen fuel cells.

In the residential sector, the main barriers to change are higher initial costs, lack of consumer awareness of technologies, split incentives and the low priority placed on energy efficiency. Overcoming these barriers will require a comprehensive policy package that may include information campaigns, fiscal and financial incentives, and other deployment policies, as well as minimum energy performance standards. Such policies must address financial constraints, develop industry capacity and boost R&D investment.

In the service sector, policies to achieve improvements in the building shell of new buildings, together with highly efficient heating, cooling and ventilation systems will be needed. Given their larger share of total use (compared to the residential sector), significant policy measures will be required to improve the efficiency of energy use in lighting and other electrical end-uses such as office equipment, information technology (IT) equipment and refrigeration.

Recent years show some encouraging signs of a shift in consumer preferences towards new technologies that can reduce CO\textsubscript{2} emissions. In 2007/08, sales of heat pumps showed double-digit growth in a number of major European markets. Demand has also been growing rapidly for solar thermal systems that can provide low-temperature heat for cooling and/or space and water heating.

Transport

The transport sector is currently responsible for 23% of energy-related CO\textsubscript{2} emissions. Given the increases in all modes of travel, especially passenger light-duty vehicles (LDVs) and aviation, the Baseline scenario shows a doubling of current transport energy use by 2050 and slightly more than a doubling of associated CO\textsubscript{2} emissions. Achieving deep cuts in CO\textsubscript{2} emissions by 2050 will depend on slowing the rise in transport fuel use through greater energy efficiency and increasing the
EXECUTIVE SUMMARY

share of low-carbon fuels. Encouraging travellers and transporters to shift from LDVs, trucks and air travel to more frequent use of bus and rail is another route for substantial savings.

While absolute reductions in transport emissions from 2007 levels are possible in OECD countries, strong population and income growth in non-OECD countries will make it extremely difficult to achieve absolute emissions reductions in the transport sector. In the BLUE Map scenario, by 2050 emissions in OECD countries are about 60% less than in 2007, but those in non-OECD countries are 60% higher on a well-to-wheel basis.

Prospects are good for cutting fuel use and CO$_2$ emissions from LDVs by improving the efficiency of ICEs, and through vehicle hybridisation and adoption of PHEVs, EVs and fuel-cell vehicles. Virtually all incremental efficiency improvements to gasoline and diesel vehicles seen in the BLUE Map scenario are paid for by fuel savings over the vehicle lifetime. Most OECD governments now have strong fuel economy standards and many governments worldwide have announced plans to support wider use of EVs and PHEVs. Taken together, these commitments could place more than 5 million EVs and PHEVs on the road by 2020.

In the BLUE Map scenario, biofuels, electricity and hydrogen together represent 50% of total transport fuel use in 2050, replacing gasoline and diesel. Biofuel demand for light-duty ICE vehicles begins to decline after 2030 owing to a strong shift towards electricity and hydrogen fuels. In contrast, biofuels use rises rapidly for trucks, ships and aircraft through 2050, replacing middle distillate petroleum fuels.

Despite promising signs that governments are introducing policies to reduce CO$_2$ emissions from transport, much more effort is needed to increase RDD&D funding and co-ordination especially to more rapidly cut the costs of advanced technologies. In addition, greater attention must be directed toward encouraging consumers to adopt the technologies and lifestyle choices that underpin the transition away from energy-intensive, fossil-fuel based transport systems.

Box ES.3 Regional differences

ETP 2010 undertook a more detailed analysis of CO$_2$ trends and abatement options for four countries or regions that will have a major role in reducing global emissions: OECD Europe, the United States, China and India. Each faces unique challenges, reflecting current and future levels of economic development and diverse endowments of natural resources (represented in their energy mixes). Thus, each will have very different starting points and future trajectories in terms of their CO$_2$ emissions and develop in different ways in both the Baseline and the BLUE Map scenarios. Although many of the same technology options are needed to reduce emissions, the policy options associated with their application may be dramatically different.

In the Baseline scenario, CO$_2$ emissions in India show the largest relative increase, rising almost fivefold by 2050. China also shows a substantial rise, with emissions almost tripling between 2007 and 2050. The United States show a much more modest rise, of 1% and emissions in OECD Europe decline by 8%. In the BLUE Map scenario, all countries show considerable reductions from the Baseline scenario: emissions in 2050 (compared to 2007) are 81% lower for the United States, 74% lower for OECD Europe and 30% lower in China, while India’s emissions rise by 10%.
The BLUE Map scenario also brings significant security of supply benefits to all four countries or regions, particularly through reduced oil use. In the United States and OECD Europe, oil demand in 2050 is between 62% and 51% lower than 2007 levels (gas demand shows similar declines). In China and India, oil demand still grows in the BLUE Map scenario, but is between 51% and 56% lower by 2050 than in the Baseline scenario.

In OECD Europe, the electricity sector will need to be almost completely decarbonised by 2050. More than 50% of electricity generation is from renewable energy, with most of the remainder from nuclear and fossil fuels using CCS (the precise energy mix varies widely among individual countries, reflecting local conditions and opportunities). In industry, energy efficiency and CCS offer the main measures for reducing emissions.

In buildings, efficiency improvements in space heating can provide the most significant energy savings and more than half of the sector’s emissions reductions in the BLUE Map scenario. Other mitigation measures include solar thermal heating, heat pumps, CHP/district heating and efficiency improvements for appliances. Transport volumes in OECD Europe are expected to remain relatively constant. Deep CO₂ emissions reductions in transport can be achieved through more efficient vehicles, a shift towards electricity and biofuels, and progressive adoption of natural gas followed by a transition to biogas and bio-syngas.

For the United States, energy efficiency and fuel switching will be important measures in reducing CO₂ emissions across all end-use sectors. Infrastructure investments will be vital to supporting the transition to a low-carbon economy, particularly in the national electricity grid and transportation networks. Most of the existing generation assets will be replaced by 2050 and low-carbon technologies such as wind, solar, biomass and nuclear offer substantial abatement opportunities. Many energy-intensive industries have substantial scope to increase energy efficiency through technological improvements. Similarly, the average energy intensity of LDVs is relatively high; doubling the fuel efficiency of new LDVs by 2030 can help reduce emissions. Advanced vehicle technologies can also play an important role in the LDV and commercial light- and medium-duty truck sectors. In buildings, improving the efficiency of space cooling, together with more efficient appliances, offers the largest opportunity to reduce CO₂ emissions.

Given the dominance of coal, China must invest heavily in cleaner coal technologies (such as CCS) and improve efficiency of coal use in power generation and industry (which accounts for the largest share of China’s energy use and CO₂ emissions). Priority should also be given to measures to improve energy efficiency and reduce CO₂ emissions in energy-intensive sectors such as iron and steel, cement and chemicals. The Chinese transport sector is evolving very rapidly, in terms of vehicle sales, infrastructure construction and the introduction of new technologies. The BLUE Map scenario shows that significant emissions reductions will depend on the electrification of transport modes and substantial decarbonisation of the electricity sector.

For India, the challenge will be to achieve rapid economic development — which implies a significant increase in energy demand for a growing population — with only a very small increase in CO₂ emissions. Electricity demand will grow strongly and the need for huge additional capacity creates a unique opportunity to build a low-carbon electricity system. While India has some of the most efficient industrial plants in the world, it also has a large share of small-scale and inefficient plants. Thus, improving overall industrial efficiency will be a significant challenge. Rising incomes and increased industrial production will spur greater demand for transport in India, making it imperative to promote public transport and new, low-carbon vehicle technologies. The buildings sector will also see strong growth in energy demand; efficiency improvements in space cooling and appliances will be critical to restraining growth in energy consumption and emissions.
Conclusion

A truly global and integrated energy technology revolution is essential to address the intertwined challenges of energy security and climate change while also meeting the growing energy needs of the developing world. ETP 2010 shows that key players, from both public and private sectors, are starting to take the steps needed to develop and deploy a very broad range of new low-carbon technologies. Action can be seen in all of the most important sectors, and across most regions of the world.

Clearly, financing remains a substantial challenge as does identifying appropriate mechanisms to accelerate the deployment of low-carbon technologies in major developing countries. A related issue is that several sources predict a severe skills shortage, which could quickly become a major barrier to deployment across all sectors and in all regions. There is an urgent need to properly assess the skills required, considering regional situations and human resource availability, and to develop recommendations on how to fulfil these needs.

As citizens of a changing world, we all live with a degree of uncertainty at all times; as energy producers and consumers entering a period of rapid change, the sense of uncertainty is likely to be amplified. The roadmaps and transition pathways presented in ETP 2010 aim to overcome existing barriers and spur much-needed RDD&D in the very near term and throughout the period to 2050. The extensive data, projections and analysis contained in this volume will provide decision makers with the detailed information and insights they need to throw their weight behind rapid acceleration — in their own backyards or at the international level — of the switch to a more secure, low-carbon energy future.

In short, the most vital message of ETP 2010 is that an energy technology revolution is within reach. Achieving it will stretch the capacities of all energy-sector stakeholders and entail substantial upfront costs, but over the long term these will be more than offset by the benefits. Governments, investors and consumers around the world need to take bold, decisive action to initiate and advance change in their respective spheres of influence — and increase their commitment to working together.
Secure, reliable and affordable energy supplies are fundamental to economic stability and development. The erosion of energy security, the threat of disruptive climate change and the growing energy needs of the developing world all pose major challenges to energy decision makers. This book deals with the role of energy technologies in meeting these challenges. This will involve both making better use of existing technologies and developing new ones.

In recent years fossil fuel prices have been very volatile. They look set to remain at high levels compared to the past. A number of factors contribute to this trend, including rising energy demand, particularly in the developing world, and concerns over the security and availability of oil and gas supplies. Reducing fossil fuel dependency is an important energy policy target in many countries.

These energy security concerns are compounded by the increasingly urgent need to mitigate greenhouse-gas emissions, including those relating to energy production and consumption. About 84% of all CO$_2$ emissions are energy-related, and about 65% of all greenhouse-gas emissions can be attributed to energy supply and energy use. The International Energy Agency’s (IEA) World Energy Outlook 2009 (WEO 2009) (IEA, 2009a) projects that by 2030, in the absence of new policies, fossil fuel demand will have increased by 37% from 2007 levels and global energy-related CO$_2$ emissions will have grown by 40%.

The current trend of rising energy demand and rising emissions runs directly counter to the major emissions reductions that are required to prevent dangerous climate change. The United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded that reductions of 50% to 85% in global CO$_2$ emissions compared to 2000 levels will need to be achieved by 2050 to limit the long-term global mean temperature rise to 2.0°C to 2.4°C (IPCC, 2007). Higher emission levels will result in more significant climate change (Table 1.1). Recent studies have suggested that climate change is occurring faster than previously expected and that even a 50% reduction in global CO$_2$ emissions by 2050 may not be enough to avoid dangerous temperature increases (UNSW, 2009).

<table>
<thead>
<tr>
<th>Temperature increase ($^\circ$C)</th>
<th>All GHGs (ppm CO$_2$-eq.)</th>
<th>CO$_2$ (ppm CO$_2$)</th>
<th>CO$_2$ emissions 2050 (% of 2000 emissions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0-2.4</td>
<td>445-490</td>
<td>350-400</td>
<td>-85 to -50</td>
</tr>
<tr>
<td>2.4-2.8</td>
<td>490-535</td>
<td>400-440</td>
<td>-60 to -30</td>
</tr>
<tr>
<td>2.8-3.2</td>
<td>535-590</td>
<td>440-485</td>
<td>-30 to +5</td>
</tr>
<tr>
<td>3.2-4.0</td>
<td>590-710</td>
<td>485-570</td>
<td>+10 to +60</td>
</tr>
<tr>
<td>4.0-4.9</td>
<td>710-885</td>
<td>570-660</td>
<td>+25 to +85</td>
</tr>
<tr>
<td>4.9-6.1</td>
<td>885-1130</td>
<td>660-790</td>
<td>+90 to +140</td>
</tr>
</tbody>
</table>

ppm: parts per million.  
The longer the current trend of increasing emissions continues, the deeper will be the future emissions cuts that are needed to protect the climate and the greater the consequential costs. WEO 2009 calculates that each year of delay before moving onto an emissions path consistent with a 2.0°C temperature increase would add approximately USD 500 billion to the global incremental investment cost. A delay of just a few years would probably put that goal completely out of reach. All countries and regions must contribute to emissions reductions if this goal is to be met. Even in the very unlikely event that the member countries of the Organisation for Economic Co-operation and Development (OECD) were to emit no CO₂ by 2050, non-OECD countries would still need to reduce their own CO₂ emissions below current levels if significant climate change was to be avoided.

The political context

At the IEA Ministerial Meeting in October 2009, Ministers agreed:

…that we need to act now to combat climate change if we are to avoid the devastating effects both for our citizens and for the world, particularly poor and developing countries. Such efforts can also contribute to economic growth, technological advancement and innovation, energy security and access to energy for the poor (IEA, 2009b).

Ministers welcomed:

…the Major Economies Forum (MEF) recognition of the scientific view that the increase in global average temperature above pre-industrial levels ought not to exceed two degrees Celsius and stated their willingness to share with all countries the goal of achieving at least a 50% reduction of global emissions by 2050 and recognise that this implies that global emissions need to peak as soon as possible and decline thereafter.

As part of this, they also acknowledged:

…the goal, as stated in the Leaders’ Declaration of the G8 L’Aquila Summit, to reduce developed countries’ collective emissions of greenhouse gases in aggregate by 80% or more by 2050 compared to 1990 or more recent years.

The Ministers also noted that:

…most of the actions to mitigate climate change need to take place in the energy sector which accounts for over 60% of global greenhouse-gas emissions and recognised that international efforts to improve energy efficiency and accelerate research, development and deployment of a wide spectrum of low-carbon technologies are essential. In turn, they agreed that more effort should be made to increase substantially public-sector investments in research, development and demonstration of these technologies, with a view to doubling such investments by 2015.

Finally, Ministers called upon the private sector to increase its investment in these areas as well.

Many of these statements were echoed in the Copenhagen Accord developed by some of the world’s largest economies at the 15th Conference of the Parties (COP15) to the United Nations Framework Convention on Climate Change (UNFCCC) in
December 2009 (UNFCCC, 2009). This Accord recognised the importance of limiting the increase in global temperature to below 2.0°C and agreed that deep cuts in global emissions were required to meet this goal. Although the Copenhagen Accord was not formally adopted by the Conference of the Parties to the UNFCCC, a vast majority of governments worldwide expressed their support. This represents a significant step forward in developing a shared global understanding of the challenges of climate change and a commitment to action to address it.

The purpose and scope of this study

The goal of the analysis in this book is to provide an IEA perspective on the potential for energy technologies to contribute to deep CO₂ emissions reduction targets and the associated costs and benefits. As in earlier editions of Energy Technology Perspectives, a suite of updated scenarios are used to explore possible future technology options and the combinations of those options across both the supply and demand sectors that can meet energy policy goals at least cost. It uses a techno-economic approach to identify the role of current and potential new technologies in reducing CO₂ emissions and improving energy security. The analysis does not deal with the political feasibility of such goals. Investment needs and financing mechanisms are reviewed but the analysis makes no attempt to allocate responsibility among countries for funding the significant investment that will be needed.

This book aims to review and assess the energy technologies that will be important in addressing climate change and energy security challenges over the next 40 years. It identifies the main technical and policy barriers to the implementation of change, and the measures that may be needed to overcome these barriers. It sets out detailed roadmaps for selected technologies. It is intended to be a reference point for policy makers and others interested in identifying how existing and emerging clean energy technologies and policies can bring about the energy revolution that is needed.

The analysis builds on Energy Technology Perspectives 2008 (IEA, 2008) and WEO 2009, by providing decision makers with more detailed practical information and tools that can help kick-start the transition to a more secure, sustainable and affordable energy future. New features in this edition include:

- **Updated scenarios** with greater regional detail that provide insights into the new technologies that are likely to be most important in different regions of the world.

- **Detailed sectoral analyses** that highlight the most significant technological challenges and opportunities in each of the main energy-using sectors and the new policies that will be needed to realise change.

- **Roadmaps and transition pathways** that identify ways of accelerating the deployment of some of the most important clean energy technologies.

The study draws heavily on the extensive IEA store of data and analysis, and is a result of close co-operation between all IEA offices. It has profited greatly from the unique international IEA network for collaboration on energy technology described
in Annex A. More than 5 000 experts from 25 IEA member countries, 17 IEA non-
member countries, 48 companies, the European Commission, the Organization of
the Petroleum Exporting Countries and the United Nations Industrial Development
Organisation participate in the IEA Implementing Agreements, part of the larger
energy technology network under the auspices of the IEA Committee on Energy
Research and Technology (CERT), its Working Parties and Expert Groups. Although
the analysis in this book has benefited from numerous contributions from network
members and other experts, the conclusions are those of the IEA Secretariat.

Energy Technology Perspective 2010 comprises two parts:

Part 1 (Chapters 2 to 11) examines the fuels and technologies that are likely to
be important in a Baseline scenario and in a range of scenarios in which global
CO₂ emissions are reduced by 50% from 2005 levels by 2050 (the BLUE Map
scenario and a series of variants of it). It provides insights into the future of energy
technologies for electricity generation and in the key end-use sectors of industry,
buildings and transport. It then analyses the current status and future energy options
for OECD Europe, the United States, China and India, which together make up
about 56% of today’s global primary energy demand.

Part 2 (Chapters 12 to 17) sets out the technology transitions that will be required
to help the world move towards a more sustainable energy future and a series
of technology roadmaps that can help to achieve this objective. It addresses how
these transitions can be financed, the role of behavioural change in facilitating
technological deployment and the diffusion of technologies from developed to
emerging economies. It also discusses the other environmental impacts of new
energy technologies.
Chapter 2

Key findings

In the absence of new policies, global energy demand and CO₂ emissions will double by 2050. This is unsustainable.

- In the Baseline scenario, global CO₂ emissions grow rapidly, oil and gas prices are high, and energy security concerns increase as imports rise. In this scenario, energy-related CO₂ emissions in 2050 would be twice the level they were in 2007. These developments are not sustainable. Nearly all of the growth in energy demand and in emissions comes from non-OECD countries.

- Liquid fuel demand in 2050 in the Baseline scenario is 58% higher than in 2007, requiring the significant use of unconventional oil and synthetic fuels. Coal demand increases by 138% and gas demand is 85% higher. The carbon intensity of primary energy use increases, largely driven by increasing coal use in power generation and, after 2030, by the increased use of coal to produce liquid transport fuels.

The widespread deployment of a range of existing and new energy technologies can lead to a more secure and sustainable energy future.

- Using a combination of existing and new technologies, as envisaged in the BLUE scenarios, it is possible to halve worldwide energy-related CO₂ emissions by 2050. Achieving this will be challenging, and will require significant investment. But the benefits in terms of environmental outcomes, improved energy security and reduced energy bills will also be large.

- In the BLUE Map scenario, oil demand in 2050 is 27% lower than in 2007 and coal and gas demand are 36% and 12% lower respectively. These reductions in demand lead to substantial fuel savings. Even so, fossil fuels remain an important element of the world’s energy supply in 2050 in all scenarios.

- The BLUE Map scenario delivers net financial benefits compared to the Baseline. Investments over the period 2010 to 2050 in the BLUE Map scenario are USD 46 trillion higher than those in the Baseline scenario. This represents an increase of 17%. But cumulative fuel savings over the same period are even larger at USD 112 trillion. Discounting both investments and fuel savings between 2010 and 2050 at a discount rate of 10% yields a net saving of USD 8 trillion.

- The outcomes envisaged in the BLUE scenarios are not possible with only the technologies that are commercially available today. The electricity sector will need to be substantially decarbonised through the use of renewable energy, nuclear power and fossil-fuel-based generation combined with carbon capture and storage (CCS). The rate of energy efficiency improvement will need to increase substantially across all end-use sectors. New low-carbon technologies will be required in transport, buildings and in industry.
Fuel switching to low- or zero-carbon fuels will be a significant source of carbon reductions. In the BLUE Map scenario, biomass use doubles and low-carbon electricity is increasingly used in buildings, transport and industry. Hydrogen also plays a role after 2030.

To reduce CO\textsubscript{2} emissions by 50% by 2050, emissions must peak around 2020 and thereafter show a steady decline. If this does not happen, the 50% reduction by 2050 will become much more costly to achieve, and possibly unachievable at any realistic price. Urgent action is needed.

Policies that raise CO\textsubscript{2} targets incrementally risk locking the world into options and strategies that are unsuited for the deep emission cuts that are needed by 2050. Many of the investments made in the next 10 years in buildings, industrial installations and power plants will still be in operation in 2050. If costly early scrapping is to be minimised, then from now on investments in energy infrastructure will need to take account of long-term CO\textsubscript{2} emission goals.

OECD countries account for less than one-third of global CO\textsubscript{2} emissions in 2050 in the Baseline scenario. In the BLUE Map scenario, these countries reduce their emissions by 70% to 80% of their 2007 levels. But global emissions can only be halved if non-OECD countries collectively also reduce their emissions below current levels. This will require the widespread deployment of low-carbon technologies in non-OECD countries.

Even if CO\textsubscript{2} emissions are reduced by 50% below current levels by 2050, this may not be enough to keep expected temperature rises to below 2 degrees centigrade (°C). While it is technically possible to reduce emissions further than this, the cost of achieving additional incremental reductions rises rapidly. Achieving much deeper emission cuts than 50% by 2050 will not be possible in the absence of more radical, and politically potentially very challenging, policy measures designed to achieve substantial lifestyle changes.

Scenario characteristics

The scenarios in Energy Technology Perspectives 2010 (ETP 2010) further develop earlier IEA scenario analyses, particularly the BLUE scenarios presented in Energy Technology Perspectives 2008 (ETP 2008) (IEA, 2008a) and the Reference and 450 parts per million (ppm) scenarios published in World Energy Outlook 2009 (IEA, 2009a).

The ETP 2010 Baseline scenario assumes that no new energy and climate policies are introduced during the scenario period. It follows the World Energy Outlook 2009 (WEO 2009) Reference scenario for the period 2007 to 2030. For the period 2030 to 2050, it updates the ETP 2008 analysis. In the Baseline scenario, the world economy grows by 3.1% a year on average between 2007 and 2050, although the pattern of economic growth changes after 2030 as population growth slows and the economies of developing countries begin to mature.
A BLUE Map scenario has also been developed, together with a number of variants which are described in detail in the relevant sector chapters (Box 2.1). The BLUE scenarios assume that global energy-related CO₂ emissions are reduced to half their current levels by 2050. The scenarios examine ways in which the introduction of existing and new low-carbon technologies might achieve this at least cost. The BLUE scenarios are consistent with a long-term global rise in temperatures of 2°C to 3°C, but only if the reduction in energy-related CO₂ emissions is combined with deep cuts in other greenhouse-gas emissions. They also bring energy security benefits in terms of reduced dependence on oil and gas, and health benefits as air pollutant emissions are also reduced. The BLUE scenarios are based on the same macro-economic assumptions as the Baseline scenario. The modelling approach and framework assumptions are described in more detail in Annex A.

**Box 2.1 ▶ Scenarios in ETP 2010**

The following scenarios have been analysed for ETP 2010.

**Economy-wide**

Two main scenarios are used in the publication:
- A Baseline scenario, which assumes that no new policies are introduced and follows the WEO 2009 Reference scenario to 2030;
- A BLUE Map scenario, which assumes that global energy-related CO₂ emissions are reduced to half their 2005 levels by 2050 and is broadly optimistic for all technologies.

In addition a number of variants are used for different sectors:

**Electricity sector**

Four variants of the BLUE scenario are used, with the following differences as compared to the BLUE Map scenario:
- BLUE hi NUC which assumes nuclear capacity of 2 000 gigawatts (GW) instead of the 1 200 GW maximum in the BLUE Map scenario;
- BLUE no CCS which assumes that CCS is not commercially deployed;
- BLUE hi REN which assumes that renewables provide 75% of global electricity production in 2050;
- BLUE 3% which uses a uniform 3% discount rate for all electricity generating technologies, rather than market rates of between 8% and 14% that are used in the BLUE Map scenario.

**Buildings**

Three variants of the BLUE Map scenario are used, with the following differences as compared to the BLUE Map scenario:
- BLUE CHP assumes more rapid declines in the costs of fuel-cell combined heat and power (CHP) units using hydrogen;
- BLUE Solar Thermal assumes that low-cost compact thermal storage is available by 2020 and that system costs come down more rapidly in the short term;
- BLUE Heat Pumps assumes the development of ultra-high efficiency air-conditioners and faster cost reductions for space and water heating applications.
Industry

Two variants are used, with the following differences as compared to the Baseline and BLUE Map scenarios:

- **High Baseline**, which assumes a higher growth in industrial production for key energy-intensive materials;
- **High BLUE**, which is consistent with the industrial production in the High Baseline.

Transport

A variant of the Baseline scenario and two variants of the BLUE Map scenario are used, with the following differences as compared to the original scenarios:

- **High Baseline** assumes a higher growth in passenger light-duty vehicle ownership in the developing world and faster growth in vehicle travel and freight transport, especially trucking;
- **BLUE Shifts** assumes that travel is shifted towards more efficient modes and a modest reduction in total travel growth;
- **BLUE Map/Shifts** combines the technology changes in BLUE Map with the travel pattern changes in BLUE Shifts.

These scenarios are not forecasts. The Baseline scenario illustrates what is likely to happen if no new action is taken through the energy system to address climate change and energy security concerns. This is used as a reference scenario, against which the potential impact of actions to further reduce CO₂ emissions can be assessed. The BLUE scenarios explore what needs to be done to meet ambitious emissions reduction goals and other policy objectives. The scenarios are internally consistent analyses, based on a set of optimistic but plausible technology assumptions, which enable an assessment of the least-cost pathways that may be available to meet these goals. The BLUE scenarios can help policy makers identify technology portfolios and policy strategies that may deliver the outcomes they are seeking. The scenarios are also the basis for technology roadmaps that can help to establish more detailed action plans, including areas in which further international technology co-operation is needed (see Chapter 13).

Technology development is inherently uncertain. The BLUE scenarios assume that technologies that are not available today are developed to the point at which they become commercial. It also requires the rapid and widespread uptake of such technologies into the market. Without the rapid commercialisation of new energy technologies, the objectives of the BLUE scenarios will be considerably more expensive and possibly completely unachievable.

The analysis does not reflect on the likelihood of these changes occurring, or on the precise mix of climate policy instruments that might best help achieve these objectives. But it is clear that achieving the outcomes implicit in the BLUE scenarios will depend on the implementation of a wide range of policies and measures to overcome barriers to the adoption of the necessary technologies. Both the public and the private sectors have major roles to play in creating and disseminating new energy technologies.
Box 2.2  Substantial CO$_2$ reductions will require a global effort

OECD countries currently account for around 45% of global energy-related CO$_2$ emissions. The Baseline scenario projects that, by 2050, this share will have fallen to less than one-third. So even in the implausible event that OECD countries emitted no CO$_2$ by 2050, the 50% reduction target could not be met unless the rest of the world also reduced its emissions below current levels. Halving global emissions by 2050 will require a global effort.

Achieving such significant CO$_2$ reductions will only be possible if a way can be found rapidly to accelerate the deployment of existing low-carbon technologies, and the development of a wide range of new low-carbon technologies and their widespread deployment in all major economies. The scenarios demonstrate that the achievement of ambitious CO$_2$ reductions requires an energy technology revolution in all energy-consuming sectors across all regions and countries. Against this background, ETP 2010 examines issues such as the massive upscaling in research and development (R&D), financing, and technology deployment and transfer that will be needed if such a revolution is to be achieved.

The increased uptake of cleaner and more efficient energy technologies envisaged in the BLUE scenarios will need to be driven by:

- **Increased support for the R&D** of energy technologies that face technical challenges and need to reduce costs before they become commercially viable;

- **Demonstration programmes** for energy technologies that need to prove they can work on a commercial scale under relevant operating conditions;

- **Deployment programmes** for energy technologies that are not yet cost-competitive but whose costs could be reduced through learning-by-doing. These programmes would be phased out when the technology becomes cost-competitive;

- **CO$_2$ reduction incentives** to encourage the adoption of low-carbon technologies. Such incentives could take a number of forms – such as regulation, pricing, tax breaks, voluntary programmes, subsidies or trading schemes. The ETP 2010 BLUE scenarios assume that policies and measures are put in place that lead to the adoption of low-carbon technologies with a cost of up to USD 175 per tonne of CO$_2$ saved in 2050;\(^1\)

- **Policy instruments** to overcome other commercialisation barriers that are not primarily economic. These include enabling standards and other regulations, third-party financing schemes, labelling schemes, information campaigns and energy auditing. These measures can play an important role in increasing the uptake of energy-efficient technologies in the buildings and transport sectors, as well as in non-energy-intensive industry sectors where energy costs are low compared to other production costs.

---

1. All costs are shown in 2008 US dollars.
Energy prices in all the scenarios respond to changes in demand and supply. In the Baseline scenario, oil prices are assumed to increase to USD 120 per barrel (bbl) in 2050. In nominal terms this means that oil prices would reach USD 312/bbl in 2050. This price trajectory is consistent with the WEO 2009 Reference scenario. At these prices, substitutes for conventional oil such as oil sands, as well as transport fuels produced from biomass, gas and coal, will begin to play a larger role. Unconventional gas is also starting to have a substantial impact in North America and may do so in other regions in the future. If the necessary investments in oil and gas production do not materialise, prices will be considerably higher (IEA, 2008b, 2009a). Reduced demand for oil and gas in the BLUE Map scenario is assumed to result in oil prices of around USD 70/bbl in 2050. But as the BLUE Map scenario has a CO₂ price of USD 175/tCO₂ in 2050, the effective oil price seen by consumers in this year is much higher, at around USD 140/bbl in real terms.

**Energy and CO₂ emission trends**

From 1990 to 2000, CO₂ emissions increased by an average of 1.1% a year. From 2000 to 2007, emissions growth accelerated to 3% a year, despite the increased focus on climate change. This was mainly as a result of high economic growth, particularly in coal-based economies, and higher oil and gas prices which led to an increase in coal-fired power generation. Emissions from coal use increased by 0.6% a year between 1990 and 2000, but by 4.8% a year between 2000 and 2007.

In the WEO 2009 Reference scenario, CO₂ emissions increase from 29 Gt CO₂ in 2007 to 40 Gt by 2030. CO₂ emissions continue to grow in the ETP 2010 Baseline scenario projections beyond 2030, reaching 57 Gt in 2050, i.e. almost double that in 2007 (Figure 2.1). For the period 2007 to 2050, this is an average increase of 1.6% a year. CO₂ emissions in 2030 and 2050 in the Baseline scenario are lower than those in ETP 2008. They are 8% lower in 2050 owing to a combination of higher fossil-fuel prices leading to lower energy demand and the greater penetration of low-carbon fuels and technologies.

Nearly all the growth in global CO₂ emissions in the Baseline scenario comes from outside the OECD. Emissions from non-OECD countries grow from 15 Gt CO₂ in 2007 to 42 Gt CO₂ in 2050. OECD emissions grow from 14 Gt CO₂ to 15 Gt CO₂ over the same period. Most of the increase in OECD countries comes after 2030.

Long-term emission projections are highly uncertain. In the WEO 2009 higher GDP case, CO₂ emissions reach 43 Gt by 2030, compared to 40 Gt in the Reference scenario and 38 Gt in the low GDP case. Similarly, the high energy demand projections for 2050 described in the sector chapters of this publication show that emissions could be up to 20% higher than the 57 Gt projected in the Baseline scenario for that date. Higher Baseline emissions in 2050 would make reaching the objectives of the BLUE scenarios much harder.

2. Nominal price assumes inflation of 2.3% per year from 2008.
3. These prices are substantially higher than in ETP 2008, reflecting market developments over the last two years. ETP 2008 used an oil price of USD 65/bbl in 2050 and was consistent with the price assumptions in the 2007 edition of the World Energy Outlook.
4. The high-demand scenarios in ETP 2010 only explore changes in a limited number of factors that impact future emissions. A review by the Intergovernmental Panel on Climate Change (IPCC, 2007) of a large number of scenarios by different organisations shows a much wider range of outcomes for 2050.
The outcomes projected in the Baseline scenario are not inevitable. The BLUE scenarios show that it is possible to completely transform the energy system over the next half century using a combination of existing and new technologies, if the
right decisions are taken early enough. This would enable a more secure and sustainable energy future, but would require significant investments to achieve substantial changes in both energy supply and energy demand infrastructure. Such investments would also generate significant fuel savings in buildings, transport and industry over the longer term.

Technologies for reducing CO₂ emissions

In the BLUE Map scenario, CO₂ emissions in 2050 are reduced to 14 Gt, around half the level emitted in 2005. This means emissions are 43 Gt lower in 2050 than the 57 Gt CO₂ projected in the Baseline scenario. Achieving these CO₂ emissions reductions will require the development and deployment of a wide range of energy-efficient and low-carbon technologies across every sector of the economy (Figure 2.2). End-use efficiency improvements in the use of fuels and electricity, and power sector measures dominate the short- and medium-term emissions reductions. But to achieve the deeper emission cuts needed by 2050, these measures will need to be supplemented by the widespread introduction of new technologies such as electric vehicles (EVs) and CCS between 2030 and 2050.

The results of the BLUE Map scenario show that 2005 emission levels can be halved by 2050 by exploiting technology options with costs of up to USD 175/tCO₂ saved. This is USD 25/tCO₂ lower than in ETP 2008. This cost reduction results from two factors: first, the need to achieve smaller emissions reductions in 2050 since the ETP 2010 Baseline scenario has a lower level of emissions in 2050 than the equivalent ETP 2008 scenario; and second, higher fossil-fuel prices, which lead to larger fuel cost savings from implementing a given low-carbon option. If technologies were not to emerge at the rate or at the cost assumed, the levels of emissions reduction needed could only be achieved at a higher cost per tonne of CO₂ saved. For example, in the BLUE variant in which CCS is not available, the marginal cost of CO₂ abatement rises to around USD 300/tCO₂. However, under all BLUE variants, most abatement options have costs that are much less than the marginal cost.

The BLUE Map scenario emissions profile (Figure 2.2) suggests a peak in CO₂ emissions at just below 31 Gt CO₂ between 2015 and 2020. Emissions then start to reduce from that point onwards. The later the peak, and the higher it is, the more difficult and costly it will be to achieve deep emission cuts by 2050.

The pledges made by countries under the Copenhagen Accord, although they represent a substantial deviation from the Baseline scenario, seem unlikely to be sufficient to deliver the BLUE Map scenario. Based on these pledges, CO₂ emissions are likely still to be on a slight upward path by 2020 and at that point around 1 Gt CO₂ a year higher than in the BLUE Map scenario.⁵ This pathway is broadly consistent with a long-term rise in global temperatures of around 3°C. Although it may not be impossible subsequently to recover from this position to a pathway that leads to a 50% emissions reduction by 2050, this could only

⁵ The business-as-usual baseline chosen by countries and other details about their pledges are not always clear and so a number of assumptions have been made in this calculation.
be achieved by measures that are likely to be much more disruptive and more expensive than any options envisaged in this publication. Given the long lead times before new policies can be put in place and have effect, there is therefore a need for strong global action to be taken urgently to implement policies that will realise the pledges currently made and to go beyond these as part of a new global deal on climate change.

**Figure 2.2**  
Key technologies for reducing CO₂ emissions under the BLUE Map scenario

![Graph showing energy emissions reduction](image)

- CCS 19%
- Renewables 17%
- Nuclear 6%
- Power generation efficiency and fuel switching 5%
- End-use fuel switching 15%
- End-use fuel and electricity efficiency 38%

**Key point**

A wide range of technologies will be necessary to reduce energy-related CO₂ emissions substantially.

All sectors will need to achieve emissions reductions between 2007 and 2050 to deliver the outcomes implicit in the BLUE Map scenario (Figure 2.3). In the next 20 years, the power sector and all end-use sectors together need to play an equal part in the emissions reduction effort. Within the end-use sectors, energy efficiency measures need to play the biggest role in the next twenty years. Beyond 2030, the transport sector has an increasingly important role to play in reducing emissions.

OECD countries account for just over 30% of the total global emissions reduction in 2050 in the BLUE Map scenario as compared to the Baseline scenario. The least-cost approach of the BLUE Map scenario leads to OECD countries reducing their emissions by 77% compared to 2005 levels. Non-OECD countries reduce their emissions by 24% over the period, although their emissions continue to grow up to 2020, reducing significantly only after 2030. These developments reflect different trends in CO₂ emissions under the Baseline scenario, with much higher CO₂ emissions growth in developing countries than in the OECD countries in coming decades. They also imply a significant and sustained effort to reduce emissions in all major economies. The sharing of any financial burden for such change is beyond the scope of this analysis.
Figure 2.3  ▶ CO₂ emissions reductions in the BLUE Map scenario by sector

Note: CO₂ emission savings from fuel transformation have been allocated to the transport sector and the CO₂ reductions from electricity savings are allocated to end-use sectors.

Key point

The share of end-use sectors in emissions reductions increases between 2030 and 2050.

In the BLUE Map scenario, end-use efficiency accounts for 38% of the CO₂ emissions reduction in 2050 (Figure 2.4). CCS in power generation, fuel transformation and industry accounts for 19% of the total emissions reduction. The increased use of renewable energy accounts for 17% of the total emissions reduction, while nuclear energy accounts for 6%. About a quarter of the renewables contribution in the BLUE Map scenario comes from biofuels, with most of the remainder from the use of renewables in the power sector. These figures downplay the full importance of nuclear and renewables, since both options already play an important role in the Baseline scenario.

Figure 2.4  ▶ CO₂ emissions reductions by technology area in 2050 in the BLUE Map scenario

Note: CO₂ savings from CCS take into account the resulting loss in energy efficiency.

Key point

End-use efficiency and power generation options account for the bulk of emissions reductions in 2050.
The scenarios presented in this publication are based on a partial equilibrium model. This takes into account technology investment and operating costs, as well as fuel costs. The costs associated with research, development, demonstration and deployment (RDD&D) have also been considered. The analysis does not specifically consider transaction costs. This may underestimate the total costs involved in reducing CO₂ emissions where millions of small-scale investment decisions are involved.

While this approach provides important insights into the cost of CO₂ reductions for consumers and for the global economy, the analysis does not assess the full impacts on gross domestic product (GDP). The redistribution of production factors will affect the growth potential of the economy. Other studies have looked into the impact of climate policies on global economic structures and on economic growth. The Stern Review (Stern, 2007) looked at 21 studies that had estimated the GDP loss for scenarios that stabilised CO₂ concentrations at 450 ppm (consistent with the BLUE Map scenario). These showed a range in 2030 between a loss of global GDP of 3.4% compared to the Baseline scenario and an increase in GDP of 3.9%. WEO 2009 calculated a narrower range for its 450 ppm CO₂ scenario, with a global GDP loss in 2030 of between 0.9% and 1.6%.

The impact on GDP is likely to grow over time and could become substantial by 2050. The OECD has calculated that in 2050 the GDP loss for a scenario which stabilises CO₂ emissions at 550 ppm is 4%. For a 450 ppm CO₂ scenario, this increases to a loss of almost 7% (OECD, 2009). However, the model used by the OECD does not include some important low-carbon technologies such as carbon capture and storage, which the ETP analysis shows can help reduce emissions at lower costs. Many studies have shown that over the longer term the cost of inaction would far outweigh the cost of reducing CO₂ emissions.

The technologies and policies needed to reduce CO₂ emissions in the BLUE Map scenario will have a considerable impact on energy demand, particularly for fossil fuels. Lower demand for oil in the BLUE Map scenario means there is less need to produce oil from costly fields higher up the supply curve in non-OPEC countries. As a result, the oil price is assumed to reach USD 90/bbl in 2020 and then decline to USD 70/bbl in 2050. This is in line with the assumptions of WEO 2009. As long-term gas supply contracts are also often indexed to oil prices, these are also assumed to be lower in the BLUE Map scenario. Coal prices are also substantially lower owing to the large shift away from coal in the BLUE Map scenario.

**Box 2.3 Economic impacts of the BLUE Map scenario**

Energy efficiency improvements in the supply and demand sectors make the single largest contribution to CO₂ emissions reductions in the BLUE Map scenario. This is in addition to significant efficiency gains already implicit in the Baseline scenario.

Final energy demand in 2050 is 4 477 million tonnes of oil equivalent (Mtoe) (31%) lower in the BLUE Map scenario than in the Baseline scenario. Around 29% of this reduction occurs in industry, 36% in the transport sector and 35% in the buildings sector. These figures include the full benefits of electrification on final
energy use, recognising that electric technologies often have much higher end-use efficiencies than those using gas or oil products.\(^6\)

Since 1973, global energy intensity (final energy use per unit of GDP) has improved at an average rate of 1.7% a year. This decoupling of energy consumption and economic growth has been the main factor restraining the growth of CO\(_2\) emissions in recent years. The carbon intensity of energy use (CO\(_2\) emissions per unit of energy) changed very little between 1973 and 2007. The improvements in final energy intensity have come from a combination of increased energy efficiency and structural changes in economies. Structural changes, such as a shift from the production of raw materials to less energy-intensive manufactured products, have played a significant role in some countries.

The impact of energy efficiency improvements in OECD countries has been to restrain growth in final energy consumption. Without the energy efficiency improvements achieved since 1973, final energy use in the OECD-11\(^7\) would have been 63% higher in 2006 than it actually was (Figure 2.5).

**Figure 2.5** Long-term energy savings from improvements in energy efficiency, OECD-11

![Graph showing energy savings](image)


**Key point**

Without 30 years of energy savings from improved energy efficiency, energy consumption in OECD countries would be much higher than it is today.

The further decoupling of energy use and economic growth continues in all scenarios (Figure 2.6). In the Baseline scenario, global final energy intensity falls by 1.8% per year, a rate similar to that seen over the past 30 years. This means that, by 2050, the amount of energy used on average to produce one unit of GDP

---

6. Final energy savings from increased electrification may not be reflected in primary energy terms because of the efficiency losses in power generation.
7. The OECD-11 comprises Australia, Denmark, Finland, France, Germany, Italy, Japan, Norway, Sweden, the United Kingdom and the United States. Together, these countries account for more than 75% of current total final energy use in OECD countries.
will be less than half that needed today. In the BLUE Map scenario, the global improvement in energy intensity increases to an average of 2.6% a year between 2007 and 2050, resulting in the energy used per unit of GDP in 2050 being only about one-third of that in 2007.

**Figure 2.6**  
**Historical and projected changes in final energy consumption per unit of GDP**

- **Key point**  
  In the BLUE Map scenario, significant additional reductions in final energy intensity above those already implicit in the Baseline scenario occur across all regions.

The energy intensity of the economies in transition improves by more than that of the OECD countries in both the Baseline and BLUE Map scenarios, reflecting the significant potential in these countries to improve energy efficiency. Many developing countries have achieved rapid improvements in their energy consumption relative to GDP as their economies have modernised. In the Baseline scenario, developing countries continue strongly to improve their energy intensity, but at a slower rate than between 1990 and 2007. In the BLUE Map scenario, the introduction of more energy-efficient end-use technologies increases the improvement in energy intensity in developing countries to 3% a year.

Globally, energy efficiency improvements average 0.7% per year in the Baseline scenario. Over the period 2007 to 2050, these improvements in energy efficiency play a significant role in limiting the increase in final energy demand under the Baseline scenario. Without these savings, final energy demand would be 35% higher in 2050. In the BLUE Map scenario, substantial additional energy savings are achieved in the final demand sectors compared to the Baseline scenario thanks to further improvements in energy efficiency. The rate of energy efficiency improvement roughly doubles to 1.5% per year.

**Power sector**

Emissions from the power sector are reduced considerably in the BLUE Map scenario, owing partly to reduced demand for electricity as a result of end-use efficiency gains, but mostly to fuel switching and the introduction of a range of low-carbon technologies. Electricity demand in the BLUE Map scenario is 13% lower...
in 2050 than in the Baseline scenario. This is as a result of much larger efficiency gains being partly offset by additional demand for CO₂-free electricity in buildings and in the transport sector, particularly for heat pumps and plug-in hybrid electric vehicles (PHEVs) and EVs.

Coal’s share of power generation in 2050 declines from 44% in the Baseline scenario to 12% in the BLUE Map scenario. At the same time, the contribution from gas declines from 23% to 15%. By 2050 in the BLUE Map scenario, more than 90% of the electricity produced from coal-fired power stations comes from plant fitted with CCS. Reflecting the fact that CCS is significantly more expensive per tonne of CO₂ saved for gas than for coal, a much smaller percentage of gas-fired generation, around 30%, comes from gas plant fitted with CCS. The share of gas generation capacity fitted with CCS is even lower, as gas peaking plants, with a low number of operating hours as backup for variable renewables, play an important role in the BLUE Map scenario.

Nuclear power generation already plays an important role in the Baseline scenario, with capacity increasing from 374 GW to 610 GW in 2050, representing 10% of total generation by the end of the period. As most of the existing capacity must be replaced in the next 40 years, the Baseline scenario implies on average around 15 new reactors a year. Without this capacity replacement, more CO₂-emitting capacity would need to be built and emissions would be even higher.

The nuclear share of global electricity generation in the BLUE Map scenario more than doubles to 24% in 2050. The build rate of nuclear power is constrained in the model to reflect growth limitations based on past experience of maximum annual reactor construction rates (about 30 GW per year).

Electricity generation from renewable energy grows almost threefold in the Baseline scenario. As a result it increases its share of global electricity generation from 18% in 2007 to 22% in 2050. The growth in non-hydro renewables is even more dramatic, with almost a ninefold increase. By 2050, these “new” renewables have a share of 10%, up from 2.5% in 2007.

The total share of renewables in power generation more than doubles in 2050 between the Baseline and BLUE Map scenarios to 48%. As total electricity production also more than doubles in the BLUE Map scenario between 2007 and 2050, this implies a more than fivefold increase in power production from renewables. Most of the growth comes from emerging renewable energy technologies: wind, solar, biomass, and to a lesser extent geothermal. The use of hydropower also almost doubles from today’s level.

**Fuel switching in end-use sectors**

Fuel switching in end-use sectors plays an important role in reducing CO₂ emissions. Fuel switching to less carbon-intensive fuels in buildings, industry and transportation contributes 21% of the CO₂ emissions reduction in the BLUE Map scenario, with an increased share of electricity and biomass making the biggest contribution.

In the Baseline scenario, electricity use increases by almost 237% between 2007 and 2050, despite significant energy efficiency gains. This means that electricity’s
share of total final consumption increases from 17% in 2007 to 23% in 2050. This is due to the rapid growth in electric end-uses such as appliances. There is also an impact from the increased use of electricity as a substitute for fossil fuels, particularly for heat pumps and PHEVs, especially in countries where the CO₂ intensity of power generation is low.

In the BLUE Map scenario the electricity sector is virtually decarbonised. This enables the buildings and transport sectors to reduce CO₂ emissions by additional electrification. As a result, the share of electricity in final consumption rises to 27% in 2050 as low-carbon electricity increasingly substitutes for fossil fuels. In the buildings sector, heat pumps play an increasing role. In the transport sector, the BLUE Map scenario assumes an important role for PHEVs and EVs.

In 2050, the share of biomass in final energy consumption increases from 10% in the Baseline scenario to 18% in the BLUE Map scenario. At the same time, the efficiency of biomass use rises considerably as traditional biomass is reduced and modern biomass technologies gain significant market shares.

Most of the increase in biomass in end-use sectors comes from the use of biofuels in the transport sector to reduce CO₂ emissions. Biofuel use increases from 34 Mtoe in 2007 to 764 Mtoe in the BLUE Map scenario. Biofuels are particularly important to decarbonise modes of transport that lack other options (especially trucks, ships and aircraft). However, the use of biofuels for all modes will depend on the development of viable, sustainable, second-generation technologies that are not commercial today. A major change in the effectiveness of the world’s management of agricultural and natural lands will also be needed.

Hydrogen is also introduced after 2030, with almost 200 Mtoe used in transport. In addition, 97 Mtoe is consumed in the buildings sector in small-scale fuel-cell CHP systems.

**Carbon capture and storage**

The use of CCS in the industrial, fuel transformation and power generation sectors accounts for 19% of the CO₂ emissions reduction in the BLUE Map scenario over the Baseline scenario. The total amount of CO₂ captured is 9.4 Gt. This is 10% to 20% more than the net CO₂ reduction achieved by the use of CCS as, even with future advanced technologies, CCS itself entails significant additional energy use. In the BLUE Map scenario, 55% of the CO₂ captured comes from the power sector (Figure 2.7). The remainder takes place in refineries, synthetic fuel (synfuel) production and blast furnaces in the fuel transformation sector and in large-scale processes such as cement kilns and ammonia plants and industrial CHP in manufacturing industry. CCS is especially important for industry because it is the only way to achieve deep emission cuts in the production of major commodities such as steel and cement.

In the power sector, the retrofit of power plants with CCS is expected to play a significant role in reducing emissions before 2030 in the BLUE Map scenario. This highlights the importance that new fossil-fuel plant built over the next 10 to 20 years utilise technologies and practices that enable such retrofitting to take place. Over
the period to 2050, 114 GW of coal-fired capacity is retrofitted with CCS, and 550 GW of new coal-fired and 298 GW of new gas-fired capacity with CCS is installed. This includes industrial large-scale generation units (CHP).

**Figure 2.7** Use of carbon capture and storage in the BLUE Map scenario, 2050

![Diagram showing carbon capture and storage](image.png)

9.4 Gt CO₂ captured

- Power generation: 55%
- Industry: 21%
- Other transformation: 24%

Note: The total amount of CO₂ captured by CCS is greater than its net contribution to CO₂ reduction because of efficiency losses.

**Key point**

Carbon capture and storage can play a significant role outside the power sector.

## Investment costs and fuel savings

The total investment⁸ implied by the developments in the Baseline scenario is estimated to be USD 270 trillion between 2007 and 2050. Most of this (USD 240 trillion) is accounted for by investments on the demand side that energy consumers will make in capital equipment that consumes energy, including vehicles, electric appliances, and plants in heavy industry. The investment required is not uniform over time; the level needed between 2030 and 2050 is almost double that for the period up to 2030. These higher investment levels are driven by the demand for cars and other consumer durables, which rises alongside incomes in emerging and developing countries.

The BLUE Map scenario results in a need for investment USD 46 trillion higher than the Baseline scenario. Consumers invest in more energy-efficient equipment, buildings, vehicles and industrial plants with CCS, while electricity generators invest in more capital-intensive renewables, nuclear and CCS-equipped plants. Additional investment needs are dominated by the transport sector, accounting for 50% of total additional investments, as consumers invest in more expensive alternative vehicle technologies. The buildings sector accounts for 26% of the total additional investment, power generation for 20%, and industry for 4%.

The additional investment needs in the BLUE Map scenario will yield significant savings in fossil fuel consumption, partially offset by increased bioenergy fuel costs.

---

⁸ Excluding upstream investments in the production and transportation of coal, oil and gas.
Overall, the undiscounted fuel savings from 2010 to 2050 total USD 112 trillion in the BLUE Map scenario. Subtracting these undiscounted fuel savings from the undiscounted additional investments that will be required, yields a net saving of USD 66 trillion over the period to 2050. Discounting the additional investment needs and the fuel savings at a 3% discount rate yields net discounted savings of USD 32 trillion. At a 10% discount rate, net savings are USD 8 trillion. These aspects are explored in more detail in Chapter 14.

Regional and country-level trends

More detailed analysis of CO₂ trends and abatement options has been undertaken for China, India, OECD Europe and the United States. Each of these four countries or regions will have a crucial role to play in helping to achieve a 50% reduction in global CO₂ emissions by 2050. But as each has different levels of current and future economic development and different endowments of natural resources, each will develop in different ways in both the Baseline and the BLUE Map scenarios.

The primary energy mix and the shares of end-use sectors of final energy demand vary widely between countries and regions (Figure 2.8). Coal dominates in China and, because of its use in power generation and in industry, delivers two-thirds of total primary energy supply. In India, biomass plays a significant role, mostly in the form of traditional fuels used for cooking and water heating in the buildings sector. Natural gas plays only a very small role in both India and China. In contrast, in OECD Europe and the United States, oil and gas are the dominant fuels, with coal having a much smaller share, reflecting a highly developed transport sector and the use of natural gas in power generation as well as in buildings and industry.

Figure 2.8  Shares of primary energy use by fuel and final energy use by sector, 2007

Key point

The primary fuel mix and share of sectors in final energy demand vary significantly between countries and regions.
Table 2.1  High-level energy indicators for the world and four countries or regions, 2007

<table>
<thead>
<tr>
<th></th>
<th>World</th>
<th>India</th>
<th>China</th>
<th>OECD Europe</th>
<th>United States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy production (Mtoe)</td>
<td>11 940</td>
<td>451</td>
<td>1 814</td>
<td>1 067</td>
<td>1 665</td>
</tr>
<tr>
<td>Net imports (Mtoe)</td>
<td>n.a.</td>
<td>150</td>
<td>194</td>
<td>846</td>
<td>714</td>
</tr>
<tr>
<td>Total primary energy supply (Mtoe)</td>
<td>12 029</td>
<td>600</td>
<td>1 994</td>
<td>1 926</td>
<td>2 387</td>
</tr>
<tr>
<td>Net oil imports (Mtoe)</td>
<td>n.a.</td>
<td>107</td>
<td>200</td>
<td>495</td>
<td>634</td>
</tr>
<tr>
<td>Oil supply (Mtoe)</td>
<td>4 090</td>
<td>146</td>
<td>382</td>
<td>735</td>
<td>957</td>
</tr>
<tr>
<td>Electricity consumption (TWh)</td>
<td>18 187</td>
<td>610</td>
<td>3 114</td>
<td>3 387</td>
<td>4 113</td>
</tr>
<tr>
<td>CO2 emissions (Gt)</td>
<td>28.86</td>
<td>1.34</td>
<td>6.15</td>
<td>4.37</td>
<td>5.92</td>
</tr>
<tr>
<td>GDP (billion USD 2000 using MER)</td>
<td>39 493</td>
<td>771</td>
<td>2 623</td>
<td>10 532</td>
<td>11 468</td>
</tr>
<tr>
<td>GDP (billion USD 2000 using PPP)</td>
<td>61 428</td>
<td>4 025</td>
<td>10 156</td>
<td>13 223</td>
<td>11 468</td>
</tr>
<tr>
<td>Population (millions)</td>
<td>6 609</td>
<td>1 123</td>
<td>1 327</td>
<td>543</td>
<td>302</td>
</tr>
<tr>
<td>Land area (million km2)</td>
<td>148.94</td>
<td>2.97</td>
<td>9.57</td>
<td>4.95</td>
<td>9.16</td>
</tr>
<tr>
<td>Total self-sufficiency</td>
<td>1.00</td>
<td>0.75</td>
<td>0.91</td>
<td>0.55</td>
<td>0.70</td>
</tr>
<tr>
<td>Coal and peat self-sufficiency</td>
<td>1.00</td>
<td>0.87</td>
<td>1.02</td>
<td>0.56</td>
<td>1.02</td>
</tr>
<tr>
<td>Oil self-sufficiency</td>
<td>1.00</td>
<td>0.27</td>
<td>0.49</td>
<td>0.32</td>
<td>0.33</td>
</tr>
<tr>
<td>Gas self-sufficiency</td>
<td>1.00</td>
<td>0.71</td>
<td>0.94</td>
<td>0.53</td>
<td>0.83</td>
</tr>
<tr>
<td>TPES/GDP (toe per thousand USD 2000)</td>
<td>0.30</td>
<td>0.78</td>
<td>0.76</td>
<td>0.18</td>
<td>0.21</td>
</tr>
<tr>
<td>TPES/GDP (toe per thousand USD 2000 PPP)</td>
<td>0.20</td>
<td>0.15</td>
<td>0.20</td>
<td>0.14</td>
<td>0.21</td>
</tr>
<tr>
<td>TPES/population (toe per capita)</td>
<td>1.82</td>
<td>0.53</td>
<td>1.50</td>
<td>3.55</td>
<td>7.90</td>
</tr>
<tr>
<td>Net oil imports /GDP (toe per thousand USD 2000)</td>
<td>n.a. 0.08</td>
<td>0.14</td>
<td>0.08</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>Oil supply /GDP (toe per thousand USD 2000)</td>
<td>0.10</td>
<td>0.19</td>
<td>0.15</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>Oil supply /population (toe/capita)</td>
<td>0.62</td>
<td>0.13</td>
<td>0.29</td>
<td>1.35</td>
<td>3.17</td>
</tr>
<tr>
<td>Electricity consumption /GDP (kWh per USD 2000)</td>
<td>0.46</td>
<td>0.79</td>
<td>1.11</td>
<td>0.32</td>
<td>0.36</td>
</tr>
<tr>
<td>Electricity consumption /population (kWh per capita)</td>
<td>2 752</td>
<td>543</td>
<td>2 347</td>
<td>6 239</td>
<td>13 616</td>
</tr>
</tbody>
</table>

Notes: MER is market exchange rates and PPP is purchasing power parity. International marine bunkers and aviation are included in TPES and CO2 emissions.

As a result of their current economic development and fuel mixes, the four countries/regions have very different starting points and future trajectories in terms of their CO2 emissions (Figure 2.9). China has recently overtaken the United States to become the biggest emitter of CO2, but its per-capita emissions are still much lower at 4.6 tCO2/capita compared to 19.6 tCO2/capita. Total CO2 emissions from OECD Europe are around three-quarters of those of the United States. Average emissions per capita are less than half the level in the United States, although this average masks substantial differences among European countries. India currently has by far the lowest absolute emissions and average emissions per capita, the latter being only 6% of those in the United States.
In the Baseline scenario, CO₂ emissions in India show the largest relative increase, rising nearly fivefold by 2050. China also shows a substantial rise, with emissions almost tripling between 2007 and 2050. In the United States emissions increase only slightly by 1%, and in OECD Europe, emissions decline by 8%. In the BLUE Map scenario, all countries/regions show considerable reductions from the Baseline scenario. For the United States and OECD Europe, CO₂ emissions are 81% and 74% respectively lower in 2050 than in 2007. China shows a 30% reduction over the same period, while emissions in India rise by 10%. As a result of these changes, per-capita emissions converge, and the gap between the United States and India narrows to a factor of just over three. China overtakes OECD Europe in terms of per-capita emissions.

Figure 2.9  
CO₂ emissions by region/country in the Baseline and BLUE Map scenarios

Note: CO₂ emissions include international aviation and marine bunkers.

Key point

The CO₂ emissions path for different countries and regions varies considerably in both the Baseline and BLUE Map scenarios.

Achieving the emissions reductions implicit in the BLUE Map scenario will be a substantial challenge for all countries and regions (Figure 2.10). Each faces particular challenges and opportunities.

For China, given the dominance of coal, special attention needs to be given to the development of cleaner coal technologies, including the more efficient use of coal in power generation and industry as well as CCS. Of the three end-use sectors, industry accounts for the largest share of China’s energy use and CO₂ emissions. The BLUE Map scenarios show that measures to improve energy efficiency and reduce CO₂ emissions in energy-intensive sectors such as iron and steel, cement, and chemicals should be a priority as they will have significant impact on the country’s overall energy use and emissions. The Chinese transport sector is evolving very rapidly, in terms of vehicle sales, infrastructure construction and the introduction of new technologies. The BLUE Map scenario shows that significant emissions reductions in China, as in many other countries, will depend on the electrification of different transport modes combined with substantial decarbonisation of the electricity sector.
India will exhibit very strong electricity demand growth over the next forty years to sustain economic development and as households increasingly become electrified. This will require huge additional capacity, which opens up the possibility of building a low-carbon electricity system almost from scratch. The BLUE Map scenario identifies solar as the most promising renewable energy technology for India and it could play an important role along with nuclear and some fossil fuel with CCS. India has some of the most efficient industrial plants in the world, but also has a large share of inefficient plants. Although there is significant potential to improve overall energy efficiency, the large number of small-scale plants, the low quality of indigenous coal and the quality of some primary sources (such as iron ore) may make this potential harder to achieve in India than in other regions.

Figure 2.10 Contribution of technologies to CO₂ emissions abatement in the BLUE Map scenario for different countries and regions, 2050

Key point

The mix of CO₂ abatement options needed to realise the BLUE Map scenario varies between countries and regions.
The increase in Indian household incomes and in industrial production will generate large increases in demand for transport. Although India’s passenger vehicle stock is already relatively efficient, improvements in new vehicle technology and the penetration of hybrid, plug-in hybrid, battery and natural gas vehicles all help to limit increases in CO₂ emissions under the BLUE Map scenario. In the buildings sector, strong growth in energy demand will be driven by increases in living conditions and higher demand for services. Migration from rural to urban areas will also play a role in increasing energy consumption. Efficiency improvements in space cooling and appliances will be critical in restraining growth in energy consumption and emissions.

In OECD Europe, the electricity sector in 2050 is nearly decarbonised under the BLUE Map scenario. More than 50% of electricity generation is projected to come from renewable energy, with most of the remainder from nuclear and fossil fuels using CCS, although the precise energy mix varies widely among individual European countries, reflecting different local conditions and opportunities. In industry, energy efficiency and CCS offer the main measures for reducing emissions in the BLUE Map scenario.

High recycling rates as well as relatively high shares of biomass in the paper industry and of alternative fuels in the cement sector contribute to limiting the growth of CO₂ emissions in the Baseline scenario in OECD Europe. In buildings, the most significant energy savings in the BLUE Map scenario come from efficiency improvements in space and water heating, which provide more than two-thirds of the emissions reduction in the buildings sector. Further important mitigation measures are solar thermal heating, heat pumps, CHP/district heating and efficiency improvements for appliances.

Transport volumes in OECD Europe are expected to remain relatively constant in the future. The BLUE Map scenario shows that deep emissions reductions can be realised by more efficient vehicles as well as the shift towards electricity and biofuels. The progressive adoption of natural gas followed by a transition to biogas and bio-syngas is a further option for decreasing emissions in the transport sector.

For the United States, the BLUE Map scenario shows that energy efficiency and fuel switching measures are very important in reducing CO₂ emissions across all end-use sectors. Infrastructure investments will also be important for supporting the transition to a low-carbon economy, particularly in the national electricity grid and transport networks. Virtually all the existing generation assets will be replaced by 2050 and low-carbon technologies such as wind, solar, biomass and nuclear offer substantial abatement opportunities.

For a variety of reasons, many of the energy-intensive industries in the United States are relatively inefficient when compared to their counterparts in other parts of the OECD. Many opportunities exist to improve efficiency through technological improvements, as well as changes in the structure of the overall industrial sector. In terms of vehicle technologies, the average energy intensity of light-duty vehicles (LDVs) in the United States is currently relatively high. The BLUE Map scenario shows how doubling the fuel efficiency of new LDVs by 2030 can help reduce emissions. Advanced vehicle technologies can also play an important role in the LDV and commercial light- and medium-duty truck sectors. In buildings, improving the efficiency of space cooling, together with more efficient appliances offers the largest opportunity to reduce CO₂ emissions.
Sectoral trends

Energy use increases in all sectors in the Baseline scenario. Energy use roughly doubles in power generation, industry, transport and buildings (Figure 2.11). The energy used for fuel transformation accelerates from an average annual growth rate of 0.8% between 2007 and 2030 to 3.0% between 2030 and 2050. This is due to the increased production of synfuels from coal and gas.

Energy consumption in the transport, buildings and industry sectors together increases on average by 1.3% a year between 2007 and 2050 in the Baseline scenario, i.e. less than the 1.7% a year that it grew between 1971 and 2007. Driven by continued strong population and income growth in developing countries, transportation demand increases on average by 1.6% a year between 2007 and 2050. Energy consumption in the industrial sector grows at an average of 1.3% a year. Nearly all the growth in industrial energy consumption occurs outside the OECD. Energy use in the buildings sector also grows by 1.1% a year, with around 64% of this growth coming from developing countries.

**Figure 2.11** Energy use by sector in the Baseline scenario

![Energy use by sector in the Baseline scenario](image)

---

**Notes:** The power generation sector includes heat plants. Other includes the net consumption of power and fuel for the transformation sectors, plus energy use in agriculture, forestry and fishing.

**Key point**

Energy demand continues to grow rapidly in all sectors in the Baseline scenario.

The growth of CO₂ emissions under the Baseline scenario and the cost of achieving emissions reductions vary according to the sector. As a consequence, the BLUE Map scenario results in different sectors achieving different levels of emissions reduction in 2050 (Table 2.2).

In the BLUE Map scenario, the energy consumption of the power generation sector in 2050 is 20% lower than in the Baseline scenario thanks to an overall reduction in the demand for electricity. The energy consumed in the fuel transformation sector, including refineries, coal-to-liquid (CTL) and gas-to-liquid (GTL) plants, is about 10% less than in the Baseline scenario. The lower demand can be explained by end-use fuel demand reductions.
Energy savings are achieved in all end-use sectors in the BLUE Map scenario compared to the Baseline scenario. As a consequence, total final energy demand is 31% lower in the BLUE Map scenario in 2050 than in the Baseline scenario (Figure 2.12). The largest absolute reductions in energy use occur in the buildings and transport sectors. In buildings, savings of 1 509 Mtoe in 2050 reflect the significant technical potential to reduce space heating and cooling needs in both existing and new buildings, as well as to improve the energy efficiency of lighting, electric appliances and equipment. OECD countries account for a little under half the total energy savings in buildings. In transport, savings of 1 631 Mtoe in 2050 come from significant fuel efficiency improvements in conventional engines, together with a move to hybrid and then fully electric vehicles. Slightly larger savings come from developing countries than from OECD countries. Industry contributes relatively smaller savings (1 350 Mtoe), reflecting the high efficiencies already achieved in a number of energy-intensive sectors and the intrinsic need for energy in many industrial processes. Around one-third of this is in OECD countries and two-thirds is in non-OECD countries.

Despite the savings achieved in the BLUE Map scenario, energy demand continues to grow in all end-use sectors between 2007 and 2050. The highest growth rate is in industry, followed by transport and buildings. Final energy consumption in the industry, buildings and transport sectors grows on average by 0.4% a year in the BLUE Map scenario.

**Table 2.2** CO$_2$ emissions reductions by sector in the BLUE Map scenario, 2050

<table>
<thead>
<tr>
<th>Sector</th>
<th>Reduction from 2007 levels</th>
<th>Reduction from 2050 Baseline levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power sector</td>
<td>-76%</td>
<td>-88%</td>
</tr>
<tr>
<td>Transport</td>
<td>-28%</td>
<td>-64%</td>
</tr>
<tr>
<td>Industry</td>
<td>-27%</td>
<td>-51%</td>
</tr>
<tr>
<td>Buildings</td>
<td>-40%</td>
<td>-57%</td>
</tr>
<tr>
<td>Total</td>
<td>-52%</td>
<td>-75%</td>
</tr>
</tbody>
</table>

**Note:** Industry includes blast furnaces and coke ovens, as well as emissions from non-energy use of petrochemical feedstocks. Industrial-process emissions are excluded. The totals include reductions in fuel transformation.

**Key point**

Final energy demand in the BLUE Map scenario is significantly less than in the Baseline scenario in 2050.
Energy trends

In the Baseline scenario, total primary energy supply (TPES) grows by 1.4% on average per year, from 12 020 Mtoe in 2007 to 22 078 Mtoe in 2050 (Figure 2.13). This rate of growth is less than the 2.2% a year that occurred between 1971 and 2007, but it still represents an increase of 84% in primary energy demand between 2007 and 2050.

Figure 2.13 World total primary energy supply

Key point

Primary energy use more than doubles in the Baseline scenario between 2007 and 2050, with a very high reliance on coal.

In the Baseline scenario, the share of fossil fuels in total demand remains fairly constant between 2007 and 2050, despite strong growth in nuclear and renewable energy in absolute terms. By 2050, coal becomes the predominant fuel and accounts for 34% of primary energy use. Oil’s share of TPES declines from 34% in 2007 to 25% in 2050. The share of natural gas stays constant at 21%. Of the non-fossil fuels, nuclear’s share remains at 6% in 2050, while the share of renewables increases to 14%. It should be noted that accounting for nuclear and renewables in primary energy terms does not properly reflect their importance for the energy system, as the conversion efficiencies from electricity to primary energy follow somewhat arbitrary statistical conventions.

The use of fossil fuels in 2050 is 59% lower in the BLUE Map scenario than in the Baseline scenario (Figure 2.14). In absolute terms, total demand for fossil fuels in the BLUE Map scenario in 2050 is 26% below the level of 2007. But even in the BLUE Map scenario, fossil fuels are an important contributor to the energy system. The reduction in fossil-fuel use can be attributed to energy efficiency gains and fuel switching. The use of carbon-free fuels increases much faster than TPES. The growth in biofuels, to a point where their use in 2050 in
the BLUE Map scenario is similar to the level of coal use today, demonstrates just how significant a change is needed to deliver the outcomes implicit in the BLUE Map scenario.

**Figure 2.14** Primary energy demand by fuel and by scenario

- **Coal**

  In the Baseline scenario, coal demand in 2050 is 138% higher than in 2007 (Figure 2.15). Coal’s share of total demand grows from 27% in 2007 to 34% in 2050. Between 2030 and 2050, coal eclipses oil as the single most important fuel. Coal’s strong growth in the Baseline scenario is driven by three factors. First, high oil prices make CTL technologies more economical, and the production of synfuels from coal increases significantly after 2030. In 2050, around 2 000 Mtoe of coal is being consumed by CTL plants. Second, high gas prices result in more new coal-fired electricity generating plants being built. Third, energy-intensive industrial production grows rapidly in developing countries, especially China and India, which have large coal reserves, but limited reserves of other energy resources.

  In the BLUE Map scenario, coal demand in 2050 is 36% below the 2007 level, a reduction of over 70% compared to the Baseline scenario. This very significant reduction comes as a result of many sectors switching out of coal in favour of lower-carbon energy sources, even with the prospect of CCS. In percentage terms, coal use declines most in OECD countries. In non-OECD countries, coal use in the BLUE Map scenario in 2050 is 22% less than today’s consumption.
Liquid fuel

Liquid fuel demand in the Baseline scenario increases by 58% between 2007 and 2050, from 4 208 Mtoe in 2008 to 6 633 Mtoe in 2050 (Figure 2.16). This is an increase from 85 million barrels a day (mbd) to 134 mbd. Such growth is unlikely to be met by conventional oil. In the Baseline scenario there is significant growth in the production of non-conventional oil from heavy oil, oil sands, shale oil and arctic oil, to about 29 mbd. These sources account for about 20% of total supply in 2050. A rising share of demand is also met by synfuels produced from coal and gas, which increase from very low levels today to 17 mbd in 2050, comprising 12% of total supply. Biofuels play a limited role in the Baseline scenario, with a 5% share. Liquid fuel demand grows most rapidly in the transport sector, at 1.6% on average a year. In the buildings sector it grows by 0.4% a year and in the industrial sector by 1.0% a year.

In the BLUE Map scenario, the increased use of biofuels and improvements in the average fuel efficiency of transportation vehicles mean that total liquid fuel demand is only 4 045 Mtoe in 2050, 39% lower than in the Baseline scenario. Oil demand in 2050 is about 23% below the 2007 level. This will make a potentially significant contribution to security of supply, although a substantial oil import dependence will remain for many countries. The significant demand reductions in the BLUE Map scenario imply that there would be much less need for non-conventional oil and synfuels. Biofuels would account for 23% of supply. This has important CO₂ benefits.

Even in the BLUE Map scenario, OPEC oil production in 2050 will need to stay at least at the level of 2007, while conventional oil from other sources declines. Given the depletion of current sources of supply, substantial new OPEC production will be needed in both the Baseline and BLUE Map scenarios. Very large investments, especially in the Middle East, will be required to meet demand growth and to maintain secure supplies of transport fuels. The development of new oil supplies is an important challenge in all of the scenarios.
**Figure 2.16** World liquid fuel supply by scenario

<table>
<thead>
<tr>
<th>Year</th>
<th>Synfuels</th>
<th>Biofuels</th>
<th>Processing gains</th>
<th>Shale oil</th>
<th>Oil sands</th>
<th>Arctic and ultra deep</th>
<th>Conventional oil (other)</th>
<th>Conventional oil (OPEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2050</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BLUE Map</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Key point**

Liquid fuel demand in 2050 returns to today’s level in the BLUE Map scenario, but with a very different mix.

**Box 2.4** Oil supply prospects

The world’s total resources of oil are large enough to support the projected rise in demand in the ETP 2010 Baseline scenario through to 2050. Estimates of remaining proven reserves of oil and natural gas liquids range from about 1.2 trillion to 1.3 trillion barrels including about 0.2 trillion bbl of non-conventional oil. They have almost doubled since 1980. This is enough to supply the world with oil for over 40 years at current rates of consumption. The volume of oil discovered each year on average has been higher since 2000 than in the 1990s, thanks to increased exploration activity and improvements in technology, although production continues to outstrip new discoveries.

Ultimately recoverable conventional oil resources, which include initial proven and probable reserves from discovered fields, reserves growth and oil that has yet to be found, are estimated at 3.5 trillion bbls. Only a third of this total, or 1.1 trillion bbl, has been produced up to now. Undiscovered resources account for about a third of the remaining recoverable oil, the largest volumes of which are thought to lie in the Middle East, Russia and the Caspian region. Non-conventional oil resources, which have been barely developed to date, are also very large. Between one and two trillion bbl of oil sands and extra-heavy oil may be ultimately recoverable economically. These resources are largely concentrated in Canada (mainly in Alberta province) and Venezuela (in the Orinoco Belt). The total long-term potentially recoverable oil-resource base, including extra-heavy oil, oil sands and oil shales (another largely undeveloped but costly resource), is estimated at around 6.5 trillion bbl. Adding production from CTL and GTL increases this potential to about 9 trillion bbl.

Globally, oil resources may be plentiful, but there can be no guarantee that they will be exploited quickly enough to meet the level of demand projected in the Baseline scenario. Annual average investments of USD 330 billion in the upstream oil and gas sector will be required over the period to 2030. That is more than is currently being spent. And there needs to be a major shift in the location of that investment. The opportunities for international companies to invest in non-OPEC regions will diminish as the resource base contracts. Much more capital needs to go to resource-rich regions, notably the Middle East, where unit costs are lowest, either directly through national companies or indirectly in partnership with foreign investors. It cannot be taken for granted that these countries will be willing to make this investment themselves or to attract sufficient foreign capital to keep up the necessary pace of investment.

The reduction in oil demand in the BLUE Map scenario can be largely attributed to the transport sector (Figure 2.17). This reflects the fact that oil demand for transport rises rapidly in the Baseline scenario. The reduction in primary oil demand is less than the reduction in the demand for oil products as synfuel production is phased out in the BLUE Map scenario.

In the Baseline scenario, non-OECD countries’ share of primary oil demand rises from 47% in 2007 to 71% in 2050. This share only drops slightly in the BLUE Map scenario.

**Figure 2.17** Reduction in oil demand by sector in the BLUE Map scenario, 2050

3,218 Mtoe savings

- **Transport**: 80%
- **Buildings**: 8%
- **Power sector**: 2%
- **Industry**: 10%

Note: Includes conventional oil, non-conventional oil, and synfuels from coal and gas.

**Key point**

The transport sector accounts for most of the savings in oil demand.

**Natural gas**

Primary demand for natural gas in the Baseline scenario grows by 85% between 2007 and 2050, rising from 2,520 Mtoe to 4,653 Mtoe (Figure 2.18). Global gas use by the electricity generation sector increases from 992 Mtoe in 2007 to 2,174 Mtoe in 2050. Natural gas used in other transformation activities grows from 254 Mtoe in 2007 to 432 Mtoe in 2050. Most of this increase is for GTL plants and refinery hydrogen production. Demand for natural gas in the final consumption sectors grows at 1.2% a year, with little difference between the growth in industry and that in buildings at the global level.

Primary demand for natural gas in non-OECD countries increases in the Baseline scenario from 1,261 Mtoe in 2007 to 3,071 Mtoe in 2050. Non-OECD countries’ share of world gas demand rises from 50% in 2007 to 66% in 2050. It rises further to 76% in the BLUE Map scenario. Almost half the growth in demand in non-OECD countries in the BLUE scenario comes from electricity generation and the remainder from end-use sectors and fuel transformation. Demand for gas in OECD countries falls from 1,259 Mtoe in 2007 to 526 Mtoe in 2050 in the BLUE Map scenario.
**Key point**

Gas demand in the BLUE Map scenario in 2050 is 12% lower than in 2007 and 52% lower than in the Baseline scenario in 2050.

**Box 2.5 Gas supply prospects**

The world’s remaining resources of natural gas are easily large enough to cover any conceivable rate of increase in demand through to 2050, although the cost of developing new resources is set to rise over the long term. Proven gas reserves at the end of 2008 totalled more than 180 trillion cubic metres (tcm) globally — equal to about 60 years of production at current rates. Over half of these reserves are located in just three countries: Russia, Iran and Qatar. Estimated remaining recoverable gas resources are much larger. The long-term global recoverable gas resource base, including only those categories of resource with currently demonstrated commercial production, is estimated at more than 850 tcm). Unconventional gas resources such as coal-bed methane, tight gas from low-permeability reservoirs and shale gas, make up about 45% of this total. To date, only 66 tcm of gas has been produced or flared.

The recent rapid development of unconventional gas resources in the United States and Canada, particularly in the last three years, has transformed the gas market outlook, both in North America and in other parts of the world. New technology, especially horizontal-well drilling combined with hydraulic fracturing, has increased productivity per well from unconventional sources, notably shale gas, and cut production costs.

The extent to which the boom in unconventional gas production in North America can be replicated in other parts of the world endowed with such resources remains highly uncertain. Outside North America, unconventional resources have not yet been appraised in detail and gas production is still small. Some regions, including China, India, Australia and Europe, are thought to hold large resources, but there are major potential obstacles to their development in some cases. These include limitations on physical access to resources, the requirement for large volumes of water for completing wells, the environmental impact and the distance of resources from the existing pipeline infrastructure. In addition, the geological characteristics of resources that have not yet been appraised may present serious technical and economic challenges to their development.

Electricity demand in the Baseline scenario increases on average by 2.0% a year between 2007 and 2050, making electricity the fastest-growing component of total final demand (Figure 2.19). Electricity demand increases from 16 999 terawatt-hours (TWh) in 2007 to 42 655 TWh in 2050. Electricity’s share of final demand increases from 17% in 2007 to 23% in 2050. These trends are driven by rapid growth in population and incomes in developing countries, by the continuing increase in the number of electricity-consuming devices used in homes and commercial buildings, and by the growth in electrically driven industrial processes.

Baseline electricity demand in non-OECD countries grows on average by 3.1% a year, almost three times as fast as in OECD countries. This is primarily due to higher population growth and rapid increases in GDP and per-capita incomes in developing countries. Between now and 2050, tens of millions of people in developing countries will gain access to electricity.

In the BLUE Map scenario, global electricity demand growth is reduced to an average of 1.8% a year, with demand reaching 36 948 TWh in 2050. Electricity demand in 2050 is 13% below the Baseline scenario level. Electricity savings occur mostly in the buildings sector and in industry in the BLUE Map scenario, but these are partially offset by increased electricity demand in the transport sector as a result of the uptake of PHEVs and EVs.

Biomass

Biomass is by far the most important source of renewable energy today, accounting for about 10% of total primary energy use and 78% of total renewable energy. Most biomass is currently used for traditional small-scale domestic heating and cooking.
Only about 10% of biomass is used on an industrial scale for the production of electricity or fuels.

The role of biomass almost triples in the BLUE Map scenario (Figure 2.20). In this scenario, bioenergy use in 2050 is slightly higher than the level of coal consumption today. This would require fundamental improvements in agriculture and forestry. The challenge is that the world population will grow by 50% during the same period, with food demand rising correspondingly. To meet this demand, the total productivity of land currently in production must triple. Such growth has happened in recent decades, but its continuation in the future will require major effort. The development and use of high-yield crops, water management, soil management and land-use policies and considerations of ecological sustainability all need to be closely co-ordinated. Recent problems with rain forest and bushland clearing for first-generation biofuel crops show that a focus on energy alone can yield undesirable outcomes.

About half of the primary bioenergy in the BLUE Map scenario would be used for the production of liquid biofuels. The other half would be used for power generation, heating and industrial feedstocks.

**Figure 2.20**  World biomass use by scenario

![World biomass use by scenario](chart.png)

**Note:** The chart includes transformation losses in the production of liquid biofuels from solid biomass.

**Key point**

*Biomass use more than triples in the BLUE Map scenario.*

In the buildings sector, the use of biomass increases by 4% in the Baseline scenario. Biomass use declines in the BLUE Map scenario but, as it is used much more efficiently, the share of biomass in delivered energy services increases. Solar water-heating and space-heating systems increase fourfold between the Baseline and BLUE Map scenarios.

In the BLUE Map scenario, the share of biomass and waste in industry increases from 6% in 2007 to 14% in 2050. Part of this is biomass for steam and process heat. Biomass feedstocks also play an increasing role.
Going beyond the BLUE scenarios

The BLUE Map scenario examines the technology options that could reduce global energy-related CO₂ emissions by 50% in 2050 compared to 2005 levels. According to the Intergovernmental Panel on Climate Change (IPCC), this is the minimum reduction necessary to keep the long-term rise in global temperatures to within 2°C to 3°C. However, the IPCC also concludes that reductions of up to 85% may be needed to keep within these temperature rises. This would imply that CO₂ emissions in 2050 should be constrained to less than 6 Gt CO₂. At the 15th Conference of the Parties (COP-15) to the United Nations Framework Convention on Climate Change (UNFCCC) in Copenhagen, some countries also argued that the appropriate temperature goal should be a rise of no more than 1.5°C.

Taking all these factors together, and given the uncertainty of technology development, a prudent approach might be to identify a portfolio of low-carbon technologies that could exceed the 50% reduction target in case deeper cuts are needed or some of the technological options identified do not become commercially available as originally thought. With these issues in mind, the ETP model has been used to examine whether it is likely to be technologically possible to reduce emissions by more than 50% in 2050 and, if so, what technological options would need to be exploited.

In 2050, power generation in the BLUE Map scenario will produce 2.9 Gt CO₂. To reduce emissions below this level, it would be possible to bring on stream more generation from nuclear, renewables or fossil fuels with CCS. Assuming that around 2 000 GW of gas capacity is needed globally for balancing services, these technologies could reduce emissions by a further 1.4 Gt CO₂ to 1.7 Gt CO₂ at an additional investment cost of up to USD 1.8 trillion.

In industry, additional reductions could be achieved by greater implementation of CCS in the iron and steel, cement, chemicals and pulp and paper sectors, by the accelerated adoption of best available technologies in new plants (including early scrapping) and all refurbishments, by greater use of CO₂-free energy and feedstock sources such as biomass, and by the earlier demonstration and deployment of breakthrough technologies. Such measures could deliver a further 0.6 Gt CO₂ reductions by 2050 at a cost of up to USD 1.3 trillion.

In buildings, additional CO₂ reductions would require the application of technologies in more expensive end-use applications. This would require wider deployment of technologies that facilitate the use of CO₂-free energy carriers such as electricity or hydrogen, or which use renewable energy (e.g. solar thermal). For example, ground-source heat pumps for space and water heating could be used more widely, even in milder climates, or solar thermal systems for space and water heating could be deployed even in areas with relatively low levels of sunshine. Up to 0.8 Gt CO₂ of additional reductions would be possible from these measures, at a total additional investment of between USD 1.2 trillion and USD 1.4 trillion.

Greater reductions in CO₂ emissions from transport could be achieved by accelerating efficiency gains, the more rapid introduction of advanced technologies such as EVs and fuel-cell vehicles into the market, and moving to higher-levels of
biofuels use. The first two options would certainly incur higher marginal costs. The greater use of biofuels could require higher-cost feedstocks, but more importantly may threaten sustainability. Thus higher levels of production would need to take account of the total availability of land and feedstocks that could sustainably be produced in the long term. On the basis of these options, further reductions of up to 1.5 Gt CO$_2$ might be achieved in 2050, at an investment cost of USD 2 trillion. In addition, the BLUE Map/Shifts scenario described in Chapter 7 shows how changes in behaviour through modal shifts could deliver a further 1.5 Gt CO$_2$ in 2050.

Taking these potentials together, the faster and more widespread introduction of technologies already considered in the BLUE Map scenario could further reduce emissions to around 9.5 Gt CO$_2$ by 2050. This would entail considerable additional investment. Behavioural changes in the transport sector could reduce this further to 8 Gt CO$_2$. This is still more than 2 Gt higher than would be needed to meet an 80% reduction in 2050. Further reductions beyond this would seem to have to rely on completely new technologies not yet envisaged or on further behavioural and lifestyle changes.
Key findings

Without a significant change in policies, global electricity generation will continue to be largely based on fossil fuels to 2050 and beyond. In the Baseline scenario, fossil fuels increase their share of electricity production slightly to reach almost 70% by 2050. Coal and gas both increase their share of generation over this timeframe. The shares of nuclear and hydro both decrease, but wind, biomass and solar all increase their shares, albeit from low starting points. As a result, CO$_2$ emissions from the electricity sector almost double between 2007 and 2050.

Significantly decarbonising the power sector over the period to 2050 will need to be at the heart of any strategy to achieve deep CO$_2$ emissions reductions worldwide. Advances in low-carbon generation technologies and their widespread deployment will be essential. Renewable energy, fossil fuels used with carbon capture and storage (CCS), and nuclear power all have an important part to play. Each faces challenges. But if a near-zero carbon electricity supply can be achieved, it will open the prospect of demand-side electrification becoming a long-term emissions abatement solution in all end-use sectors.

By 2050 in the BLUE Map scenario, the carbon intensity of electricity generation has been reduced by almost 90% compared to 2007 levels. Renewable energy accounts for almost half of total global electricity production, while nuclear energy’s share is just less than one-quarter. The remainder is from fossil fuels, largely combined with CCS. While the optimum low-carbon generation mix in 2050 is subject to considerable uncertainty, the BLUE variants show that a range of low- or zero-carbon generation technologies will be needed to keep additional costs to a minimum.

Significant investment will be needed in electricity generation over the next 40 years whatever pathway is followed. In the Baseline scenario, investment requirements in electricity generation, transmission and distribution to 2050 total USD 23.5 trillion. More than half of this (USD 15 trillion) is needed for new power-generation plants. The BLUE Map scenario requires the investment of an additional USD 9.3 trillion (40%) over the investment in the Baseline scenario, mostly in power generation.

There are some promising signs of increased activity to develop and deploy low-carbon electricity generating technologies. Wind capacity is increasing rapidly in Europe, the United States and China. Photovoltaic (PV) capacity is also increasing in Europe. China has an ambitious programme of new nuclear build and a number of countries are actively considering new nuclear capacity additions. Several hundred CCS demonstrations are being planned at various scales and work on mapping storage sites and developing regulatory structures is being stepped up.

It will not be possible to fully decarbonise electricity without greater policy intervention. Today, many low-carbon alternatives are considerably more expensive than traditional fossil-based technologies. Governments will need to continue and
expand research, development and demonstration (RD&D) support, and to create market mechanisms to foster technological innovation and to move low-carbon technologies towards market competitiveness. These incentives should be tailored to the maturity of the technology and decrease over time. This should be accompanied by policies that encourage the closure of the dirtiest and least efficient plants at the earliest opportunity.

Some low-carbon generation technologies have specific requirements that will need to be addressed. For example, system integration will be needed to support significant quantities of variable renewables such as wind, solar PV, run-of-river hydropower, wave and tidal power. Comprehensive regulatory approaches will be needed to enable the large-scale commercial deployment of CCS. For nuclear power, further progress needs to be made towards building and operating facilities for the disposal of high-level radioactive wastes.

Introduction

Electricity production accounts for 32% of total global fossil fuel use and around 41% of total energy-related CO\textsubscript{2} emissions. Transforming the electricity generation sector will therefore need to be at the heart of any efforts to make substantial reductions in global CO\textsubscript{2} emissions. Improving the efficiency of production, switching to lower-carbon fossil fuels, increasing renewable and nuclear generation and the introduction of CCS will all need to play a part in this transformation.

The analysis in this chapter explores the possible future contribution of the most important electricity generation technologies and fuels in the Baseline scenario and in five variants of the BLUE scenario. These have the following characteristics:

- **BLUE Map** which is broadly optimistic for all technologies.
- **High nuclear (BLUE hi NUC)** which assumes nuclear capacity of 2 000 GW instead of the 1 200 GW maximum in the BLUE Map scenario.
- **No carbon capture and storage (BLUE no CCS)** which assumes that CCS is not commercially deployed.
- **High renewables (BLUE hi REN)** which assumes that renewables provide 75% of global electricity production in 2050.
- **3% discount rate (BLUE 3%)** which uses a lower single discount rate for all electricity generating technologies.

The status and prospects for each of the key technology groups are also briefly discussed.

Achieving deep CO\textsubscript{2} reductions will also require changes in electricity transmission and distribution networks. These are discussed in Chapter 4.


**Recent trends**

**Generation mix by fuel**

Global electricity generation\(^1\) has increased by 67% since 1990, reaching almost 19 800 TWh in 2007 (Figure 3.1). Almost 70% of this electricity generation is from fossil fuels and this share has increased since 1990. Coal is the most important energy source for electricity production. Between 1990 and 2007, its share of total generation increased from 37% to 42%. The use of gas has grown rapidly over the same period, increasing from 15% to 21% of all generation. The share of oil has fallen to 6% of total electricity generation in 2007.

Total non-fossil fuel-based electricity generation has increased in absolute terms since 1990, but not fast enough to keep pace with rising electricity demand. As a result, the share of non-fossil fuels in electricity production has fallen. The contribution from nuclear power has fallen from 17% in 1990 to 14% in 2007. Over the same period hydropower has fallen from 18% to 16%. Electricity production from non-hydro renewable energy sources has increased markedly since 1990, but from a low base. The share of biomass and waste increased slightly from 1.1% in 1990 to 1.3% in 2007. Other renewables such as wind, geothermal and solar increased their share from 0.4% to 1.2% over the same period.

**Figure 3.1**  
*Historical trends in global electricity production*

![Historical trends in global electricity production](chart)

**Note:** Unless otherwise indicated, all material derives from IEA data and analysis.

**Key point**

Electricity production has increased rapidly in recent years and continues to be dominated by fossil fuels.

The current electricity production mix varies considerably between countries, depending on their access to natural resources and their energy and environmental policies. The mix is a critical determinant of the level of CO\(_2\) emissions per unit of electricity generated. On average, the share of electricity production from fossil

---

\(^1\) Global electricity generation includes production from public electricity and public combined heat and power (CHP) plants, as well as by enterprises that generate electricity primarily for their own use.
fuels in OECD countries was 63% in 2007. Non-OECD countries have a higher share, 74% on average. A number of individual countries also have significantly higher shares of fossil-fuelled electricity production than these average figures: Poland (98%), South Africa (94%) and Australia (93%) all generate more than 90% of their electricity from fossil fuels, mainly coal. In some other countries, electricity is mainly produced from non-fossil fuel sources. Electricity generation in Iceland (100%), Norway (99%) and Brazil (88%) is mostly based on renewable resources and in France (78%) is based on a high share of nuclear power.

**Efficiency of electricity generation**

CO$_2$ emissions are also significantly influenced by the efficiency of fossil fuel electricity generation. In the case of coal-fired plant, the global average efficiency has remained broadly constant at around 35% between 1990 and 2007 (Figure 3.2). This is the result of a small upward trend in many countries, offset by a greater proportion of global coal-fired generation being in non-OECD countries that typically have lower generation efficiencies.

**Figure 3.2  Efficiency of electricity production from fossil fuels**

The efficiency of electricity generation from natural gas has increased steadily, but average coal and oil generation efficiency has not changed significantly since 1990.

The efficiency of coal-fired plants depends on a range of factors including the technology employed, the type and quality of coal used and operating conditions and practices. For example, average coal-fired generation efficiency in India in 2007 was 26% partly as a result of the widespread use of subcritical plants burning unwashed coal with high ash content, and of the use of coal-fired plants for peak load electricity production. By contrast, Denmark and Japan have some of the most efficient coal-fired power plants in the world, averaging efficiencies of almost 43% and 42% respectively, including a new generation of pulverised coal supercritical (SC) plants that were introduced in the 1990s.

---

2. All electricity generation efficiencies in this chapter are expressed on a gross output basis using net calorific values unless otherwise stated.
The average efficiency of natural gas-fired electricity production in 2007 was 47% in OECD countries and around 35% in non-OECD countries. The average efficiency of natural gas plants in individual countries varies considerably, with Luxembourg having the highest average efficiency of 55%. Since 1990, the efficiencies of natural gas-fired plants have risen significantly in many OECD countries and as a result the average has increased by almost 8 percentage points. In contrast, non-OECD countries have seen only a 1 percentage point rise. The widespread introduction of successively more efficient natural gas combined-cycle (NGCC) plants in OECD countries has been the main driver behind the increase in both the use of natural gas for electricity production and the average generation efficiency. The latest NGCC plants have efficiencies approaching 60%.

The use of oil in electricity production is declining, but it is still important in a few countries. The current average efficiency of oil-fired electricity production in OECD countries is 37%. In non-OECD countries the average efficiency is 35%. Average efficiencies for oil-fired electricity production in most countries and regions have not changed much in recent years.

**CO₂ emissions**

Between 1990 and 2007, CO₂ emissions from global electricity production increased by 59% to reach 12 Gt (Figure 3.3). Most of the rise in CO₂ emissions was driven by increases in electricity generation from coal. In 2007, coal-fired power plants accounted for 73% of total emissions from the sector, up from a share of 66% in 1990. Total CO₂ emissions from natural gas-fired plants are around only 25% of those from coal, despite the fact that they generate nearly half as much electricity. This is due to gas having a lower carbon content than coal per unit of delivered energy, together with the higher average efficiency of gas-fired electricity generation compared to coal plants.

**Figure 3.3** CO₂ emissions from global electricity generation

![CO₂ emissions from global electricity generation](image)

Note: Other includes industrial waste and non-renewable municipal waste.

**Key point**

Electricity production from coal is the main source of CO₂ emissions from the sector.
Future scenarios

Baseline scenario

In the Baseline scenario, global electricity production increases by 134% between 2007 and 2050 (Figure 3.4). Fossil fuels maintain their high share in the electricity generation mix, accounting for two-thirds of the total. In 2050, coal-based generation is 149% higher than in 2007, accounting for 44% of all power generation. The share of gas-fired power generation increases slightly to 23%, while oil is almost completely phased out. Nuclear decreases to 10%, hydro decreases to 12%, and wind increases to account for 5% of all power generation. As a result of the continued dependence on fossil fuels, \( \text{CO}_2 \) emissions from electricity generation almost double between 2007 and 2050.

In the Baseline scenario, investment in the electricity sector, including for generation, transmission and distribution, is USD 23.5 trillion between 2010 and 2050. More than half of this (USD 15 trillion) is needed for new power generation plants, with USD 5.8 trillion for maintaining and expanding the electricity distribution network and USD 2.5 trillion for the electricity transmission network. Investment in gas, coal, biomass, hydro and nuclear technologies dominates the total for the power generation sector. Over 3 800 gigawatts (GW) of gas-fired capacity is added in the Baseline scenario between 2007 and 2050, and just over 3 200 GW of coal-fired capacity.

Figure 3.4  Global electricity production by energy source and by scenario

![Graph showing global electricity production by energy source and by scenario](image)

Note: Other includes electricity generation from geothermal and ocean technologies.

Key point

There is a major shift from fossil fuels to low-carbon alternatives in the BLUE Map scenario.

3. All costs in this chapter are expressed in 2008 USD.
BLUE Map scenario

Electricity demand in 2050 in the BLUE Map scenario is 13% lower than in the Baseline scenario owing to increased energy efficiency in the end-use sectors. This is despite the fact that some of the increased efficiency in industry and buildings is offset by higher demand for electricity for additional uses, such as heat pumps and plug-in hybrid vehicles (PHEVs) and electric vehicles (EVs).

As well as reducing electricity demand, the CO₂ emissions reduction incentives and other measures introduced in the BLUE Map scenario radically change the electricity generation mix relative to the Baseline scenario. Low-carbon energy sources, such as nuclear and renewables, become more attractive compared to fossil-fuelled power. By 2050, a variety of renewables generate almost half the electricity in the BLUE Map scenario and nuclear increases its share to 24%. Coal-fired generation reduces to 12% by 2050, more than 90% of which is combined with CCS. Gas-fired generation is also much lower than in the Baseline scenario with a 15% share, of which almost one-third is fitted with CCS.

By 2050, these changes lead to CO₂ emissions reductions of just over 14 Gt in the BLUE Map scenario compared with the Baseline scenario, and the power sector becomes virtually decarbonised. In 2007, the average emissions intensity of electricity production was 507 grammes of CO₂ (g CO₂) per kilowatt-hour (kWh). By 2050, this reduces to 459 gCO₂/kWh in the Baseline scenario. In the BLUE Map scenario, the emissions intensity in 2050 falls dramatically to 67g CO₂/kWh with OECD countries having lower emissions intensity than non-OECD countries (Figure 3.5). Different supply-side measures play a role in achieving this emissions abatement (Figure 3.6).

**Figure 3.5**  ▶ CO₂ intensity of electricity production by scenario

<table>
<thead>
<tr>
<th>Year</th>
<th>CO₂ intensity (g CO₂/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>507</td>
</tr>
<tr>
<td>Baseline 2050</td>
<td>459</td>
</tr>
<tr>
<td>BLUE Map 2050</td>
<td>67</td>
</tr>
</tbody>
</table>

Key point

The power sector is virtually decarbonised by 2050 in the BLUE Map scenario.
Figure 3.6 The contribution of different power sector technologies to reductions in CO₂ emissions in the BLUE Map scenario

BLUE Map 14 Gt CO₂ reduction

- Fuel switching coal to gas: 7%
- Gas efficiency: 2%
- SC/USC coal: 3%
- IGCC coal: 4%
- CCS: 31%
- Nuclear: 19%
- Hydro: 2%
- Wind: 11%
- Solar PV: 7%
- Solar CSP: 9%
- Geothermal: 3%
- Biomass and waste: 2%

Note: Excludes the impact on CO₂ emissions of changes in the level of electricity generation between the two scenarios.

Key point

Reducing CO₂ emissions from the power sector will require a mix of generation based on renewables, nuclear and fossil fuels with CCS.

The share of all electricity generation from renewables increases from 18% in 2007 to 48% in the BLUE Map scenario (Figure 3.7). This results in CO₂ emissions reductions of 4.7 Gt in 2050 compared to the Baseline scenario. Variable renewable generation (wind, PV and ocean) produces almost 19% of electricity worldwide in 2050 from a capacity of about 3 160 GW. The integration of a large volume of variable capacity in grids will need careful management and will require electricity systems to become more flexible through the use of smart grids and greater electricity storage capacity.

Biomass and wind constitute the bulk of new renewables capacity up to 2020. After 2020, solar power starts to make a more significant contribution. Hydro grows continuously over the whole period, but this growth levels off in later years for lack of suitable new sites. By 2050, hydro, wind and solar each make similar contributions to total electricity production in the BLUE Map scenario.

By 2050, biomass is mostly used in dedicated plants, including those employing combined heat and power (CHP). Co-firing with coal increases significantly, particularly in the period to 2020. Most of the increase in electricity from wind is from onshore turbines. Electricity generation from offshore turbines grows very rapidly, but from a low starting point. In 2050, about two-thirds of total electricity production from wind still comes from onshore plant. Around 75% of the anticipated solar capacity is based on PV, with the balance coming from concentrating solar power (CSP). On average, the capacity factor for CSP is significantly higher than that of PV, thanks to the use of thermal storage. As a result, CSP generates more than 50% of total solar power generation.
Electricity generation from renewables grows strongly in the BLUE Map scenario with hydropower, wind and solar being the most important technologies by 2050.

The underlying average efficiency of fossil-fuel power plant increases substantially in all the BLUE scenarios, as the efficiencies of coal-fired and gas-fired plants without CCS are higher than in the Baseline scenario (Figure 3.8). Integrated-gasification combined-cycle (IGCC) and ultra-supercritical steam cycle (USCSC) plants both play a role in achieving this outcome. However, the use of CCS incurs a significant energy penalty. As a result, efficiencies in 2050 are reduced by between 6 and 8 percentage points, depending on the plant.

The efficiencies of power plants increase in the BLUE Map scenario, but the fitting of CCS reduces the gains significantly.
The use of CHP approximately triples in the BLUE Map scenario in absolute terms between 2007 and 2050. The share of CHP in power generation increases to 13% over this period, up from 10% in the Baseline scenario.

The efficiency improvements from new fossil-fuelled technologies and the greater use of CHP, combined with fuel switching from coal to gas, result in CO$_2$ emissions reductions of 1.9 Gt in 2050.

By 2050, the use of CCS in electricity generation accounts for a reduction of 4.4 Gt CO$_2$ in the BLUE Map scenario. More than 90% of the electricity generated by coal-fired power plants, and 30% of the gas-fired power generation, comes from plants equipped with CCS (Figure 3.9). In the BLUE Map scenario, 340 GW of coal-fired power plant capacity without CCS is retired early. By 2050, 75% of the 728 GW of coal-fired plant is equipped with CCS from the outset and 16% retrofitted with CCS. The remaining 9% of capacity continues to operate without CCS.

Additional CO$_2$ emissions reduction is achieved in the BLUE Map scenario by using biomass generation fitted with CCS. By 2050, 13% of electricity from biomass is generated in plants using CCS, which results in net negative emissions of CO$_2$. But this approach is costly. Biomass transportation costs limit the size of plant that makes economic sense and so combining CCS with biomass plant does not result in the same economies of scale as when used with fossil fuels.

**Figure 3.9** - Global deployment of CCS and CO$_2$ captured in the power sector in the BLUE Map scenario in 2050

**Key point**

In the power sector, CCS is mostly used to abate emissions from coal-fired plants.

In the BLUE Map scenario, increased energy efficiency in the end-use sectors lowers electricity demand compared to the Baseline scenario, thereby reducing the need for new capacity. But there is also significant new investment in more capital-intensive renewables, nuclear and CCS-equipped thermal generation. As a result, overall
investment needs in the electricity generating sector between 2010 and 2050 are USD 9.3 trillion (40%) higher than in the Baseline scenario. USD 6.0 trillion additional investment is made in power generation plants, plus USD 1.7 trillion extra for transmission systems and USD 1.6 trillion more for distribution. The additional investment in transmission is to provide transmission lines that connect more remote renewables to the grid and to reinforce grids to handle the connection of variable renewables.

**BLUE scenario variants**

The future electricity mix is highly uncertain, being subject to a wide range of factors. Some of these factors have been explored through variants of the BLUE scenario (Table 3.1). The variant scenarios explore the effect of flexing the contribution of particular technologies under two different conditions. First, by using the same marginal carbon price of USD 175/t CO₂ as in the BLUE Map scenario and letting the amount of emissions abatement vary and, second, by examining the marginal carbon price that is necessary to achieve the same level of CO₂ emissions abatement as in the BLUE Map scenario.

Among the BLUE variant scenarios, BLUE no CCS results in the highest emissions when the BLUE Map carbon price is applied. Emissions are 4.2 Gt CO₂ higher in 2050 than in the BLUE Map scenario. In this variant, the share of coal-fired generation drops to 3%. Total electricity demand is 4% lower and the share of renewables increases to 54%. Nuclear power does not increase its share because of the assumption of a 1 200 GW limit on capacity in 2050 that is retained from the BLUE Map scenario. CO₂ emissions increase not only in electricity generation, but also in industry and in the fuel transformation sector. This scenario requires additional investments of USD 4.7 trillion compared to the BLUE Map scenario, and leads to the highest average electricity generation costs, increasing by 38% in 2050 compared to the Baseline scenario. These high costs demonstrate the importance of the availability of CCS as an option for mitigating CO₂ emissions, particularly if large-scale investment in nuclear power proves unachievable.

In the BLUE hi NUC variant, where the maximum allowed nuclear generation capacity is increased to 2 000 GW in 2050, almost all of the nuclear potential is used and the share of nuclear generation increases to 39%. The increase in nuclear generation is at the expense of coal with CCS and renewables, whose shares both decrease: from 12% to 8% for coal with CCS and from 48% to 42% for renewables. Total global emissions in this variant are around 1 Gt CO₂ lower in 2050 than in the BLUE Map scenario. This variant reflects a world in which nuclear power has greater public and political acceptability. However, it would require average reactor construction rates of 50 GW per year between 2010 and 2050, significantly higher than those achieved historically. It would also imply a much larger increase in the supply of nuclear fuel than the BLUE Map scenario. As well as greatly increased uranium production, this would probably require large-scale recycling of spent nuclear fuel and hence the earlier introduction of advanced nuclear systems. In this scenario, investment costs rise by USD 0.3 trillion. But average generation costs are lower than in the BLUE Map scenario and only 6% above those in the Baseline scenario.
Table 3.1  Global electricity production by energy source and by scenario

<table>
<thead>
<tr>
<th>Production (TWh)</th>
<th>2007</th>
<th>Baseline 2050</th>
<th>BLUE Map 2050</th>
<th>BLUE no CCS 2050</th>
<th>BLUE hi NUC 2050</th>
<th>BLUE hi REN 2050</th>
<th>BLUE 3% 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>2 719</td>
<td>4 825</td>
<td>9 608</td>
<td>9 608</td>
<td>15 859</td>
<td>4 358</td>
<td>9 608</td>
</tr>
<tr>
<td>Oil</td>
<td>1 117</td>
<td>311</td>
<td>226</td>
<td>148</td>
<td>170</td>
<td>197</td>
<td>290</td>
</tr>
<tr>
<td>Coal</td>
<td>8 216</td>
<td>20 459</td>
<td>238</td>
<td>1 164</td>
<td>21</td>
<td>333</td>
<td>236</td>
</tr>
<tr>
<td>Coal + CCS</td>
<td>0</td>
<td>0</td>
<td>4 746</td>
<td>0</td>
<td>3 395</td>
<td>910</td>
<td>4 463</td>
</tr>
<tr>
<td>Gas</td>
<td>4 126</td>
<td>10 622</td>
<td>4 283</td>
<td>6 939</td>
<td>2 840</td>
<td>2 983</td>
<td>2 184</td>
</tr>
<tr>
<td>Gas + CCS</td>
<td>0</td>
<td>0</td>
<td>1 815</td>
<td>0</td>
<td>1 536</td>
<td>771</td>
<td>1 440</td>
</tr>
<tr>
<td>Hydro</td>
<td>3 078</td>
<td>5 344</td>
<td>5 749</td>
<td>5 582</td>
<td>5 747</td>
<td>6 043</td>
<td>5 919</td>
</tr>
<tr>
<td>Biomass/waste</td>
<td>259</td>
<td>1 249</td>
<td>2 149</td>
<td>2 703</td>
<td>2 044</td>
<td>2 488</td>
<td>2 105</td>
</tr>
<tr>
<td>Biomass + CCS</td>
<td>0</td>
<td>0</td>
<td>311</td>
<td>0</td>
<td>251</td>
<td>146</td>
<td>278</td>
</tr>
<tr>
<td>Geothermal</td>
<td>62</td>
<td>297</td>
<td>1 005</td>
<td>1 007</td>
<td>932</td>
<td>1 411</td>
<td>1 137</td>
</tr>
<tr>
<td>Wind</td>
<td>173</td>
<td>2 149</td>
<td>4 916</td>
<td>5 589</td>
<td>3 943</td>
<td>8 193</td>
<td>6 267</td>
</tr>
<tr>
<td>Ocean</td>
<td>1</td>
<td>25</td>
<td>133</td>
<td>274</td>
<td>97</td>
<td>552</td>
<td>408</td>
</tr>
<tr>
<td>Solar</td>
<td>5</td>
<td>905</td>
<td>4 958</td>
<td>5 512</td>
<td>4 113</td>
<td>9 274</td>
<td>7 608</td>
</tr>
<tr>
<td>TOTAL</td>
<td>19 756</td>
<td>46 186</td>
<td>40 137</td>
<td>38 526</td>
<td>41 139</td>
<td>37 656</td>
<td>41 944</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Share (%)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>14</td>
<td>10</td>
<td>24</td>
<td>25</td>
<td>39</td>
<td>12</td>
<td>23</td>
</tr>
<tr>
<td>Oil</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Coal</td>
<td>42</td>
<td>44</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Coal + CCS</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>0</td>
<td>8</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>Gas</td>
<td>21</td>
<td>23</td>
<td>11</td>
<td>18</td>
<td>7</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Gas + CCS</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Hydro</td>
<td>16</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Biomass/waste</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Biomass + CCS</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Geothermal</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Wind</td>
<td>1</td>
<td>5</td>
<td>12</td>
<td>15</td>
<td>10</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>Ocean</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Solar</td>
<td>0</td>
<td>2</td>
<td>12</td>
<td>14</td>
<td>10</td>
<td>25</td>
<td>18</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Share of renewables (%) in 2050</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>18</td>
<td>22</td>
<td>48</td>
<td>54</td>
<td>42</td>
<td>75</td>
<td>58</td>
</tr>
<tr>
<td>Oil</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Coal</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Coal + CCS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gas</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gas + CCS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hydro</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Biomass/waste</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Biomass + CCS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Geothermal</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wind</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ocean</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Solar</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total CO₂ emissions (Gt CO₂/yr)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>28.9</td>
<td>57.0</td>
<td>14.0</td>
<td>18.2</td>
<td>13.1</td>
<td>12.9</td>
<td>13.2</td>
</tr>
<tr>
<td>Oil</td>
<td>6.0</td>
<td>10.7</td>
<td>6.3</td>
<td>12.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal + CCS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas + CCS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydro</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass/waste</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass + CCS</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geothermal</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocean</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additional investment cost</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>compared to the Baseline (2010-2050) USD (trn)</td>
<td>6.0</td>
<td>10.7</td>
<td>6.3</td>
<td>12.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average generation cost increase from Baseline (2050)</td>
<td>19%</td>
<td>38%</td>
<td>6%</td>
<td>31%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marginal cost in 2050 to meet target (USD/CO₂)</td>
<td>175</td>
<td>293</td>
<td>159</td>
<td>153</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: The CO₂ emissions, additional investment costs and increase in average generation costs of the BLUE variants are all calculated assuming the same marginal carbon price as in the BLUE Map scenario. The marginal costs of the BLUE variants are calculated using the same CO₂ emissions target in 2050 as in the BLUE Map scenario.
In the **BLUE hi REN** variant, the share of renewables in total electricity generation is set at 75% in 2050. While such a high proportion of renewables is not economically optimal from a CO$_2$ reduction perspective, it could be driven by the use of renewables to pursue other policy goals such as energy security and local environmental benefits. The increased generation from renewables is mostly at the expense of coal with CCS and nuclear, whose respective shares in the total electricity supply become 2% and 12%. CO$_2$ emissions in 2050 are slightly lower than in the **BLUE hi NUC** scenario. The **BLUE hi REN** scenario requires additional investments of around USD 6.1 trillion compared to the **BLUE Map** scenario, and results in an increase in average electricity generation costs of 10% over the **BLUE Map** scenario and 31% over the Baseline scenario.

The **BLUE 3%** variant is used to explore the impact on the electricity sector of using a single lower discount rate to reflect social time preferences, rather than the market rates of between 8% and 14% used in the **BLUE Map** scenario. With the same carbon price as in the **BLUE Map** scenario, this assumption results in much higher levels of renewables and in fossil fuels in end-use sectors being replaced increasingly by electricity. There is no increase in nuclear power because of the assumed capacity constraint. CO$_2$ emissions in this variant fall compared to those in the **BLUE Map** scenario.

A second way to use these scenario variants is to assume a constant level of CO$_2$ reduction and to compare the impact on marginal costs. The highest marginal costs are observed in the **BLUE no CCS** variant, where they increase by 75% to just less than USD 300 per tonne of CO$_2$ saved. In the **BLUE hi NUC** variant, marginal costs are USD 16/tCO$_2$ less than in the **BLUE Map** scenario as the constraints on economically attractive nuclear power are relaxed. In the **BLUE hi REN** variant, the marginal cost of CO$_2$ reductions is reduced by USD 22/tCO$_2$ as higher cost renewable generation is forced into the mix, causing lower-cost CO$_2$ reduction options to be the marginal technology.

### Fossil fuel power plants

#### Overview

Electricity generation is currently largely based on fossil fuels in many countries and regions (Figure 3.10). In the Baseline scenario, in the absence of new policies, coal use in electricity generation increases significantly. By 2050, 44% of the world’s electricity comes from coal, slightly higher than its current share. The contribution from gas increases to 23%, while that from oil dwindles to almost zero. Pulverised coal combustion (PCC) remains the dominant technology for coal. From 2015, the output from subcritical PCC plant begins to reduce, while the role of SC and ultra-supercritical (USC) PCC plant in the mix grows, and they become the prevailing technologies from 2030. Fluidised bed combustion (FBC) plant contributes in niche applications, e.g. in the combustion of poorer-quality fuels. There is also a small contribution from IGCC from 2020. For gas, NGCC remains the technology of choice for electricity generation, with its capacity growing consistently to 2050. Some natural gas open-cycle (NGOC) plant is also used to meet peak electricity requirements.
**Figure 3.10** Share of fossil-fuelled electricity generation in selected countries and regions, 2007

<table>
<thead>
<tr>
<th></th>
<th>Natural gas</th>
<th>Oil</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>13.5</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Poland</td>
<td>1.9</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>South Africa</td>
<td>2.7</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>China</td>
<td>3.1</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>India</td>
<td>0.7</td>
<td>1.9</td>
<td>0.7</td>
</tr>
<tr>
<td>United States</td>
<td>0.7</td>
<td>1.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Japan</td>
<td>0.7</td>
<td>1.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Russia</td>
<td>1.9</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>OECD Europe</td>
<td>0.7</td>
<td>1.9</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Note: Values above the columns are the absolute level of generation in PWh.

**Key point**

Many major countries and regions rely on fossil fuels for their electricity generation.

In the BLUE Map scenario, fossil fuel use reduces significantly. By 2050, coal and gas together contribute around 28% of total electricity generation, compared to around 67% in the Baseline scenario. By 2050, much of the remaining fossil fuel generation capacity is equipped with CCS. Generation from coal plants without CCS declines steeply after 2015. As a result of its slightly lower cost, IGCC with CCS predominates over PCC with CCS. Oxyfuel combustion is also introduced into the mix from 2020, and within 15 years is generating more electricity than PCC with CCS. The role of NGCC, though much reduced from that in the Baseline scenario, remains significant to 2050. CCS applied to NGCC plants begins to grow from 2025 (Figure 3.11).

**Figure 3.11** Electricity generation from fossil fuels by technology type and by scenario, 2050

**Baseline 31.2 PWh**

- Coal, SC/USC/IGCC: 40%
- Oil, all types: 1%
- Gas, CHP: 12%
- Gas, NGCC and NGOC: 21%

**BLUE Map 11.3 PWh**

- Coal, CCS: 22%
- Gas, CHP: 42%
- Gas, NGCC and NGOC: 18%
- Gas, NGCC with CCS: 8%

**Key point**

The fossil fuel generation mix changes radically between the Baseline and BLUE Map scenarios.
Technology status and prospects

There are essentially three ways to reduce CO₂ emissions from fossil fuel-fired plants:

- by improving the stock of operational plants, e.g. by closure of the most inefficient plants, modernising and refurbishing existing plants or improving their operation and maintenance, and by deploying best available technologies in new plants;
- by switching to lower-carbon fuels, e.g. by switching from coal to natural gas or by co-firing coal with biomass; or
- by employing CCS.

In practice, the choice will depend on the degree of CO₂ mitigation required, on the price of competing fuels and the cost of alternative technologies.

A number of factors influence the efficiencies of coal-fired power plant. Efficiencies may be improved by the closure of poorly performing plant, by upgrading existing plant or by installing new generation technology. Operating procedures and fuel quality are also important to good performance. Running plants below their rated output substantially reduces their efficiency.

Pulverised coal combustion

PCC is currently the predominant technology for generating electricity from coal. It accounts for more than 97% of the world’s coal-fired capacity. Most existing plants operate at less than SC steam conditions, with the best examples reaching 39% efficiency. In recent years, a substantial number of plants employing SC steam conditions have been constructed. These are capable of reaching significantly higher efficiencies. This has been made possible largely through progress in materials development which has enabled SC plants to operate at high temperatures with steam pressures greater than 221 bar. Such plants are often subdivided into two categories, SC and USC, depending on the temperatures at which they operate. Although there is no agreed definition, some manufacturers refer to those plants operating with steam temperatures in excess of 600°C as being USC. The efficiencies of SC and USC plants installed in recent years range from 42% to 47%, depending on the actual steam values, the quality of the coal and the ambient conditions. Advances in materials have paved the way for larger unit capacities, with single units of 1 000 MW now in commercial operation. Further developments in materials are under way to permit the use of steam temperatures at 700°C and higher. This requires the use of nickel-based super alloys, which would offer the potential to raise net efficiencies to 50% and beyond.

The average global efficiency of PCC plant has been broadly static at around 34% over the past decade or longer. In recent years, substantial capacity has been added, particularly in the larger developing economies of China and India. Given the long lifespans of coal plant, even with the majority of new capacity comprising well-performing plants, there is a considerable complement of underperforming existing plants. A number of countries have policies to close the smallest, least efficient plants. Even then, a large amount of inefficient current plants may continue to generate for many years to come.
A programme to refurbish these plants could lead to large reductions in emissions. For example, raising the efficiency of a plant with 35% efficiency by one percentage point would reduce its CO₂ emissions by about 3%. Such a programme would include the retrofitting of components by replacement and upgrade, installing more advanced control systems and improving operation and maintenance (O&M) procedures.

Some countries have large resources of brown coal (or lignite). Given its higher moisture content and lower heat content, the use of this coal may restrict technology choices and result in lower thermal efficiencies. Recently developed coal-drying techniques could have the potential to significantly improve the efficiency from such plants.

Technologies have been developed to reduce the emission of particulates, sulphur dioxide (SO₂) and nitrogen oxides (NOₓ) from PCC plants to extremely low levels. These technologies are mature, with a competitive market. In practice, the levels of emissions reductions achieved are more often a function of the requirements of national legislation or local regulations rather than of the capability of modern pollution control technologies.

**Fluidised bed combustion**

FBC offers an alternative to PCC for generating electricity from coal. Today it is most often employed in particular or niche applications, for instance where fuel flexibility is required. FBC deals effectively with low-quality coals, biomass and general waste. Worldwide, there are several hundred FBC plants in operation. There are two main technology variants, bubbling bed (BFBC) and the more common circulating bed (CFBC). Both BFBC and CFBC offer the potential for integrated in-bed sulphur reduction and, as a result of the lower operating temperatures, lower NOₓ emissions than PCC.

FBC plant is generally smaller than PCC plant, although a number of FBC plants of between 250 MW and 300 MW are in operation. In June 2009, a 460 MW CFBC plant at Lagisza in Poland began its commissioning programme. The plant will burn domestic bituminous coal and has a design efficiency of 43%. In the future, manufacturers hope to scale up designs to offer units within the range 500 MW to 800 MW.

**Natural gas combined cycle**

Natural gas-fired power generation has been the preferred power generating technology over the past two decades in many OECD countries and some non-OECD countries. Exhibiting higher efficiencies, lower capital costs, shorter construction times and lower CO₂ emissions, NGCC potentially offers a number of advantages over coal-fired power generation. The availability and relative costs of coal and gas have largely determined technology choices. Evolving gas turbine technology has led to efficiencies approaching 60%, with further developments in hand.
Integrated gasification combined cycle

Integrated gasification combined cycle plant has inherently lower emissions of some pollutants than PCC and the potential to achieve levels of efficiency as high as those of PCC plants. A fuel gas mainly comprising carbon monoxide and hydrogen is generated by partially combusting coal in air or oxygen at elevated pressure. Following cooling, the fuel gas is treated to reduce the concentration of particulates, sulphur and nitrogen compounds to extremely low levels before it is burned in the combustion chamber of a gas turbine. Electricity is produced through the combined cycle of gas and steam turbines. There are a number of variants of the technology depending, for example, on whether air or oxygen is used as the oxidising medium and whether the coal is fed to the gasifier dry or as slurry. Future designs offer the potential for efficiencies of over 50%.

The 1970s and 1980s saw a surge of interest in the development of IGCC plants, particularly in Europe, Japan and the United States. Concerns relating to the cost and reliability of IGCC plant meant that the technology fell out of favour towards the end of the 1990s. Of the plants that were commissioned in the 1990s, only four continue to operate on a commercial basis, two in Europe and two in the United States. The capacity of each of these plants lies in the 250 MW to 300 MW range and their net efficiencies are between 40% and 43%.

Interest in IGCC technologies has recently revived. By adding a water-gas shift reactor, additional hydrogen can be produced and carbon monoxide can be converted to CO₂ for capture and storage. The hydrogen that remains can be used to generate power through a gas turbine or a fuel cell. Alternatively, the fuel gas could be used to synthesise substitute transport fuels or a range of other chemicals. The flexibility for an IGCC plant to generate a range of products, electricity, hydrogen transport fuels and/or chemicals, is commonly referred to as polygeneration.

Given the attraction and flexibility of an IGCC plant, significant effort is being devoted to the development of IGCC technologies, particularly in China, the United States, Japan and Europe. However, a number of technical obstacles will need to be overcome if IGCC is to become widely deployed.

Combined heat and power

By making use of both heat and power, CHP plants generally convert 75% to 80% of the input fuel energy into useful energy. Many modern plants reach efficiencies of 90% or more. CHP plant tends to be situated close to end-users as the heat output from electricity production is often used for space heating or other heat applications in industry. This also helps to reduce electricity transmission and distribution losses.

Almost any fuel is suitable for CHP, although natural gas and coal currently predominate. Some CHP technologies can be fired by multiple fuel types, providing valuable flexibility at a time of growing fuel choice. CHP plant sizes range from 1 kW to 500 MW. For plants larger than 1 MW, equipment is generally tailored to the individual site, but smaller-scale applications can often utilise pre-packaged units. CHP plants are usually sized to meet the required heat demand, selling the excess electricity produced back to the grid.
The amount of electricity produced globally from CHP has been gradually increasing, and has now reached more than 1 970 TWh per year, or more than 10% of total global electricity production. The amount of heat that is co-generated is in the range of 120 million tonnes of oil equivalent (Mtoe) to 360 Mtoe per year, representing an important share of industrial, commercial and residential heat supply.

The penetration of CHP in the power generation sector varies widely from country to country. Denmark, Finland and the Netherlands already have high penetration rates. Russia and China have substantial lower-efficiency CHP capacity that offers significant opportunity for efficiency improvement. China also has very significant potential for growth in CHP given its increased attention to energy efficiency and its rapidly growing industrial base. Many other countries have significant potential to expand their use of CHP, if they take steps to address barriers such as unfavourable regulatory frameworks in the form of buy-back tariffs, exit fees, and backup fees, challenges in locating suitable heat users, and the relative cost-ineffectiveness of CHP units of less than 1 MW capacity.

Costs

The costs of coal and gas plants can vary substantially from country to country. Variations depend largely on the competition for power plant design and construction resources, commodities, equipment and manufacturing capacity. Fuel availability and costs, and the time needed for construction, are the major determinants of choices between coal or gas plant. With the increasing focus on reducing CO₂ emissions, there is significant ongoing effort to raise the efficiencies of both coal and gas plants. There have been significant developments in SC coal technologies in recent years, although the potential cost savings arising from more efficient SC and USC plants are offset by the need for more expensive materials, more complex boiler fabrication and the more precise control systems required. Costs for both coal and gas technologies are expected to fall in the future. For other technologies such as IGCC, improvements resulting from experience and learning will lead to lower costs, as will the development of innovative technologies to replace those available at present.

The assumptions about investment and O&M (excluding fuel) costs for new plant used in the scenarios are summarised in Table 3.2.

Table 3.2 Cost assumptions for hard coal- and natural gas-fired electricity generation

<table>
<thead>
<tr>
<th>Technology</th>
<th>Investment cost 2010</th>
<th>Investment cost 2050</th>
<th>O&amp;M cost 2010</th>
<th>O&amp;M cost 2050</th>
<th>Net efficiency 2010</th>
<th>Net efficiency 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC PCC</td>
<td>2 100</td>
<td>1 650</td>
<td>42</td>
<td>32</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>USC PCC</td>
<td>2 200</td>
<td>1 700</td>
<td>44</td>
<td>34</td>
<td>46</td>
<td>52</td>
</tr>
<tr>
<td>IGCC</td>
<td>2 400</td>
<td>1 850</td>
<td>72</td>
<td>56</td>
<td>42</td>
<td>54</td>
</tr>
<tr>
<td>NGCC</td>
<td>900</td>
<td>750</td>
<td>27</td>
<td>23</td>
<td>57</td>
<td>63</td>
</tr>
</tbody>
</table>

Note: Estimates of costs and efficiencies in 2050 are inevitably subject to great uncertainty. These data refer to plants in the United States. Cost data in other world regions are calculated by multiplying these costs by region-specific multipliers for the investment and O&M costs. The lower investment costs in many of the non-OECD regions converge to US levels by 2050.
Carbon capture and storage

Overview

In the BLUE Map scenario, almost two-thirds of all fossil-fuel electricity is produced from plants which incorporate CCS. Most of the remainder comes from high efficiency NGCC. Over 20% of all electricity produced from biomass and waste is from plants that incorporate CCS.

From 2010 to 2050, the use of CCS in power generation in the BLUE Map scenario results in cumulative capture and storage of some 79 Gt CO₂. By 2050, coal-fired plants account for around 87% (69 Gt) of the cumulative CO₂ captured from power generation. Capture from gas-fired plants accounts for 10% (8.2 Gt) and capture from biomass plants accounts for around 3% (2.0 Gt). Total global installed CCS capacity rises to over 1 000 GW by 2050, of which coal-fired CCS accounts for almost two-thirds. Realising this goal will present major development and investment challenges. CCS-fitted plants account for only 19% of total electricity generation in 2050 in the BLUE Map scenario.

Figure 3.12 Regional deployment of CCS in power generation under the BLUE Map scenario

The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Key point

CCS is initially deployed mostly in OECD countries, but by 2050 India and China have the largest share of any region.

Of the three methods of CO₂ capture relevant to power generation (post-combustion, pre-combustion and oxy-fuelling), the BLUE Map scenario envisages near-term projects mainly consisting of post-combustion capture technologies
from coal-fired power plants in OECD regions with other capture technologies then taking an increasing share over time. Post-combustion capture is the most extensively demonstrated of the three capture options at present, and capture from coal-fired power plant is cheaper than from gas-fired power plant given coal’s higher CO₂ intensity. Post-combustion capture is also seen as the technology most suitable for retrofit, which means it will have the greatest impact on existing plant and on plant that is currently under construction.

The BLUE Map scenario shows that the share of CCS deployment within non-OECD regions will need to increase very significantly around 2025 to 2030 and beyond if emissions from new coal-fired power plants built in emerging economies are to be tackled (Figure 3.12). To meet the emissions reduction objectives of the BLUE Map scenario, the capture and storage of emissions from plants in China and India alone will need to account for around 36% of global CCS deployment in power generation by 2050.

Technology status and prospects

Carbon capture and storage is a system of technologies that integrates three stages: CO₂ capture, transport, and geological storage. Each of these stages is technically viable and has been demonstrated individually in relation to electricity generation. But none of the five fully integrated, commercial-scale CCS projects in operation involves capture of CO₂ from power generation.

To catalyse the deployment of CCS in power generation, OECD governments will need to increase funding for CCS demonstration projects. In addition, mechanisms need to be established to stimulate commercialisation beyond 2020 in the form of mandates, greenhouse-gas reduction incentives, tax rebates or other financing mechanisms. Carbon capture and storage technology must also be spread rapidly to the developing world. There is a need to develop near-term regulatory approaches to facilitate CCS demonstration activities, while at the same time developing comprehensive approaches for the large-scale commercial deployment of CCS.

Carbon dioxide capture

Carbon dioxide capture technologies have long been used by industry to remove CO₂ from gas streams where it is not wanted or to separate CO₂ as a product gas. But these technologies have only been combined with power generation on a small scale. Carbon capture and storage from power generation has only been demonstrated with sub-commercial volumes of flue gas, from small pilot plant or from flue-gas slip-streams from larger plant. Challenges associated with scaling up and integrating these technologies at scale need to be overcome. This can only be achieved through the experience of building and operating commercial-scale CCS facilities in a variety of settings. The demonstration of CO₂ capture from power generation in the next ten years will be critical to accelerating wider deployment between 2020 and 2050.

There are currently three primary methods for CO₂ capture: post-combustion, pre-combustion and oxy-fuel. Currently all three capture options result in a significant energy penalty to the base plant. It is expected that this energy penalty can be reduced through continued R&D and experience in operating plants at scale. The clean coal roadmap from the IEA Clean Coal Centre suggests a target range for
efficiencies of power generation technologies with CO$_2$ capture of 40% to 45%.$^4$ This assumes that performance approaches that of current non-capture systems, avoiding major impacts on fuel and other costs (Henderson and Mills, 2009).

**Box 3.1** Recent developments in CCS

The IEA CCS Roadmap (IEA, 2009) concludes that 100 large-scale CCS projects should be in operation by 2020 to enable widespread deployment in the following decades. In 2008, there were just five large-scale CCS projects in operation and none of these was in electricity generation. In the last two years there has been extensive investment in the development of CCS. A recent snapshot indicates some 240 active CCS projects at some stage in the planning process (GCCSI, 2010). Of these, 80 were large-scale and would demonstrate the entire process chain, i.e. they would include CO$_2$ capture, transport and storage.

To implement large-scale CCS plant requires extensive additional funding that, in the present energy market, cannot be justified commercially. In recognition of this market failure, governments have been taking an active role to address the financial gap. Although more funding is needed for first-of-a-kind CCS plants to be built in the numbers required, collectively more than USD 26 billion has been committed by governments, including those of Australia, Canada, Norway, the Republic of Korea, the United Kingdom and the United States, as well as the European Union.

The identification of suitable CO$_2$ storage reservoirs is critical to CCS deployment. In the last few years, several countries/regions have embarked upon strategies to map CO$_2$ storage potential, including Australia, Canada, China, the European Union, Mexico and the United States. For CCS to meet its potential beyond 2020, such mapping will need to accelerate over the coming decade.

Establishing effective, comprehensive legal and regulatory frameworks is essential for the broad deployment of CCS in the future. For first-of-a-kind or demonstration plants to be constructed and operated, exemptions or derogations from existing processes or regulations may be possible; but these can only offer an interim solution. Until recently, progress on the development of legal and regulatory frameworks has been fragmentary. This is no longer the case. The IEA, through its “Regulators’ Network”, and others have been instrumental in driving change. For example, Australia, the European Union, Japan and the United States have each introduced integrated legislation to facilitate the deployment of CCS.

**Carbon dioxide transport**

CO$_2$ has been transported in pipelines for more than 30 years in North America. Over 30 Mt CO$_2$ from natural and anthropogenic sources is transported each year through more than 3 000 km of pipelines in the United States and Canada (CSLF, 2009). CO$_2$ is transported predominantly in high-pressure pipeline networks. Ships, trucks and trains have also been used for CO$_2$ transport in early demonstration projects and in regions with inadequate storage. Although CO$_2$ captured from power generation may have different minor constituents in it due to the capture process and fuel used, it should not require any significant modifications to the current methods for CO$_2$ transport.

---

$^4$ Based on net output and net calorific values.
The challenge for the future of transport technology is to develop long-term strategies to cluster CO₂ sources and develop CO₂ pipeline networks that will optimise the source-to-sink transmission of CO₂. The development of appropriate pipeline routes presents a number of regulatory, access, public acceptance and planning challenges. To address these, governments will need to initiate planning at a regional level and develop incentives for the creation of CO₂ transport hubs.

Carbon dioxide storage

Carbon dioxide storage involves the injection of CO₂ into geological formations such as saline formations, oil and gas reservoirs, and deep unmineable coal seams. Of these, it is expected that saline formations will provide the opportunity to store the greatest quantities of CO₂, followed by oil and gas reservoirs. Monitoring data from projects involving injection into depleted oil and gas fields and saline formations have shown that the CO₂ performs as anticipated after injection, with no observable leakage. A number of projects involving the injection of CO₂ into oil reservoirs have also been conducted, primarily in the United States and Canada. Most of these projects use the CO₂ for enhanced oil recovery (EOR), but some seek also to establish long-term storage.

There is an urgent need to advance the state of global knowledge of CO₂ storage opportunities. Although depleted oil and gas fields are well mapped and offer promising low-cost opportunities, deep saline formations are the most viable option for the long term. But only a few regions have adequately mapped the CO₂ storage potential of these formations. There is also a need to develop common international methods for CO₂ storage site selection, monitoring and verification, and risk assessment.

Box 3.2 CCS retrofit and capture-ready plants: avoiding lock-in of non-CCS plants

In the short term there is a risk that increased electricity demand in many countries will be met by building new fossil fuel power plants to which CCS cannot be retrofitted once it becomes commercially available. If so, the building of these plants will lock in a large amount of CO₂ emissions over their operational lives of 40 years or more. It is critical that, wherever practical, fossil-fuelled plants built over the next 10 to 20 years utilise technologies and practices that enable CCS retrofitting.

To demonstrate capture-readiness, plants need to ensure the provision of sufficient space and access for the additional capture facilities that would be required, and identify reasonable methods for storing CO₂ (IEA GHG, 2007). Pre-investment in addressing these issues is relatively inexpensive and could result in significant reductions in the costs and down time involved in retrofitting CCS in due course.

5. CO₂ storage in basalt formations is also a potentially important option for regions such as the Indian subcontinent.
In the BLUE Map scenario, 16% of the total coal capacity operating with CCS in 2050 are plants that have been retrofitted. If these plants were unable to be retrofitted it would result in a significant increase in CO₂ emissions or in the cost of achieving emissions reduction targets. This demonstrates the importance of ensuring new build plant over the next 10 to 20 years has CCS fitted from the outset or is ready for retrofitting as soon as it can be achieved.

Costs

The capture, storage and transport of CO₂ all add to the cost of generating electricity. Capture raises costs by reducing electric efficiency, which means that more gross power capacity is needed for the same output, together with the cost of the additional capture equipment and the cost of additional fuel. The relative importance of these three components depends on the fuel price and the particular power plant and capture technologies employed.

Carbon capture and storage is expected to be more expensive to apply to power generation than to some industrial processes such as chemicals and gas processing, but cheaper than to fuel transformation and cement production. Most of the additional costs of CO₂ transport and storage will occur in respect of capital investment. These costs will depend on a number of factors, including whether the storage site is onshore or offshore, the distance between sources and sinks, the extent to which different projects can share a common transport infrastructure and the number of wells that are needed to inject and store a given amount of CO₂. Although the initial investment in CO₂ transport and storage infrastructure may be significant, the cost of CO₂ capture will represent the major component of the total additional cost over the lifetime of a project (Table 3.3). The costs of capture technologies are forecast to fall over time with increased demonstration of integrated projects and technology cost reductions, while transport costs will decrease with progressive optimisation of regional pipeline infrastructure.

Table 3.3

<table>
<thead>
<tr>
<th></th>
<th>Investment cost USD/kW</th>
<th>O&amp;M cost USD/kW/yr</th>
<th>Net efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2050</td>
<td>2010</td>
</tr>
<tr>
<td>USC PCC+ post-comb capture</td>
<td>3 400</td>
<td>2 500</td>
<td>102</td>
</tr>
<tr>
<td>USC PCC + oxy-fuelling</td>
<td>3 700</td>
<td>2 700</td>
<td>111</td>
</tr>
<tr>
<td>IGCC + pre-comb capture</td>
<td>3 200</td>
<td>2 450</td>
<td>96</td>
</tr>
<tr>
<td>NGCC+ post-comb capture</td>
<td>1 450</td>
<td>1 100</td>
<td>44</td>
</tr>
<tr>
<td>NGCC + oxy-fuelling</td>
<td>1 650</td>
<td>1 350</td>
<td>50</td>
</tr>
</tbody>
</table>

Note: Estimates of costs and efficiencies in 2050 are inevitably subject to great uncertainty. These data refer to plants in the United States. Cost data in other world regions are calculated by multiplying these costs by region-specific multipliers for the investment and O&M costs. The lower investment costs in many of the non-OECD regions converge to United States levels by 2050.
Renewable energy

Overview

Renewable energy sources can generate electricity with low or very low net CO₂ emissions over their lifecycle. They therefore have the potential to make a significant long-term contribution to decarbonising the power sector. The local availability of many renewable energy sources can also help decrease energy dependence and increase the energy security of countries.

In 2007, renewable energy sources represented 18% of power generation worldwide. This share has been decreasing for several years, mainly because of the slow growth of the largest renewable power source, hydro, compared to the growth of fossil-based power. The mix of renewables is also changing. For the first time in 2007 more electricity was produced from wind than from solid biomass (Figure 3.13).

![Composition of renewable power generation, 2007](image)

**Key point**

Hydro power is currently the most important renewable energy source for electricity generation.

Wind power has grown at an average rate of almost 30% per year over the last ten years. In terms of installed capacity, solar PV has grown even faster. The overall contribution of solar PV to total power generation remains small and, in many countries, hard to measure as many systems are off-grid.

In 2007, OECD Europe produced more than 20% of its electricity from renewable sources. Central and Latin America produced almost 70%. In the BLUE Map scenario, these regions are projected to retain a lead in generating electricity from renewables up to 2030. By 2050, Africa overtakes OECD Europe, with more than 80% of electricity coming from renewables, and Latin America generates 87% of its total electricity from renewables.

China generates about 34% of its electricity from renewables in 2050. Although the lowest share among the ten regions, this is very significant in absolute terms.
Electricity generation in the Middle East is projected to undergo major changes between 2007 and 2050. In 2007, about 3% of the electricity generated in the region came from renewables. By 2050 the development particularly of solar and wind power results in just over 50% of the total electricity in the region coming from renewables in the BLUE Map scenario (Figure 3.14).

**Figure 3.14** Renewable electricity generation in the BLUE Map scenario for key countries and regions in 2050

Note: Percentages above columns show the share of renewables in total electricity generation.

**Key point**

In the BLUE Map scenario, renewable energy makes a significant contribution to electricity generation in many countries and regions.

Compared to the BLUE Map scenario, overall electricity demand in 2050 is about 6% lower in the BLUE hi REN scenario. Wind, solar and ocean energy all have a higher share of electricity generation, at the expense of coal with CCS and nuclear. Solar energy is the largest source of electricity generation, accounting for almost 25% of the total. Solar generation comes about equally from CSP and PV technologies. Wind has the next largest share, followed by hydro. A high penetration of variable renewables, such as solar, wind and ocean, is complemented by the availability of flexible hydro and gas-fired capacity. These plants can provide backup in the absence of suitable conditions for electricity generation from variable renewables. A high share of variable renewable power will also require a number of other actions to increase the overall flexibility of power systems, including the development of smart grids, international interconnections, storage and demand-side response measures.

By 2050, all world regions produce at least 50% of their electricity from renewables. Africa and Central and South America achieve shares of more than 90%. China has the highest generation from both onshore and offshore wind. The deployment of solar CSP is significant in all regions with good resource conditions, *i.e.* Africa, Middle East, India and the United States. By 2050 the United States is the region with the highest electricity generation from CSP. Solar PV develops across all world regions, with the Middle East and the United States having most generation.
Ocean energy increases fourfold in the BLUE hi REN scenario compared to the BLUE Map scenario. More than half of total ocean-based electricity generation is in OECD Europe.

**Technology status and prospects**

Renewable energy technologies have a long history. Hydro and traditional geothermal and biomass technologies have been around for many decades and were first built in locations with abundant resources. In recent years, wind and solar technologies (both PV and CSP) have developed rapidly. These technologies are still subject to significant learning which, together with economies of scale, should contribute to significant cost reductions in the future. In recent years, their deployment has been subject to a range of incentive schemes that have helped to speed up learning. Ocean and enhanced geothermal technologies are in the demonstration stage and need further RD&D.

To achieve the BLUE Map scenario objectives, significant action is needed in renewable technology innovation and RD&D, policy frameworks, and infrastructure and energy system integration. Government budgets for renewable energy RD&D have increased moderately over the last 20 years in those OECD countries for which data are available, but are still lower than they were 30 years ago. To achieve the deployment of renewables envisaged under the BLUE Map scenario, RD&D priorities will need to be clearly set and additional long-term funds guaranteed. International collaboration will be crucial to maximise impacts, increase the efficiency of national programmes and avoid wasteful duplication.

Policy frameworks also need to be improved. Achieving a stable carbon price through a global carbon market will be an important element in fostering the deployment of renewable technologies in the longer term. But it is likely to take some time to achieve. In the meantime, national policies supporting renewables will be crucial. In 2008 and 2009, the governments of many countries committed additional funds for renewable energy through economic recovery and stimulus packages. These short-term measures need also to be coupled with more long-term oriented policy action to tackle non-economic barriers to the wider deployment of renewables. As technologies mature and renewable deployment increases, so incentive policies will need to evolve and become more market-oriented.

With the rapid deployment of additional renewables, system integration issues will become more important. The output from variable renewable energy such as wind, solar PV, run-of-river hydropower, wave and tidal power, requires greater power system flexibility than is the case with most conventional sources in order rapidly to supplement periods of low output and to manage production peaks. Modest shares of variable renewables have been shown to have little or no impact on power system operation. But larger shares will present new challenges. A number of options and technologies including smart grids and additional electricity storage capacity will need to be developed to increase the flexibility of electricity systems and allow the integration of larger proportions of variable renewables (see Chapter 4).
Hydropower

Hydropower is the largest source of renewable electricity today. It has a particular advantage in that it can adjust quickly and flexibly to sudden load changes. Hydro reservoirs serve as a means of storage in power systems and therefore play an important role in helping to cover peak loads and sudden losses of power from other sources, for example variable technologies such as wind. Hydro is also cheap to operate and maintain and produces no waste or CO₂ emissions. In some circumstances it can lead to methane emissions which need to be monitored and managed. Initial costs are relatively high but hydro plants have a very long lifespan. Existing hydropower plants are therefore often the cheapest means of generating electricity because once the initial construction costs are amortised, the electricity is produced with very little cost.

Hydropower is divided into large and small systems with the cut-off point between 10 MW and 50 MW, depending on the country. Small systems are usually run-of-the-river designs. These are normally environmentally benign as they do not alter river flows. They often provide an alternative to diesel generators in rural areas. Small hydro still has a huge potential for deployment especially in Africa, Asia and Central and South America. Large hydropower plants can be more controversial. They often alter water availability downstream, can cause the relocation of populations, and have a significant impact on existing ecosystems. The further development of large hydropower systems may be constrained by public concerns and by the availability of less environmentally damaging alternatives.

Hydropower is also susceptible to constraints resulting from climate change. Rainfall patterns are changing in some cases with consequences for electricity production from hydro sources. Efforts to improve hydro technology focus primarily on improving efficiency and sustainability. Refurbishing existing plants with modern turbines often offers a relatively cheap way to increase hydro capacities.

Bioenergy

Bioenergy is a renewable resource that can be converted to all final energy uses, i.e. to produce electricity, heat, or fuels for the transport sector. The term bioenergy encompasses a number of feedstocks together with several technologies that can convert these feedstocks into electricity. Bioenergy feedstocks include solid biomass, wood wastes, agricultural wastes, wastes from the paper and pulp industry, energy crops, biogases, landfill gases, biodegradable components of municipal solid waste, and liquid biofuels. Typical conversion technologies for electricity purposes are combustion, co-firing, gasification, and anaerobic digestion.

Steam turbines and steam piston engines have been proven with biomass feedstocks. They can be operated in electricity mode or in CHP mode. For smaller plants of 5 MW to 10 MW capacity, electricity efficiencies are around 25%. Larger plants of at least 50 MW capacity can achieve electricity efficiencies of more than 30% in CHP mode and about 40% in electricity-only mode. For small applications there are several other options, including the organic rankine cycle (ORC) which uses oil as the working fluid instead of water. Another option, although not yet commercially viable, is to use an externally fired Stirling engine.
Biomass is an interesting option for electricity production in parts of the world where supplies of residues from agriculture or the forest products industry are abundant. But the rapid development of second-generation liquid biofuel technologies to produce transport fuels may create competition for feedstocks between the two uses.

The co-firing of biomass with coal is becoming increasingly popular because it offers CO₂ and local pollutant emission benefits without requiring the modification of existing coal-fired plants and with only a small reduction in plant efficiency. Co-firing can also add economic value to agricultural or forestry residues that would otherwise often be disposed of through burning. Developing countries can use co-firing as a low-cost option to reduce their emissions.

Biomass, like coal, can be gasified. The resulting gas can then run an engine, steam or gas turbine to produce electricity, heat or steam. This technology is used, for example, with the waste from agriculture and the paper and pulp industry.

Anaerobic digestion is another way to convert organic wastes into a biogas, primarily methane. The gas can then be used to run an engine to produce electricity. This technology is particularly valuable in some developing countries for small-scale rural electrification.

Biomass technology improvement efforts are primarily focused on the improvement of the reliability, economic viability and efficiency of gasification systems. Other objectives include improving efficiencies, increasing yields for feedstocks, and the optimisation of production and logistics chains.

Solar photovoltaic

Photovoltaic (PV) cells are semiconductor devices that convert solar energy into direct-current electricity. Photovoltaic cells are interconnected to form PV modules with a power capacity of up to several hundred watts. Photovoltaic modules are then combined to form PV systems. Photovoltaic systems can be used for on-grid and off-grid applications. They are highly modular, i.e. modules can be linked together to provide power in a range of from a few watts to several megawatts.

Commercial PV technologies can be divided into two groups: wafer-based crystalline silicon and thin films. A separate range of technologies, including concentrating PV or organic solar cells, is emerging with significant potential for performance increases and cost reductions. The technologies differ in their costs as well as their performance. Thin films currently represent a low-cost, lower-efficiency technology, while concentrating PV offers high efficiency but at a high cost. The biggest share of the market is currently taken by crystalline silicon technologies that have mid-range efficiencies and costs.

Photovoltaic technologies can be applied in a very diverse range of applications, including in residential systems, commercial systems, utility-scale systems and off-grid applications of varying sizes. Different PV technologies may suit different uses. Off-grid applications offer the potential for the electrification of remote areas.
Photovoltaic module costs have decreased in the past with a learning rate of between 15% and 22%. System prices fell by 40% in 2008/09 (IEA, 2010a). The installed worldwide capacity of PV has been growing on average by 40% per year for almost 10 years, and with incentive schemes in several countries encouraging PV deployment, this trend is expected to continue. This will help bring costs down further and should allow PV to achieve grid parity with electricity retail prices in many countries over the next decade. Deployment incentives need to be balanced with RD&D supporting measures, in order to allow for optimal technology progress, cost reduction and the ramp-up of industrial manufacturing.

The various photovoltaic technologies are at differing levels of maturity. All of them have a significant potential for improvement. Increased and sustained RD&D efforts are needed over the long term in order to accelerate cost reductions and the transfer to industry of the current mainstream technologies, to develop and improve medium-term cell and system technologies, and to design and bring novel concepts to industrialisation.

Other priorities for PV include developing technical solutions to enable the integration of PV systems in electricity grids. RD&D is also needed on the use of PV as a building material and architectural element. This will help respond to a range of technical, functional and aesthetic requirements and help reduce costs.

### Concentrating solar power

Concentrating solar power (CSP) systems use concentrated solar radiation as a high-temperature energy source to produce electrical power and heat and to drive chemical reactions. A CSP plant comprises a field of solar collectors, receivers, and a power block where the heat collected in the solar field is transformed to run a turbine and produce electricity. Wet or dry cooling systems can be used. In some cases CSP plant incorporates heat storage devices or is backed up by power systems using a combustible fuel.

Concentrating solar power requires clear skies and strong sunlight because only direct insolation, i.e. parallel sunrays, can be transformed into useful energy. In practice this means that CSP will be most effective in areas such as North Africa, the Middle East, southern Africa, western India, the south western United States, Mexico, central Asian countries, Australia and some parts of South America.

Currently there are four major CSP technologies. Troughs and Fresnel reflectors track the sun along one axis, while towers and dishes track the sun along two axes.

Troughs are the most mature technology. They concentrate solar rays on long heat collector pipes. Synthetic oils are used as a heat transfer fluid that is circulated through the pipes then passed through heat exchangers where water is preheated, then evaporated, then superheated. The superheated steam runs a turbine, which drives an electric generator. Some recent plants have several hours of storage capacity, and most existing plants use some combustible fuel as a backup.

---

6. The learning rate describes how costs reduce with increased deployment of a technology. It is defined as the percentage cost reduction associated with a doubling of cumulative installed capacity.
Linear Fresnel reflectors (LFR) approximate to a parabolic shape with long ground-level rows of flat or slightly curved mirrors reflecting the solar rays onto a downward-facing linear fixed receiver. Saturated steam is directly generated in the receiver tubes.

Towers, also called central receiver systems, concentrate the sun rays on top of a fixed tower. This allows for higher temperatures and efficiencies than linear systems. Towers can generate saturated or superheated steam directly, or use molten salts, air or other media as heat transfer fluids. Molten salts can also be used to store heat for several hours.

Parabolic dishes concentrate the sunrays on a focal point that moves together with the dish tracking the sun. Dishes have an independent engine/generator at the focus point, usually an external combustion Stirling engine, although Brayton micro-turbines could be used as well. These systems offer the highest conversion performance at capacities of tens of kilowatts or less. Mass production may allow them to compete with larger systems that benefit from economies of scale. But the size of solar dishes, their absence of water needs, and their low compatibility with thermal storage and hybridisation, put them in competition with PV modules as much as with other solar thermal technologies.

Concentrating solar power technologies are still developing. Improvements can be expected in all aspects of CSP plants (mirrors, receivers, working fluids, power blocks, and cooling systems) as well as in automated control and maintenance systems (IEA, 2010b). Special attention needs to be paid to storage designs. With storage available for even only a few hours, CSP plants can offer a very interesting option in countries with good direct insolation for covering evening peak loads. With larger storage, CSP could become an option for firm baseload power.

Wind

Wind is the second-largest contributor to renewable electricity today after hydro. The average newly installed grid-connected turbine has a rated capacity of about 1.6 MW. It extracts energy from the wind by means of a horizontal rotor, upwind of the tower, with blades that can be pitched to control the rotational speed of a shaft linked via a gearbox to a generator, all housed in the nacelle on top of the tower. Today’s offshore wind turbines are essentially large land turbines with, for example, enhanced corrosion protection. However, an offshore wind industry is developing, particularly in Europe, and a specific offshore supply chain is emerging.

Wind turbines generate electricity from wind speeds ranging from around 15 km/h to 90 km/h. Wind power output varies as the wind rises and falls. Even when available for operation, wind plants will not operate at full power all of the time. This variability will become increasingly significant as wind generation rises above around 10% of grid totals, at which level management of the power system may need to be improved to maintain reliability. Substantially higher wind penetrations will require additional system flexibility through some combination of quickly dispatchable generation, demand-side response, interconnection, and/or storage.
Technology improvements in the past have focused primarily on the scaling-up of turbines, an important driver for cost reductions. The largest turbines now have a rated capacity of 7 MW and even larger ones are under development. Materials with higher strength to mass ratios are important to enable the continued cost-effective development of very large turbines. Technological innovation should continue to improve energy capture by the rotor, particularly at low speeds, in complex terrains and under turbulent conditions, to increase the time offshore plants are available for operation, to reduce O&M requirements, to extend turbine lifespans, and to reduce the cost of components. In addition, RD&D needs to improve transmission technology and design and to develop enabling technologies including smart grids that will enhance the overall flexibility of power systems and allow for their operation with large shares of wind power.

Geothermal

Geothermal energy is heat extracted from the earth. It can be used for several energy purposes. Electricity generation from geothermal energy mainly uses high-temperature heat, for example in tectonically active regions near plate boundaries or rift zones, and mantle plumes or hot spots. These include the countries around the “Ring of Fire” (Indonesia, the Philippines, Japan, New Zealand, Central America, and the western coast of the United States) and the rift zones of Iceland and East Africa. The penetration of large-scale geothermal power installations is currently relatively limited.

Geothermal energy is independent of season, and immune to weather effects and climate change impacts. It is therefore a reliable source of baseload electricity. Geothermal power can be produced in steam plants, binary cycle plants or by enhanced geothermal systems. Conventional steam plants use steam separated from hot geothermal fluid to drive turbine generators to produce electricity. Binary plants often use lower temperature (<180°C) fluid in a heat exchanger to boil a secondary fluid to create a gas that drives the turbine generators. The separated water and condensate are typically reinjected back into the ground, although the separated water can first be used in binary plants to generate more electricity. Enhanced geothermal systems circulate water from the surface down wells into deep enhanced permeable volumes of hot rock in a closed loop. The water heats up, is brought up to the surface through other wells, and then is sent to binary plants to produce electricity.

Recent improvements in technology, especially for binary plants, have resulted in electricity production from fluids with temperatures as low as 73°C. This theoretically allows electricity production using enhanced geothermal systems almost anywhere in the world. But environmental concerns, including those relating to induced seismicity, land subsidence and water use, need to be resolved if such enhanced geothermal systems are to spread more widely.

Further technology advances are expected in terms of better methods for more accurate estimates of resource potential prior to drilling, better drilling methods and equipment, more reliable high temperature and pressure downhole pumps and logging tools, better methods for creating deep hot reservoirs, and better control or mitigation of induced seismicity.
Ocean

Ocean energy technologies are in the early stages of development compared with other renewable technologies. There are only a few tidal barrage installations operating in the world on a commercial basis. Ocean energy technologies can be divided into the following categories: tidal rise and fall, waves, tidal currents, ocean currents, thermal gradients and salinity gradients.

The technology required to convert the energy in the rise and fall of tides into electricity is similar to that used in hydropower plants. Electricity is generated in turbines by water flowing in and out of a dam or a barrage built across a tidal bay or estuary, ideally where there is a height difference of at least five metres between high and low tides. Tidal barrages can face considerable environmental challenges because they are potentially intrusive to the area surrounding the catch basins.

The kinetic energy associated with tidal and other marine currents can be harnessed using devices which generate energy from the flow of water. Technologies for extracting energy from marine currents include horizontal and vertical axis turbines or oscillating foils. These technologies are at, or near, full-scale development and undergoing sea trials.

There is a wide variety of methods for extracting energy associated with ocean waves, including oscillating water column systems, absorber systems (point, multi-point and linear) or overtopping devices. These devices and systems use different techniques for “capturing” the wave energy and employ a variety of different methods for converting it to electricity.

The temperature difference between surface seawater (at 20°C to 25°C) and deep water (at 4°C to 5°C) can be harnessed using ocean thermal energy conversion (OTEC) processes. Prototype technologies and test facilities were constructed in the 1970s but R&D was later abandoned. There has been a resurgence of interest recently in OTEC, with new R&D being undertaken in several countries.

Where fresh water mixes with salt water, the energy associated with the resultant salinity gradient can be harnessed, using a pressure retarded reverse osmosis process and associated conversion technologies. The world’s first prototype plant was commissioned in October 2009.

Ocean energy technologies still need to overcome some technical barriers. An issue specific to these technologies is that pilot projects need to be relatively large scale in order to withstand offshore conditions. Such projects are costly and at the same time carry high risks. They therefore need government support. After successful pilot projects, the confidence of investors grows and commercial financing becomes easier.

Non-financial barriers include the need for resource assessment, setting performance assessment guidelines and standards, and developing energy production forecasting. Environmental effects are expected to be low but are still uncertain. Electrical connection may present similar challenges as for offshore wind.
Recent developments in renewable electricity generation

Despite the economic crisis, significant amounts of new renewable energy were deployed in 2008 and 2009, especially wind and solar technologies. Investment in renewable power reached an all-time high in 2008, and remained at a similar level in 2009. Investment levels were mainly boosted by rapid increases in capacity in Asia, and particularly in China. Stimulus packages played only a minor role in maintaining levels of investment. It is estimated that only about 9% of the total funds available were spent in the year 2009.

Renewable power installations represented 61% of all new power generation capacity in the European Union in 2009, the second successive year that renewable investment exceeded 50% of the total. More wind capacity was installed in 2009 than any other electricity generating technology, comprising 39% of all new EU installations. Although smaller in absolute terms, solar PV technology also expanded very rapidly in Europe during 2008 and 2009. Germany, Spain and Italy are the main PV markets. Europe is also showing renewed interest in CSP, mostly in Spain. Several projects started operation in 2008 and 2009 and many others are under construction.

In 2009 in the United States, almost 10 GW of wind capacity was installed. The solar market also seems to be taking off in the United States with several CSP projects under construction and important developments in the PV market during 2009. The United States is likely to become the leading PV market outside Europe in 2010, outperforming Japan. High gas prices in 2007 and 2008 and the American Recovery and Reinvestment Act (ARRA) helped to drive these developments. The expenditure of ARRA funds will be spread out over several years and therefore their impact should continue for this period. But renewables in the United States are likely to face competition from cheap unconventional gas.

Renewable power is growing not only in OECD countries. Emerging economies are becoming increasingly important players. China was the world’s largest wind market in 2009. Solar programmes in China and India have stimulated a significant pipeline of PV projects. The development of non-OECD markets is mostly target-driven but some emerging economies, such as South Africa, are starting to introduce incentive schemes to support the development of renewable energy.

Costs

The costs of renewables vary between technologies. They are often highly site-specific. Costs are influenced by natural resource (e.g. wind speeds, global or direct normal insolation, the availability of biomass), the size of the plant, distance to the grid, commodity prices (e.g. steel, silicon) and many other factors. With RD&D, technological learning, mass production and economies of scale at both manufacturer and plant levels, the cost of renewables is expected to fall in the future.

Investment and O&M costs in the BLUE Map scenario are summarised in Table 3.4. Bioenergy electricity generation technologies vary in size as well as in technologies and the feedstocks used. Costs are dependent on all these factors. Bioenergy is the only renewable power source that is subject to fuel costs. Geothermal costs depend heavily on the costs of exploration and well-drilling but also on the local resource system and reservoir. Exploration and drilling costs can account for as much as
50% of the total cost of a geothermal project. Solar PV costs consist of the costs of modules, which are roughly 60% of the total cost with mounting structures, and inverters and cabling, which account for the rest. Costs are dependent on the price of commodities such as silicon.

**Table 3.4**  
Cost assumptions for renewable electricity generation

<table>
<thead>
<tr>
<th>Technology</th>
<th>Investment cost USD/kW</th>
<th>O&amp;M cost USD/kW/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2050</td>
</tr>
<tr>
<td>Biomass steam turbine</td>
<td>2 500</td>
<td>1 950</td>
</tr>
<tr>
<td>Geothermal</td>
<td>2 400-5 500</td>
<td>2 150-3 600</td>
</tr>
<tr>
<td>Large hydro</td>
<td>2 000</td>
<td>2 000</td>
</tr>
<tr>
<td>Small hydro</td>
<td>3 000</td>
<td>3 000</td>
</tr>
<tr>
<td>Solar PV</td>
<td>3 500-5 600</td>
<td>1 000-1 600</td>
</tr>
<tr>
<td>Solar CSP</td>
<td>4 500-7 000</td>
<td>1 950-3 000</td>
</tr>
<tr>
<td>Ocean</td>
<td>3 000-5 000</td>
<td>2 000-2 450</td>
</tr>
<tr>
<td>Wind onshore</td>
<td>1 450-2 200</td>
<td>1 200-1 600</td>
</tr>
<tr>
<td>Wind offshore</td>
<td>3 000-3 700</td>
<td>2 100-2 600</td>
</tr>
</tbody>
</table>

*Note: The upper bound of the investment cost range represents the costs for enhanced geothermal systems. Estimates of costs and efficiencies in 2050 are inevitably subject to great uncertainty. These data refer to plants in the United States. Cost data in other world regions are calculated by multiplying these costs by region-specific multipliers for the investment and O&M costs. The lower investment costs in many of the non-OECD regions converge to United States levels by 2050.*

Solar CSP investment costs differ considerably between plants with and without storage. But in terms of the cost of the energy they produce, they are broadly comparable because the presence of storage increases the capacity factor of plants. For ocean systems, the numbers in the table reflect the costs of existing tidal barrage systems. The costs of all other technologies are still very high.

For onshore wind, the turbine cost typically represents about 75% of the total cost, with infrastructure, grid connection and foundations accounting for the rest. Costs are linked to the price of commodities such as steel and copper. The costs of offshore turbines take account of additional factors such as the water depth and distance to the coast. In terms of the cost of the energy produced, the additional costs of offshore wind turbines are partly balanced by increased electricity production due to higher wind speeds for longer periods.

**Nuclear power**

**Overview**

Nuclear power has the capacity to provide large-scale electricity production with very low net CO₂ emissions over the plant lifecycle. The technology is already proven, although new designs hold out the prospect of better levels of performance.
and reliability, as well as enhanced safety systems. Nuclear power is already in use in 30 countries and provides around 14% of global electricity supply. The share of nuclear energy in countries with operating reactors ranges from less than 2% to more than 75%. Nuclear power has the potential to play a very significant role in the decarbonisation of electricity generation in many countries.

Nuclear capacity grew rapidly in the 1970s and 1980s as countries sought to reduce dependence on fossil fuels (Figure 3.15). In most countries, growth stagnated in the 1990s. Reasons for this included increased concerns about safety, higher than expected costs and poor performance in some cases, and low fossil fuel prices.

In the Baseline scenario, installed nuclear capacity increases to 610 GW in 2050, compared to 374 GW at the beginning of 2010. In the BLUE Map scenario, nuclear capacity rises further to 1 200 GW, a level that is constrained by the assumptions in the scenario, in 2050. This nuclear capacity provides around 9 600 TWh annually by that date, or around 24% of the electricity generated worldwide and constitutes the single largest source of electricity. In the BLUE hi NUC scenario, the installed nuclear capacity reaches significantly higher levels of 2 000 GW in 2050.

**Figure 3.15**  World nuclear generating capacity

<table>
<thead>
<tr>
<th>Year</th>
<th>OECD North America</th>
<th>OECD Europe</th>
<th>OECD Pacific</th>
<th>Non-OECD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>50</td>
<td>100</td>
<td>150</td>
<td>300</td>
</tr>
<tr>
<td>1975</td>
<td>100</td>
<td>200</td>
<td>300</td>
<td>600</td>
</tr>
<tr>
<td>1980</td>
<td>200</td>
<td>300</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>1985</td>
<td>300</td>
<td>400</td>
<td>700</td>
<td>2000</td>
</tr>
<tr>
<td>1990</td>
<td>400</td>
<td>500</td>
<td>900</td>
<td>3000</td>
</tr>
<tr>
<td>1995</td>
<td>500</td>
<td>600</td>
<td>1100</td>
<td>4000</td>
</tr>
<tr>
<td>2000</td>
<td>600</td>
<td>700</td>
<td>1300</td>
<td>5000</td>
</tr>
<tr>
<td>2005</td>
<td>700</td>
<td>800</td>
<td>1500</td>
<td>6000</td>
</tr>
<tr>
<td>2010</td>
<td>800</td>
<td>900</td>
<td>1700</td>
<td>7000</td>
</tr>
<tr>
<td>2015</td>
<td>900</td>
<td>1000</td>
<td>1900</td>
<td>8000</td>
</tr>
<tr>
<td>2020</td>
<td>1000</td>
<td>1100</td>
<td>2100</td>
<td>9000</td>
</tr>
<tr>
<td>2025</td>
<td>1100</td>
<td>1200</td>
<td>2300</td>
<td>10000</td>
</tr>
<tr>
<td>2030</td>
<td>1200</td>
<td>1300</td>
<td>2500</td>
<td>11000</td>
</tr>
<tr>
<td>2035</td>
<td>1300</td>
<td>1400</td>
<td>2700</td>
<td>12000</td>
</tr>
<tr>
<td>2040</td>
<td>1400</td>
<td>1500</td>
<td>2900</td>
<td>13000</td>
</tr>
<tr>
<td>2045</td>
<td>1500</td>
<td>1600</td>
<td>3100</td>
<td>14000</td>
</tr>
<tr>
<td>2050</td>
<td>1600</td>
<td>1700</td>
<td>3300</td>
<td>15000</td>
</tr>
</tbody>
</table>

**Key point**

Nuclear generating capacity grew rapidly in the three decades from its first commercial deployment in the 1960s, but the rate of growth has since slowed.

Although the installation of 1 200 GW of nuclear capacity by 2050 would be an ambitious goal, it appears achievable from a technical and industrial perspective. Assuming that by 2050 all reactors in operation today will have been decommissioned, some 30 units of 1 GW each would need to be connected to the grid on average each year between 2010 and 2050. Similar or higher rates of construction were achieved in the 1980s, even though a smaller number of countries were implementing nuclear programmes and industrial capabilities were less developed at that time.
In practice, the required construction rate to achieve the BLUE Map scenario is likely to be lower. Many existing units are licensed for up to 60 years of operation and plant-life extensions are being approved in many countries. So some existing plants are likely to remain in operation in 2050. In addition, many current reactor designs have a capacity larger than 1 GW, typically in the range 1.2 GW to 1.7 GW, and these are likely to be chosen in countries where electricity demand is high enough and grids are adapted to large units. Taking these factors into account, an average of about 23 nuclear units per year would need to be constructed over a 40-year period to achieve the levels of nuclear capacity in the BLUE Map scenario, with the rate of construction gradually increasing over the period.

As a result of higher nuclear power production in the BLUE Map scenario, uranium consumption will amount to about 5.6 million tonnes between 2010 and 2050, 70% higher than in the Baseline scenario. This is roughly equivalent to current known conventional uranium resources of about 5.5 million tonnes, although so-called unconventional resources in phosphate rocks could amount to a further 22 million tonnes (NEA, 2008). Increased uranium demand can be expected to result in greater exploration efforts and the discovery of additional conventional resources to replace exploited resources. In the longer term, the commercial deployment of advanced nuclear reactor and fuel cycle systems could permit much greater amounts of energy to be obtained from each tonne of uranium. It seems probable that the increase in nuclear capacity in the BLUE Map scenario by 2050 could be achieved without the large-scale deployment of advanced nuclear systems, although achieving the capacity growth seen in the BLUE hi NUC scenario would most likely require the earlier introduction of such systems.

**Technology status and prospects**

The low level of orders for nuclear power plants since the 1980s has resulted in the contraction of the nuclear industry in most parts of the world, and in a series of industry consolidations over the last 15 years. The latest designs available from each of the main suppliers offer a comparable level of technology, sometimes known collectively as Generation III or III+. In developing Generation III reactors, the aim has been to design out many of the issues that were encountered in the construction and operation of the existing Generation II plants, and to offer better levels of performance and reliability as well as enhanced safety systems. Design simplification is an important theme, with the aim of reducing construction times. The intention is to offer, as far as possible, a standardised design worldwide to reduce the risk of construction delays caused by design changes. The plants are designed from the outset to operate for up to 60 years at high capacity factors.

Existing designs being built today are highly developed, and evolutionary improvements can be expected to continue over the coming decades. Significant RD&D efforts in the field of advanced nuclear systems are also continuing in several countries, to prepare the next generation of nuclear systems which will compete with alternatives mainly in the second half of the century.

---

7. This calculation assumes no recycling.
The main challenges facing accelerated deployment of nuclear energy are policy issues that need to be addressed in a timely manner in order to enable the growth of nuclear energy’s contribution to the world energy supply mix. Political support and public acceptance are key to the implementation of nuclear energy programmes. A clear and stable definition of the role of nuclear energy in national energy policy is a prerequisite for investors to embark on nuclear projects and for the nuclear industry to maintain and develop capabilities and competitiveness.

Industrial capabilities and human resources need to be adapted to higher demand for the construction and operation of an increasingly large fleet of nuclear power plants. Fuel cycle capacities, including for uranium production, also need to be increased. Such increased capacities will take some years to implement.

The management and disposal of radioactive wastes is an essential component of all nuclear programmes. Progress needs to be made towards building and operating facilities for the disposal of high-level wastes. Although technological solutions are available, it is often difficult to gain political and public acceptance for these.

The international system of safeguards on nuclear technology and materials, designed to avoid its misuse for non-peaceful purposes, must be maintained and strengthened. Ensuring that countries relying on nuclear power have access to reliable supplies of nuclear fuel while avoiding the spread of sensitive technologies will be a challenge for the international community.

Box 3.4  Recent developments in nuclear power

At the end of 2009, 56 new power reactors were under construction in 14 countries. Of these, China had the largest programme, with 20 units under construction. Russia also had several large units under construction. Among OECD countries, Korea had the largest expansion under way, while Finland, France, Japan and the Slovak Republic were each building one or two new units. In the United States, a long-stalled nuclear project has been reactivated. In total, these new units can be expected to add around 50 GW of new capacity to the existing capacity of 374 GW. A few gigawatts of older capacity are expected to close over the next few years. The process of planning, licensing and building new nuclear power plants takes typically at least seven to ten years. So most of the nuclear capacity that is likely to be in operation by 2020 will already be in operation or in the planning and licensing processes.

Some countries with active nuclear construction are expected to continue their nuclear expansion with further construction starts in the next few years. In particular, major expansion of nuclear capacity is planned in China, India and Russia. Several other countries with existing nuclear plants but where no new construction has been launched in recent years are also actively considering new nuclear capacity, with final decisions expected to be taken in the next few years. These include Canada, the Czech Republic, the United Kingdom and the United States.
Future nuclear technologies

Nearly all nuclear units in operation or under construction are based on light or heavy water-cooled reactors. These proven technologies and designs will remain dominant up to 2050, although a few advanced systems such as sodium fast reactors and high-temperature gas reactors are likely to be built and operated before 2050. In the second half of the century, advanced nuclear systems are expected to be available on the market as the result of RD&D already being pursued in many countries and within international endeavours. Advanced nuclear energy systems, including so-called Generation IV systems, aim at an improved response to evolving technical, economic, environmental and social requirements.

Box 3.5  
Nuclear fusion

Fusion is a nuclear process that releases energy by combining light elements – it is essentially the direct opposite of fission. In principle, fusion holds the promise of a long-term, sustainable, economic and safe energy source for electricity generation, with relatively inexpensive fuel. The amount of radioactive waste produced from fusion devices is hundreds of times less than that of a fission reactor, the fusion process produces no long-lived radioactive waste and it is impossible for any fusion reactor to undergo a large-scale runaway chain reaction.

Over the past two decades, the operation of a series of experimental devices has enabled considerable advances in this technology. However, the plasma created in current prototype devices is not significant enough to achieve sustained power. The International Thermonuclear Experimental Reactor (ITER) is a new, significantly larger, prototype fusion device designed to demonstrate the scientific and technological feasibility of fusion energy on a large scale. Seven partners are involved in the ITER project: the European Union, China, India, Japan, Korea, Russia and the United States. ITER is planned to be the bridge towards a first demonstration plant of large-scale production of electrical power.

If work with ITER goes as planned, then a first demonstration plant will start operations in the early 2030s, with fusion power into the grid expected in the 2040s. As fusion is not likely to be deployed for commercial electricity production until at least the second half of this century, it is not considered in the ETP 2010 scenarios.

Costs

Three main factors contribute to the direct costs of nuclear power: construction costs, O&M and fuel costs, and back-end waste management and decommissioning costs. Four variables primarily control construction costs: the length and complexity of the pre-construction period, capital costs (excluding interest), construction time, and the cost of capital (interest rates).

The pre-construction period is the time taken to secure permits and planning approvals. Historically, this process has been lengthy in many countries. Governments can reduce the length and, therefore, the cost of the pre-construction period through improvements in planning and licensing regimes.
Reliable capital cost data are difficult to obtain. Most nuclear power cost studies base capital cost estimates on recent new-build experience or on vendor estimates. However, there is no internationally agreed definition of capital cost, and opinions vary on the subject. Vendors have a commercial interest in minimising the apparent cost of new plants, and turnkey prices are inevitably commercially sensitive. The assumptions on capital costs used in the scenarios are derived from data in IEA/NEA 2010 (Table 3.5). Long construction times increase interest costs. Since the 1980s, average worldwide construction times have steadily increased. Recent experience from Asia, however, where average construction times of 62 months are being achieved, has shown a marked reduction in time from construction start to commercial operation. The cost of capital, which depends on aspects of the financing scheme such as the ratio between debt and equity, the interest rate of the debt, and the internal rate of return required by shareholders, has a major impact on construction costs.

Table 3.5  | Cost assumptions for nuclear electricity generation technologies

<table>
<thead>
<tr>
<th></th>
<th>Investment cost</th>
<th>O&amp;M cost</th>
<th>Net efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>USD/kW</td>
<td>USD/kW/yr</td>
<td>%</td>
</tr>
<tr>
<td>2010</td>
<td>3 000 – 3 700</td>
<td>90 – 111</td>
<td>36</td>
</tr>
<tr>
<td>2050</td>
<td>2 700 – 3 300</td>
<td>81 – 99</td>
<td>37</td>
</tr>
</tbody>
</table>

Note: Estimates of costs and efficiencies in 2050 are inevitably subject to great uncertainty. These data refer to plants in the United States. Cost data in other world regions are calculated by multiplying these costs by region-specific multipliers for the investment and O&M costs. The lower investment costs in many of the non-OECD regions converge to United States levels by 2050.

Operation and maintenance costs are incurred in the safe running and upkeep of a power station during its lifetime. They generally include the costs of safety inspections and safeguards as well as labour, insurance, and security costs, corporate overheads, and the costs of maintaining a level of spare generation capacity. Extensive data are available on these costs. These show a wide degree of variability that reflects, for example, differences in labour costs, plant sizes and age distributions in different countries, as well as differences resulting from government versus private security. Nuclear O&M costs are particularly influenced by changing regulatory requirements.

Waste management and decommissioning liabilities are regarded by some stakeholders as major impediments to nuclear power generation. For the first-generation reactors, many of which were effectively prototypes with little if any provision for back-end costs, these costs are potentially significant and subject to considerable uncertainty. The back-end costs for future nuclear plants should be predictable, provided that radioactive waste disposal facilities are available and that regulatory requirements are stable. In the scenario analysis, fuel cycle costs including fuel production, disposal and storage are assumed to be around USD 9/MWh (IEA/NEA, 2010). Decommissioning and the majority of associated waste management costs are not incurred until the end of the reactor’s life, allowing the operator to accumulate funds from revenues. As a result, electricity generating costs are not particularly sensitive to back-end costs.
Key findings

- Demand for electricity will continue to rise between now and 2050 in both the Baseline and BLUE Map scenarios. Together with changing demand and generation profiles, this will require changes in the design, operation and deployment of electricity networks.

- Regional characteristics such as increases in electricity demand, regulatory structures and the maturity of the existing electricity infrastructure will need to be considered in deciding how best to develop electricity networks to meet future needs.

- Smart grids have the potential to address many future electricity network challenges. This would include the ability to increase system flexibility to enable the balancing of variable generation and demand, the better management of peak loads and assisting in the delivery of energy efficiency programmes. But technical work is still required, especially to demonstrate such grids at system scale.

- Combined with smart grids, a range of electricity and thermal storage technologies can contribute to increasing the system flexibility that will be needed as a result of the expected increase in variable generation and demand.

- For developing countries, the deployment of smart grids could bring significant benefits over traditional technologies in the strengthening or expansion of their electricity grids, while addressing specific needs. The potential of smart grids to reduce transmission and distribution losses is especially relevant for these countries, where they can be very high.

- Smart grids can contribute directly and indirectly to $CO_2$ emissions reductions from electricity generation and use. Under the BLUE Map scenario, the global deployment of smart grids is estimated to reduce $CO_2$ emissions by between 0.9 gigatonnes of carbon dioxide (Gt CO$_2$) and 2.2 Gt CO$_2$ annually by 2050. More work is needed to develop quantified methodologies in this area.

- The cost of smart grids has not been examined in detail on a global level. A better understanding of costs will be needed to evaluate technologies, policy and regulatory approaches and the most appropriate market models to support deployment.

- A number of regulatory, policy and market barriers stand in the way of the most effective deployment of smart grids. Significant effort is required to develop well-informed and technically appropriate recommendations for change. Solutions must be developed with input from all electricity system stakeholders to ensure that creative and practical approaches and technologies are deployed.

- Skill constraints in the power industry are predicted to be severe in the near future. This could become a significant barrier to the deployment of needed power system investments. A detailed assessment of the skills required, considering regional situations to best fit human resource availability, must be carried out along with recommendations on how to fulfil these needs.
Introduction

The availability of reliable supplies of electricity has become increasingly essential for daily living for most people in both developed and developing countries. It lights homes and work places, powers computers and enables industrial activity. Most electrical power, regardless of how it is produced or used, is transferred from generation plant to consumers through electricity networks, known as electricity grids or the grid.

To meet the demand for reliable supply, the grid must operate 24 hours a day, 365 days a year, meeting and balancing ever-changing levels of demand and supply. And it must do so in a cost-effective way, often using an ageing infrastructure. The complexity of this operation will be further complicated by steps to increase the use of electricity for both public and private transportation, the bringing on stream of greater amounts of renewable energy and other distributed generation, and increasing demand for electricity in general.

In the developing world and emerging economies, electricity demand is increasing at significant rates in response to economic and social development. Development and growth vary between regions and there continues to be a need to address energy poverty in many areas. Existing electricity systems are insufficiently flexible or robust for today’s needs in many parts of the world, let alone those of the future. Change and investment will be required to enable further development and growth.

The changes projected in electricity generation and demand, both in the Baseline scenario and still more to achieve the ambitions of the BLUE Map scenario in 2050, will require an enormous investment in the electricity grid. Investment choices will have long-term implications. Investment in so-called smart grid technologies will be fundamental to enabling these changes, and will in parallel offer many other additional benefits.

History of the grid

The electricity grid has traditionally been developed, designed and implemented in such a way that electricity flows one-way from large generators to widely distributed loads. This highly structured and centralised approach has drawbacks at three distinct levels in the system:

- **Distribution system operators** have little or no detailed information on the demand from different sectors or nodes on the grid. So, for example, when a residential power outage occurs, the supply utility typically only becomes aware of it when consumers phone to ask what is happening.

- **Transmission system operators** have more intelligence about changes in demand and supply on the network. But this is still insufficient at times to allow utilities to anticipate or receive prior warning of developing problems. This limits the extent to which generators can proactively dispatch grid support or isolate minor problems so as to prevent the sort of large-scale outages that have been seen in the United States, Canada and Italy in recent years.
Many end users are billed according to the amount of electricity they have used over an extended time period. They, therefore, have no access to detailed information on how or when they are using electricity. So they have no means of readily identifying ways of reducing or shifting their electricity use to minimise their demand and costs.

In OECD member countries, as already old grid infrastructure ages, significant investment is required to update and maintain it in order to ensure reliability. Power generation is increasingly becoming dispersed, e.g. in the form of combined heat and power (CHP) systems, in response to efforts to improve fuel usage or to take advantage of changing market structures. There has also been an increase in the amount of variable generation\(^1\) being brought on line.

These changes are all challenging weaknesses in the traditional electricity grid. They need to be met by the implementation of new technology and methodologies for the design, maintenance and operation of electricity distribution systems. These need to be better adapted to modern circumstances, such as the emerging growth in consumers wanting to generate their own electricity with the option to sell any excess generation back to the grid.

Developing countries may have the opportunity to make early technological leaps to the implementation of smart grids, without going through the extensive development of traditional grids. This will enable them to benefit from these new technologies early in the implementation of a more widespread electricity infrastructure.

### Electricity demand

#### Electricity demand by region

Worldwide electricity demand is expected to more than double between 2007 and 2050. In the Baseline scenario, demand increases by 151% and in the BLUE Map scenario it increases by 117%. This increase is not spread equally across regions. Those regions that currently have small electrical demands will see the largest growth between 2007 and 2050 (Table 4.1).

The need for grid maintenance and expansion will be different for those regions with high growth than for those with low growth. The three areas with projected low growth (OECD North America, OECD Europe and OECD Pacific) are areas that have a large legacy infrastructure that is ageing, the replacement of which is constrained by regulatory regimes which set limits on capital expenditure. In areas with greater growth, primarily non-OECD member countries, ageing infrastructure and reliability are also of concern. But these regions will also be committing to new construction, providing an opportunity to deploy modern electricity grid technology and to learn from the experience of other regions. The best way forward in some cases may be to render existing unreliable or inflexible infrastructure redundant.

---

1. Examples of variable electricity generation include wind, solar photovoltaics, tidal and combined heat and power in which generation is dependent on variable external resources such as insolation, local wind speed, tidal flows or heat demand in the case of CHP.
Table 4.1  
Regional electricity demand and future growth

<table>
<thead>
<tr>
<th>Region</th>
<th>2007 electricity demand [TWh]</th>
<th>2050 BLUE Map electricity demand [TWh]</th>
<th>BLUE Map percent growth 2007 to 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>OECD North America</td>
<td>4,664</td>
<td>6,252</td>
<td>34%</td>
</tr>
<tr>
<td>OECD Europe</td>
<td>3,136</td>
<td>4,071</td>
<td>30%</td>
</tr>
<tr>
<td>OECD Pacific</td>
<td>1,681</td>
<td>2,311</td>
<td>37%</td>
</tr>
<tr>
<td>Economies in transition</td>
<td>1,149</td>
<td>2,348</td>
<td>104%</td>
</tr>
<tr>
<td>China</td>
<td>2,856</td>
<td>9,500</td>
<td>233%</td>
</tr>
<tr>
<td>India</td>
<td>567</td>
<td>3,453</td>
<td>500%</td>
</tr>
<tr>
<td>Other Asia</td>
<td>853</td>
<td>2,822</td>
<td>231%</td>
</tr>
<tr>
<td>Africa</td>
<td>521</td>
<td>1,691</td>
<td>225%</td>
</tr>
<tr>
<td>Latin America</td>
<td>808</td>
<td>2,062</td>
<td>155%</td>
</tr>
<tr>
<td>Middle East</td>
<td>594</td>
<td>2,437</td>
<td>310%</td>
</tr>
<tr>
<td>World</td>
<td>16,999</td>
<td>36,948</td>
<td>117%</td>
</tr>
</tbody>
</table>

Note: Electricity demand equals generation minus losses.

China is currently making large investments in electrical infrastructure and technology in response to its past, current and anticipated growth. China’s electricity demand is nearly the same as OECD Europe and its growth rate is much higher. This is expected to result in the highest regional electricity demand by 2050, at 26% of world electricity demand.

Electricity demand by sector

In addition to the increase in absolute electricity demand, electricity is also expected to continue to increase as a percentage of final end-use energy. Electricity represented 17% of total final energy use in 2007. By 2050, this increases in the Baseline scenario to 23% and in the BLUE Map scenario to 28%. In the BLUE Map scenario, electricity demand increases at a slower rate than in the Baseline scenario, and with a different distribution by sector (Figure 4.1).

Figure 4.1  
Global electricity demand by sector

Key point

The share of electricity demand from individual sectors changes in the BLUE Map scenario over time.
In the Baseline scenario, there is a broadly commensurate increase in electricity demand across all sectors. In the BLUE Map scenario, overall electricity consumption reduces by over 12% by 2015 compared to the Baseline scenario. This becomes a 17% reduction by 2030, coupled with changes in the sector shares of overall demand. By 2050, electricity use in the transport sector is 11% of overall electricity demand. This increased use of electricity in the transport sector offsets some of the otherwise much greater reduction of electricity use as compared with the Baseline scenario. The residential and service sectors, despite significant efficiency improvements, will also use more electricity e.g. for space heating with heat pump technology.

It is expected that the demand for electricity from transport will continue to increase beyond 2050. This demonstrates the importance of designing grid solutions in the short term which are capable of responding to the longer-term features of this load and its impact on the grid. The approaches used for grid to vehicle (G2V) charging will have significant impacts on the electrical system. Generating electricity from electric vehicles (EVs) when they are parked could also be used to support the grid in a way that would not significantly impact on driver needs. This is sometimes referred to as vehicle to grid (V2G) generation.

**Demand profiles**

The amount of instantaneous electrical power required on any system fluctuates throughout the day. It also varies over the course of the year between a minimum base load and peak load. This aspect is demonstrated by load duration curves that show the number of hours that a given average hourly load occurs in an electricity system over the course of a year (Figure 4.2).

These data show that the minimum demand on the system in selected countries and regions is less than half of the peak demand. The generation, transmission and distribution infrastructure must be designed in a way that it can work reliably within this entire range. In France, for example, the peak 10% of generating capacity is only required 3% of the time. And about 20% of the total demand over a year is supplied by plants that operate just over 15% of the time. Securing private funding for investment in generation capacity to meet peak demand can be difficult if market structures do not provide revenue security for such high value, low call-off generation.

Baseload considerations are also becoming more important for system management, especially in the light of increases in the regional trading of electricity. For many years, base load was supplied by large fossil or nuclear plants from which output remained virtually constant throughout the year. Recently, fluctuations in electricity supply and demand have required large-scale base load plants to curtail and then increase their generation output. As a result, there is new interest in developing technologies that can enable these plants to provide responsive and flexible generation.3

---

2. Jan Peters from Enexis estimates that in Holland the use of smart approaches in the electrification of transportation will reduce enabling grid infrastructure costs by 60% compared to using non-intelligent approaches. www.mobilesmartgrid.eu/index.php?id=16.
**Figure 4.2**  ▶ Load duration curves for several countries in 2008

![Load duration curves for several countries in 2008](image)

**Note:** PJM is a Regional Transmission Organisation which is part of the Eastern Interconnection Grid in the United States. 
**Source:** Data from ENTSO-E, PJM, Korea.

**Key point**

*Annual electricity demand on the overall systems varies significantly across the year.*

The understanding of sector-specific demand profiles can enable solutions to be developed to reduce overall system peak demand. Residential and service sector demand varies over the course of the day and between seasons (Figure 4.3).

**Figure 4.3**  ▶ Daily average residential electricity demand in a sample of homes in Florida, United States with a high penetration of central air-conditioning load

![Daily average residential electricity demand in a sample of homes](image)

**Source:** Parker (2002).

**Key point**

*Residential electricity demand varies over the course of the day and on a seasonal basis.*
The curves in Figure 4.3 represent a region with large amounts of residential central air-conditioning. It would not be representative of many areas in Europe that have much lower levels of central air-conditioning. This illustrates the importance of identifying sector-specific load profiles in a given region as a basis for determining appropriate ways to improve demand profiles.

The degree to which sector-specific peak demand affects overall electrical systems is dependent on its share of the overall electricity power demand. Industrial sectors, for example, often make up a large percentage of the electricity demand and contractual arrangements are often put in place to curtail their demand in circumstances where the grid needs to reduce peak demand. As sector demand patterns change in future, with increased residential loads and/or the wider electrification of transportation, peaks may become more difficult to manage.

**Electricity generation**

There will be significant changes in the way electricity is generated in the future. In addition to large centralised power plants, distributed generation in the form of both renewable and non-renewable generation is increasing, including plants connected directly to the distribution system and micro-generation at the household level.

Electricity generation aspects of the Baseline and BLUE Map scenarios have been discussed in previous chapters. In examining issues related to the grid, the most significant factor is the extent to which power generation is variable. CHP and variable renewable energy (varRE) technologies such as wind, solar PV, run of river hydro and tidal, present particular challenges to the transmission system (Figure 4.4). Unlike non-variable power generation, where the generation can be contracted and dispatched with high degrees of certainty over long time frames and where the fluctuations can be managed in a controlled manner, varRE generation is difficult for system operators to predict both in terms of the uncertainty of its availability and the short time frame in which the speed and magnitude of any fluctuations can be predicted (Boyle, 2009).

In many electricity systems, merit orders require that all available renewable power is used at all times in order to minimise generation emissions or variable costs. This means the grid operator needs to manage the available non-variable generation to respond to changes in supply from the varRE generation and to meet a constantly changing level of demand, so as to maintain grid stability and reliability of supply.

---

4. Bioenergy, hydropower with water storage, geothermal and concentrating solar power generation with thermal storage would be considered as non-variable forms of renewable energy.
**Figure 4.4**  ▶ Global electricity generation mix

In the Baseline scenario, varRE generation in 2050 makes up 6% of all generation worldwide. Variability up to this level\(^5\) can be readily managed using conventional technology currently employed in electricity systems. In the BLUE Map scenario, the progressive decarbonisation of electricity generation leads to varRE generation making up 19% of all generation. This proportion ranges from 10% to 27% by region by 2050 (Figure 4.5).

**Figure 4.5**  ▶ Regional generation mix in 2050, BLUE Map scenario

By 2050, all regions will have increased amounts of both variable and non-variable renewable generation compared to both 2007 levels and the Baseline scenario levels.

---

\(^5\) Some regional systems are already more variable than this.
Areas with higher amounts of varRE will need grid systems designed to handle their variability. Regions that may intend to move to higher levels of varRE will need to plan for that as they upgrade and develop their grid systems. In some countries and regions, other forms of variable generation such as CHP will also need to be taken into account. In CHP plants, operation is typically dictated by the demand for heat from the system rather than by the demand for power. In the absence of some form of thermal storage to enable constant generation, CHP generation is variable rather than non-variable.

**Power system flexibility**

A flexible power system can both rapidly supplement periods of low variable generation to meet demand as required, and manage large surpluses when demand is low. A flexible system is one which is able to transport, store, trade and consume electricity to maintain reliable supply in the face of rapid changes and potentially very large imbalances in supply and demand.

Power systems worldwide vary enormously in terms of scale, interconnection, generation, storage, transmission and distribution, demand behaviour, and market rules. The most appropriate way to handle large-scale varRE shares will depend on the specific characteristics of the overall system into which the varRE is being supplied. Power systems can be adapted in a number of ways to provide more flexibility to balance variable generation including:

- **Increasing the size of balancing areas** – to enable a geographically larger area to rely on a smaller proportion of reserve generation capacity to maintain system reliability, to enable imbalances to be resolved where they cost least, and to take advantage of the smoother average generation that is likely to result from a large geographic spread of varRE.

- **Demand shaping through demand-side management** – using prices to move some demand from peak to off-peak periods.

- **Improving output forecasting and intra-hour RE dispatch** – to allow more efficient scheduling of flexible reserves.

- **Increasing control of transmission and distribution assets** – to increase transmission capacity and reduce congestion during key periods and over critical line lengths.

Once all the options for optimising the use of existing flexibility resources of a system have been exhausted, still larger amounts of varRE generation will need to be balanced by increased capacity of these resources. Such measures may include additional flexible power plant capacity; additional storage capacity, e.g. through pumped hydro or new storage sources such as EVs; the reinforcement and expansion of transmission and distribution networks; and interconnection between adjacent grid areas.

**Electricity network losses**

In the electricity system, more electricity is produced than is actually consumed by end users. The balance is lost primarily through direct use in generation plants,
through transmission and distribution (T&D) losses and through electricity storage inefficiency (Table 4.2).

<table>
<thead>
<tr>
<th></th>
<th>Direct use in plant</th>
<th>T&amp;D losses</th>
<th>Pumped storage</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>OECD North America</td>
<td>4%</td>
<td>7%</td>
<td>1%</td>
<td>12%</td>
</tr>
<tr>
<td>OECD Europe</td>
<td>5%</td>
<td>7%</td>
<td>1%</td>
<td>13%</td>
</tr>
<tr>
<td>OECD Pacific</td>
<td>4%</td>
<td>5%</td>
<td>1%</td>
<td>10%</td>
</tr>
<tr>
<td>Economies in transition</td>
<td>7%</td>
<td>12%</td>
<td>0%</td>
<td>20%</td>
</tr>
<tr>
<td>China</td>
<td>8%</td>
<td>7%</td>
<td>0%</td>
<td>15%</td>
</tr>
<tr>
<td>India</td>
<td>7%</td>
<td>26%</td>
<td>0%</td>
<td>33%</td>
</tr>
<tr>
<td>Other Asia</td>
<td>4%</td>
<td>9%</td>
<td>0%</td>
<td>13%</td>
</tr>
<tr>
<td>Latin America</td>
<td>3%</td>
<td>17%</td>
<td>0%</td>
<td>20%</td>
</tr>
<tr>
<td>Africa</td>
<td>5%</td>
<td>11%</td>
<td>1%</td>
<td>17%</td>
</tr>
<tr>
<td>Middle East</td>
<td>5%</td>
<td>13%</td>
<td>0%</td>
<td>18%</td>
</tr>
<tr>
<td>World</td>
<td>5%</td>
<td>9%</td>
<td>1%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Note: At pumped storage plants, electricity is used during periods of low demand to pump water into reservoirs to be used for electricity generation during times of peak electricity demand.

Electricity used in generation plants ranges from 3.0% to 8.3%. It can be reduced by system improvements and modernisation at the plant level. Carbon capture and storage (CCS) technology will increase direct use in plant. T&D losses are larger, accounting for more than 9% of all generation worldwide, and vary much more between regions. OECD countries and China have the lowest percentage T&D losses, ranging from 5.0% to 7.2%. Even so, these losses represent a large amount of electricity, equivalent to more than the T&D losses from all other regions combined. In non-OECD countries T&D losses are higher as a percentage of total generation. A large portion of these losses are often attributed to non-technical losses, i.e. theft. For example, in India some regions experience losses as high as 35% due to theft (IEA, 2007).

Many of these losses can be reduced by the modernisation of the electricity grid. Better system level and end-use metering in particular will enable the losses to be identified and resolved.

**Vision for the grid of the future**

Growth and change in the electricity system over the next 50 years will require major investment both of financial resources and in the development of expertise and know-how. The electricity grid of the future will need to demonstrate the same primary functional characteristics as today. But it will need to accomplish this with added flexibility in order to enable an environment with a different mix of both centralised and distributed, non-variable and variable generation and new demand profiles. In order for the grid to operate optimally in this environment,

---

6. The electricity is technically not lost, but its use is unmetered. As a result, it is not possible for suppliers to manage, plan or recover system costs.
utilising both existing and new assets, there will be a need for the grid to become more intelligent, i.e. to become smarter.

**Box 4.1  What is a smart grid?**

A smart grid is an electricity network that uses digital technology to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users. Such grids will be able to co-ordinate the needs and capabilities of all generators, grid operators, end users and electricity market stakeholders in such a way that it can optimise asset utilisation and operation and, in the process, minimise both costs and environmental impacts while maintaining system reliability, resilience and stability (Figure 4.6).7

**Figure 4.6  A smart grid**

A smart grid includes generation, transmission, distribution and end-use technology and stakeholders, connected by integrated information, communication and control technology.

**Smart grid technology**

The grid is an enabler. It enables sources of generation to be linked to consumers. A range of technologies are primarily grid related, as distinct from being generation related or consumer related (Table 4.3).

---

Table 4.3  Functional smart grid technology areas

<table>
<thead>
<tr>
<th>Technology areas</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity generation control, automation and power</td>
<td>Communication with, and the intelligent control of, generation sources are part of a smart grid, but not the generation itself. For example, power electronics technologies that allow wind generation to supply reactive power are essential to the smart grid. The wind turbine is not.</td>
</tr>
<tr>
<td>electronics</td>
<td></td>
</tr>
<tr>
<td>Advanced computing and grid control software</td>
<td>The data created from embedded sensor and metering technology will require significant computing and system control software to enable the use and management of the grid and to meet stakeholder needs.</td>
</tr>
<tr>
<td>Embedded grid sensing, automation, measurement</td>
<td>This technology provides the information and control capability to optimise grid operation and manage power flows within the constraints of the grid technology. Flexible alternating current transmission systems, phasor measurement units and automated switch gear are examples.</td>
</tr>
<tr>
<td>and control technology</td>
<td></td>
</tr>
<tr>
<td>Communication infrastructure</td>
<td>The infrastructure required for two-way communication including wireless, internet and satellite communications may use existing or specialised methods.</td>
</tr>
<tr>
<td>Conductor technology and approaches</td>
<td>Advanced conductor technology such as high temperature superconductors (HTSs) can enable electricity systems to respond to operating changes more quickly, benefiting automated control, which will be especially important with the increase in remote variable renewable generation. High voltage direct current configurations can also offer management and control benefits to the grid.</td>
</tr>
<tr>
<td>Electrical load control and advanced meters</td>
<td>Advanced metering at residential, commercial and industrial levels can give customers and electricity providers the information they need to be able to respond to operational signals either by choice or automatically. Smart meters* can enable demand response initiatives.</td>
</tr>
<tr>
<td>Energy storage</td>
<td>Energy storage can be used as a load or as a generation source to help peak load management. Storage could also be used to provide ancillary services such as reactive power for frequency and voltage support.</td>
</tr>
<tr>
<td>EV charging infrastructure</td>
<td>The EV charging infrastructure will have an impact on grid operation. It must be capable of being managed intelligently.</td>
</tr>
</tbody>
</table>

* The European Smart Meters Industry Group (ESMIG) defines four minimum functionalities of a smart meter: remote reading, two-way communication, support for advance tariffing and payment systems and remote disablement and enablement of supply.

Benefits of smart grids

Smart grids will offer the capability:

- **To reduce peak demand by actively managing consumer demand:** more appliances and equipment are expected to come onto the market that can respond to both consumer and utility operator priorities. As they do, the ability to manage power requirements in both directions – to the utility as well as from the utility – will reduce the need for power. For example, during high-use periods such as hot summer afternoons when the cost of producing and delivering power is extremely high, the system will enable consumers more directly to be informed of those costs and to reduce their demand, or increase their local generation output, accordingly.

- **To balance consumer reliability and power quality needs:** although some uses of electricity require near perfect reliability and quality, others are almost insensitive to these needs. A smart grid will be able to distinguish differences in demand and, where appropriate, to provide less reliable and lower quality power at a reduced cost.

---

8. Adapted from Gridwise Alliance (2010).
To encourage the proactive application of energy efficiency opportunities: a smart grid will furnish consumers and utilities with accurate, timely and detailed information about energy use. Armed with this information, consumers will be able to identify ways of reducing energy consumption with minimal impacts on safety, comfort and security.

To improve overall operational efficiency: smart grids will become increasingly automated, and smart sensors and controls will be integral to their design and operation. Utility operators will be able more easily to identify, diagnose and correct problems, and will even have the capability to anticipate problems before they happen.

To integrate clean energy technologies: EVs, roof-top solar systems, wind farms and storage devices will become essential parts of the grid, all contributing in a co-ordinated fashion to the achievement of economic and environmental goals.

Smart grid CO₂ emissions reduction

Although electricity consumption only represents 17% of final energy use today, it leads to 40% of global CO₂ emissions. This is largely due to the fact that almost 70% of electricity is produced from fossil fuels. In the Baseline scenario, this stays largely the same in 2050, but in the BLUE Map scenario, as a result of decarbonisation, power generation contributes only 21% of global CO₂ emissions, representing an annual reduction of 20.2 Gt of CO₂ compared to the Baseline scenario. Smart grids will be needed to contribute directly to these reductions and to enable some of the required technologies (Figure 4.7).

Figure 4.7

Smart grid CO₂ reductions in 2050 in the BLUE Map scenario compared to the Baseline scenario

Note: The methodology for calculating CO₂ reductions has been adapted from EPRI (2008).⁹

Key point

Smart grids have the potential to reduce CO₂ emissions in the electricity sector both directly and indirectly.

⁹ This methodology is preliminary in nature and provides a range for the quantification of CO₂ emissions reductions attributed to the smart grid. Using the ETP 2010 analysis, this methodology has been modified to provide a first estimate of global emissions reduction attributable to smart grids. Actual regional CO₂ reductions depend on specific regional characteristics such as energy efficiency, demand structure and electricity generation mix.
Direct reductions are those that would only occur through the implementation of smart grid technologies or operating approaches. Indirect benefits are those that are the result of the deployment of other technologies, but require the capability of a smart grid to be fully realised. For example, smart grid technology will be needed to support the wider introduction of EVs and plug-in hybrid EVs.

Compared to the Baseline scenario in 2050, smart grids offer the potential to achieve savings of between 0.9 Gt CO₂ and 2.2 Gt CO₂ a year.

Benefits for developing countries

Smart grids could bring even more benefit to developing countries than to developed countries. Across the globe an estimated three billion people continue to lack access to sustainable and affordable modern energy (WEF, 2009). As developing countries respond to this, they may be able to implement smart grids from the outset, without going through the prior stage of increasingly outmoded technologies. A less carbon-intensive electricity generation infrastructure rather than one based on fossil fuels, along with demand control, could be used to reduce capital and operating costs while providing more robust operation.

Approaching electrification in this way has the potential to accelerate development and do so in a more sustainable way, reducing dependence on foreign sources of fuel. Many of the lessons learned both technically and economically by developed countries could be applied at the early stages of such development. Alternative approaches that may benefit given regions, such as micro grids and remote grids could take significant advantage of smart grid technologies in order to develop solutions that are tailored to specific needs.

Storage technology

With increasing variability of both generation and demand, storage will become increasingly important in enabling the grid to operate in a stable and reliable manner. Storage, by acting as both a load and a generation source, can play a major role in increasing system flexibility.

Storage technologies will be important in the development of smart grids in providing both grid support and enabling overall energy management. Direct electricity storage can, for example, decrease bottlenecks on both the transmission and distribution systems and be used to improve or maintain the delivery of power during outages. The output of excess generation from varREs in periods of high output and low electricity demand can be stored for later use. Apart from pumped hydro, these technologies are not yet financially viable other than in very specific applications. But continuing development can be expected to improve both cost-effectiveness and reliability. A range of storage technologies has recently been reviewed by the IEA (Inage, 2009a).

Thermal storage is likely to become increasingly important in the long term as thermal loads begin increasingly to use electricity generated through heat pump technologies and as CHP plays a stronger role. Heat pump technology can reduce
electrical load during both heating and cooling operations by utilising the thermal energy stored in the air or ground. Intelligent control of these heating and cooling loads can be used to manage peak demand with no noticeable impact on the end user. CHP units can be converted from variable generation to non-variable generation by responding to electricity system signals and storing excess heat energy for use at a later time in response to heat demand. Overall system efficiencies need to be better understood, so that they can influence technology choices and business cases to maximise the benefits for both system operators and end users.

Analysis of electricity storage needs

In 2009, the IEA estimated the global need for large-scale direct electricity storage technology in 2050 using the BLUE Map 2008 scenario with global wind and PV generation at 12% and 11% respectively of overall electricity generation (Inage, 2009a). The amount of storage has been estimated by modelling the storage required to balance the grid over a 24 hour period in response to 15% net variations in wind generation on the scale of seconds and minutes. Simplifications were made to yield initial results on which to build. These do not take into account regionally specific transmission or distribution bottlenecks that can increase the need for storage, or the smoothing effects of complementary generation technologies or the full deployment of smart grid technologies that could reduce the need for storage. The modelling was performed in three stages, first by using only electricity storage as a balancing mechanism, second by combining electricity storage and V2G input through EV technology, and third bymodelling combined electricity storage and the impact of heat pump technology deployment (Table 4.4).

<table>
<thead>
<tr>
<th>Table 4.4</th>
<th>Estimated global electricity storage needs in 2050 in the BLUE Map scenario, using different approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity storage (ES)</td>
<td>189</td>
</tr>
<tr>
<td>ES + V2G</td>
<td>122</td>
</tr>
<tr>
<td>ES + heat pump deployment</td>
<td>154</td>
</tr>
</tbody>
</table>

Sources: Inage (2009a and 2009b) and additional analysis.

The modelling indicates that different approaches lead to a need for different levels of storage capacity. Using several forms of storage technologies together may provide additional flexibility. At the upper bound, these estimates probably reflect an unlikely occurrence of very high generation and very low demand. But they may signal some important conclusions about the relationships between a range of technologies that can be used to increase the flexibility of the grid. Currently, approximately 100 GW of electricity storage is in use globally, primarily in the form of pumped hydro storage. Since not all regions have the natural resources to take advantage of pumped hydro, other technologies will need to be used, requiring continued investment and development. As smart grid concepts develop, and as implementation proceeds, more detailed modelling will need to be carried out to incorporate all demand and generation elements to improve the estimates of electricity storage needs and costs to determine the best technology solutions.
How much does the grid of the future cost?

**Capital expenses**

The *ETP 2010* scenarios calculate electrical system capital costs based on previous infrastructure investment data and future energy requirements. T&D investment is estimated to account for USD 8.4 trillion and USD 12.3 trillion in the Baseline and BLUE Map scenarios respectively. The increase in the estimated T&D investment in the BLUE Map scenario is due to increased demand for electricity for transportation, the increased deployment of varRE and smart grid costs, offset significantly by reductions in electricity demand through energy efficiency in all sectors. After 2050, it is expected that electricity demand in the BLUE Map scenario will eventually become greater than in the Baseline scenario, due to the further electrification of transportation and heating loads through technologies such as heat pumps which will impact on system costs further at the distribution level.

The detailed cost of smart grids compared to conventional grid designs is not fully understood. The total cost of smart grids may be lower than that of conventional grids as the ability to reduce peak loads and to increase energy efficiency may enable savings in infrastructure costs for T&D lines, transformers and switch gear. These cost reductions will be at least partially offset by increased costs for smart grid technologies such as smart meters, phasor measurement units and the information and communication infrastructure needed. A detailed analysis is required to estimate costs more precisely to determine the support needed at financial, policy and regulatory levels.

**Operating expenditures**

The use of digital technology has demonstrated opportunities for reducing operating expenditures in many industries. The same can be expected for the electricity sector, especially with respect to smart grids. Savings can already be seen in the use of automatic meter reading enabled by smart meters which in some applications have underpinned a business case to justify the required capital investment. The improved maintenance and utilisation of assets through the embedding of sensing equipment along with the potential for reductions in line losses could offer opportunities for additional savings. These savings in turn could defer and in some cases eliminate the need for infrastructure investments. It has not yet proved possible to estimate these savings quantitatively.

**Barriers to electricity grid investment**

Despite the benefits that the modernisation of the electricity grid will bring, there are many barriers to its achievement (Figure 4.8). These barriers must be addressed by engaging the full range of stakeholders in both private and public sectors, including market participants from all parts of the system, e.g. generators, T&D system operators, regulators and consumers. It is only in this way that creative and practical solutions will be found.
### Figure 4.8 Barriers to electricity grid investment

| Market barriers | Policy and regulation | • Market uncertainty and unclear policy on market structure and rules  
|                 |                     | • Revenue uncertainty due to regulatory structures  
|                 | Financing            | • Difficulties in defining priorities of technology investments  
|                 |                     | • Business case fragmentation  
| Public barrier  | Consumer engagement | • Low public awareness and engagement  
| Technology      | Technology           | • Lack of R&D co-ordination  
|                 |                     | • Lack of large-scale deployment projects  
| Technology      | Standards            | • Interoperability and scalability assurance  
|                 |                     | • Fragmentation and lengthy process for technology standards  
|                 | Skills and knowledge | • Insufficient skilled resources  
|                 |                     | • Limited understanding of smart grids in public planning  
|                 | Cyber security       | • Threats to cyber security in networks and consumer information  
|                 | and data privacy     | • Concerns about private data misusage  

Source: MEF (2009).

**Key point**

Technology, public and market barriers must be addressed to enable smart grid deployment.

### Priorities for next steps

The process for modernising the electricity grid as well as the transition to smart grids is already happening. It will continue as a transitional process rather than a step change. Grid investments tend to be very long term. They need to reflect deliberate and forward thinking that takes account of likely medium- and long-term changes in need. The IEA’s planned development of a smart grid roadmap will help in this.

### Regional assessment of grid needs

Regional needs, and the benefits that will result from meeting those needs through smart grid technologies, will differ. An assessment of needs and the grouping of regional needs will provide the opportunity for collaboration. This will also provide the opportunity to discuss what aspects should be addressed in what order. For example, in some regions, the need for the greenfield development of grid infrastructure may lead to the use of the latest conductor technology and controls which will provide flexibility in generation choice in the long term. Other regions,
with mature markets and ageing infrastructure, may more appropriately focus on demand-side management and demand response to meet these medium-term needs while developing long-term upgrading plans.

**Technology research, development and demonstration (RD&D) needs**

RD&D is needed in the development of electricity systems. Priority should be given to:

- Advanced system level modelling for planning, building, operating and maintaining smart grids that include all related elements of generation, transmission, distribution, demand, electricity and thermal storage.

- System level demonstrations of smart grids of increasing scale, eventually to the city and country scale, incorporating a range of technologies in a variable generation and demand environment in both developed and developing country contexts. These demonstrators can undertake the real-world testing of concerns including cyber security, reliability and cost.

- Continued development in electricity storage technology to increase efficiency and longevity and to reduce costs.

- Power electronics technology development to provide more capability and flexibility for system components on the grid such as wind generation.

- Continued development in transmission technology to help achieve better interconnection between areas with different supply and demand characteristics. This includes high-temperature superconductors to reduce both cost and risk and provide real world demonstration of benefits.

- Increasing the reliability of cables, subsea grids and overhead lines and reducing their impact on the environment. The development of smart grids could be a catalyst for increased action in these areas.

- Standards development as an enabler for innovation through both RD&D and deployment. This must continue to ensure technologies will allow inter-operability to reduce supplier risk and allow new market entrants.

**Markets**

The structure of electricity markets influences the construction, maintenance and operation of the grid. Around the world there are a number of different market structures that include the range from vertically integrated state-run monopolies to structures with a mix of unbundled private sector operations and state-run monopolies. As changes occur to the generation and demand sides, new business models will be needed with the ability to provide new services such as grid balancing or the aggregation of demand side reduction. This can ensure that all stakeholders, including customers, are appropriately incentivised to make appropriate investments and changes to operating procedures.
Regulatory and policy needs

The electricity sector has seen significant changes in regulation over the last 20 years in many regions. Changes in the generation, transmission, distribution and retail businesses have brought both positive and negative consequences. From a customer point of view, the introduction of competition into parts of the electricity value chain have brought new service offerings and driven down prices. From a generation point of view this process has allowed new entrants into the market, bringing new capital for investment both in conventional generation technologies and also in distributed technologies such as CHP and renewables.

Transmission and distribution systems are often viewed as natural monopolies. Although they have not generally been opened to competition, they are now in many countries more heavily regulated to ensure that customers are treated fairly.

To ensure that a low carbon electricity system can be developed at least overall cost, policy makers and regulators will need to strike an appropriate balance between the various parts of the value chain. Investments in generation will influence grid costs, and grid investments may change the balance of advantage between different generation investment alternatives. Regulators and policy makers need to understand the long-term needs of the electricity system in the round, so that they can ensure that short- and medium-term investment needs in generation and in grids optimise outcomes.

Public education and public engagement

The understanding of the benefits of smart grids to the end user must be better analysed and understood. This needs to include studies to understand what benefits end users will value and what they will not. Listening to and addressing the questions and concerns will increase up take and minimise public resistance that may be founded on rational or irrational understanding.

Human resources

According to a Canadian study, it is estimated that over 28% of the current Canadian electricity workforce is expected to retire between 2007 and 2012 (ESC, 2009). Similar trends can be seen in many other OECD countries. In developing regions, the human resource challenge is based around the development of technical capacity from a relatively low level today. Human resource constraints could undermine the ability for the industry to respond to increased demand and development in the electricity sector. They need to be considered in long-term planning. As the resultant changes in planning, design, operation and maintenance of the electricity system occur, the skills and competencies needed will also change. A detailed skills assessment considering both near and long-term demands will be required, with recommended actions to deliver these skills over the appropriate time frame.
Key findings

- Energy efficiency in industry has improved significantly in the last decade, but additional improvements are still possible through the implementation of best available technologies (BATs). Efficiency measures offer some of the least-cost options to reduce carbon dioxide (CO₂) emissions in industry. Implementation of BATs could reduce current emissions by 12% to 26%. Greater implementation of many well-known, cost-effective policy instruments is needed to achieve this potential. The removal of energy price subsidies should be a priority in countries where they persist.

- For the industry sector to make its contribution to the halving of CO₂ emissions by 2050 envisaged in the BLUE scenario, it will need to reduce its direct emissions in 2050 by 24% compared to 2007 levels. This can only be achieved if all major industrialised countries and all industry sectors contribute.

- Efficiency measures alone will not be enough to offset strong demand growth. New technologies such as carbon capture and storage (CCS), smelting reduction, separation membranes and black liquor gasification will be needed to reduce direct emissions in industry.

- Indirect CO₂ emissions from the use of electricity currently represent 34% of total industry emissions. These emissions are nearly eliminated by 2050 in the BLUE Map scenario as electricity generation progressively decarbonises through a mix of renewable and nuclear energy, and fossil fuel generation coupled with CCS.

- A decarbonised power sector will offer new opportunities to electrify industrial processes further to reduce the CO₂ intensity of industrial production. Research and development (R&D) is needed in this area.

- CCS represents the most important new technology option for reducing direct emissions in industry, with the potential to save an estimated 1.7 to 2.5 gigatonnes (Gt) of CO₂ in 2050. Without CCS, direct emissions in 2050 could only be brought back to current levels. Urgent action is needed to develop and demonstrate CCS applications in industry. The large-scale demonstration of capture technologies in industry should be undertaken in parallel with demonstration projects planned for the power sector.

- Fuel and feedstock substitution with biomass and waste represents another important option to reduce CO₂ emissions. There will be significant competition for limited biomass resources from the power, transport, pulp and paper and buildings sectors. This will increase cost and possibly make industrial applications less attractive. Policy design for biomass and waste use should support an optimum use of limited resources.

- Greater investment by both government and industry is needed to research, develop, demonstrate and deploy a wide range of promising new technologies and to identify and advance novel processes which allow for the CO₂-free production of materials in the longer term.
Clear, stable, long-term policies that put a price on CO\textsubscript{2} emissions will be necessary if industry is to implement the technology transition needed to produce deep emissions reductions. The current situation, in which developed countries are subject to greenhouse-gas emission constraints while developing countries are not, gives rise to concerns about competitiveness and carbon leakage.

A global system of emissions trading may eventually provide the most efficient way of achieving this. In the short to medium term, international agreements covering specific energy-intensive sectors may be a practical first step. Government intervention will also be needed in the form of standards, incentives and regulatory reforms.

Introduction

Nearly one-third of global energy demand and almost 40% of worldwide CO\textsubscript{2} emissions are attributable to industrial activities. The bulk of these emissions are related to the large primary materials industries, such as chemicals and petrochemicals, iron and steel, cement, pulp and paper, and aluminium. If climate change is to be successfully tackled, industry will need to transform the way it uses energy and significantly reduce its CO\textsubscript{2} emissions.

Although industrial energy efficiency has improved and CO\textsubscript{2} intensity has declined substantially in many sectors in recent decades, this progress has been more than offset by growing industrial production worldwide. As a result, total industrial energy consumption and CO\textsubscript{2} emissions have continued to rise. Over the next 40 years, demand for industrial materials in most sectors is expected to double or triple. Projections of future energy use and emissions based on current technologies show that, without decisive action, these trends will continue. This is not sustainable.

Making substantial cuts in industrial CO\textsubscript{2} emissions will require the widespread adoption of BATs and the development and deployment of a range of new technologies. This technology transition is urgent. Industrial emissions must peak in the coming decade if the worse impacts of climate change are to be avoided. Industry and governments will need to work together to research, develop, demonstrate and deploy the promising new technologies that have already been identified, and also to find and advance novel processes that will allow for the CO\textsubscript{2}-free production of common industrial materials in the longer term.

Industrial energy use and CO\textsubscript{2} emissions

Total final energy use by industry reached 3 015 million tonnes of oil equivalent (Mtoe) in 2007, representing almost a doubling of energy use since 1971 (Figure 5.1). The five most energy-intensive sectors, namely iron and steel, cement, chemical and petrochemical, pulp and paper, and aluminium, together accounted for two-thirds of total industrial energy use and about 77% of total direct CO\textsubscript{2} emissions in industry. Energy intensity over this period has improved significantly in most sectors.
as a result of improvements in energy efficiency and material flow management. For example, in the cement sector, production since 1971 has risen 4.5 times. In the same period, energy use has risen only by a factor of 1.5 as technology advancement and higher rates of clinker substitution have helped to reduce the energy intensity of cement production by half. Higher recycling levels, together with a range of energy efficiency measures, have led to similar substantial improvements in energy use in the production of iron and steel, pulp and paper and aluminium.

**Figure 5.1** World industrial energy use by sector

China accounts for about 75% of the industrial production growth since 1971 and for a similar share of the increase in industrial energy use. As the country’s energy base is dominated by coal, rapid industrial production growth has resulted in China becoming the largest emitter of CO₂ in the world, overtaking the United States in 2007. Approximately 60% of China’s emissions are attributable to industry. In the United States, industry’s share of total emissions is less than 20%, with the largest share (44%) of emissions coming from the buildings sector.

China, the United States and OECD Europe together accounted for over 50% of total global industrial energy use in 2007 (Figure 5.2). Action in these countries will be a major determinant of overall global industrial energy and CO₂ trends. In the United States and Europe, oil and gas represent the main sources of energy for industrial use. This is dominated by the feedstock needs of the chemical and petrochemical sector which account for 23% of total industrial energy use in these countries. In China, coal is the major source of industrial energy. As a result, China’s share of global industrial CO₂ emissions (35%) is significantly higher than its share of industrial energy use (24%).

Notes: Includes feedstock used in the production of chemicals and petrochemicals. Iron and steel includes coke ovens and blast furnaces. Unless otherwise indicated, all material derives from IEA data and analysis.

Key point

Energy use in industry has risen sharply since 1971, with strong growth seen in the chemical and petrochemical, iron and steel and non-metallic minerals industries.
Figure 5.2 Industrial energy use by region and by fuel, 2007

Key point

China, OECD North America and OECD Europe represent more than half of total energy use in industry.
Significant energy and CO₂ savings in industry are possible through the implementation of currently available BATs. The application of BATs in the five most energy-intensive sectors could reduce final energy use by between 10% and 26% according to sector (Table 5.1). Total estimated savings for the five sectors analysed is 357 Mtoe per year, equivalent to 12% of energy use in industry and 4% of global energy consumption in 2007. In terms of CO₂ savings, the sector potentials vary from 12% to 26%, in total amounting to 1.3 Gt of CO₂. This equates to a reduction of 11% of total industry emissions and 4% of total global emissions in 2007.

<table>
<thead>
<tr>
<th></th>
<th>Energy savings potential (Mtoe/yr)</th>
<th>Share of current energy use in the sector (%)</th>
<th>CO₂ savings potential (Mt CO₂/yr)</th>
<th>Share of current emissions in the sector (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemicals</td>
<td>121</td>
<td>15%</td>
<td>300</td>
<td>20%</td>
</tr>
<tr>
<td>Iron and steel</td>
<td>133</td>
<td>22%</td>
<td>420</td>
<td>19%</td>
</tr>
<tr>
<td>Cement</td>
<td>63</td>
<td>26%</td>
<td>520</td>
<td>26%</td>
</tr>
<tr>
<td>Pulp and paper</td>
<td>35</td>
<td>21%</td>
<td>80</td>
<td>20%</td>
</tr>
<tr>
<td>Aluminium</td>
<td>9.7</td>
<td>10%</td>
<td>45</td>
<td>12%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>357</strong></td>
<td><strong>1295</strong></td>
<td><strong>1295</strong></td>
<td><strong>1295</strong></td>
</tr>
</tbody>
</table>

**Potential as share of industrial energy and CO₂ emissions**

12% 11%

**Potential as share of total energy use and CO₂ emissions**

4% 4%

*Note: Work at the IEA is seeking to improve the quality of the underpinning data and to refine the methodologies used in calculating the savings potential in the industrial sector.*

It will take time to achieve these savings. The rate of implementation of BATs in practice depends on a number of factors, including capital stock turnover, relative energy costs, raw material availability, rates of return on investment and regulation. Energy subsidies undermine the ability of markets to signal least-cost options to maximise energy efficiency. Removing these subsidies will help to realise higher levels of energy efficiency.

CO₂ emissions reductions will be needed across all industry sectors. But action is particularly crucial in the five most energy-intensive sectors. Together, these sectors currently account for 77% of total direct CO₂ emissions from industry (Figure 5.3).

---

1. The potentials shown are technical. The economic potentials are substantially lower.
**Energy and CO₂ scenarios**

**Scenario assumptions**

The BLUE scenarios enable the exploration of the technological options that will need to be exploited if global CO₂ emissions are to be halved by 2050 at least cost. Reaching the global CO₂ emissions objective in the most cost-effective way will require each economic sector to make a contribution according to its costs of abatement. Some sectors may, therefore, need to reduce emissions by less than 50% while others will have to reduce them by more.

Given the recent global economic crisis and uncertainties about projecting long-term growth in consumption, a low-demand and a high-demand case have been developed for each industry. In the five sectors covered in this analysis, demand is assumed to be between 15% and 30% lower in the low-demand cases than in the high-demand cases in 2050, depending on the sector. As the BLUE low- and high-demand scenarios are driven by the same level of CO₂ emissions in 2050, greater reductions in emission levels are needed in the high-demand scenario than in the low-demand one. As a result, costs are also higher in the high-demand case.

The scenarios take an optimistic view of technology development and assume that technologies are adopted as they become cost-competitive. The analysis does not assess the likelihood of these assumptions being fulfilled. But it is clear that deep CO₂ reductions can only be achieved if the whole world plays its part both in seeking to achieve that outcome and in engaging in the development and deployment of technologies that can help to bring it about.
Trends in materials production and demand projections for industry

Growth in industrial production since 1990 has been dominated by China, India and other developing Asian countries. Together, these countries accounted for over 80% of the increase in industrial production over this period. Today China is the largest producer of ammonia, cement, iron and steel, methanol and many other products. In OECD countries, industrial production since 1990 has increased only modestly. The IEA scenario analysis assumes that in the next twenty years, as industrial development matures, there will be another significant change in the pattern of industrial production growth (Figure 5.4). Production in China will flatten or, in cement production, decline as the economy matures and demand for materials levels off. But in India, other developing Asian countries, and Africa and the Middle East, industrial development will accelerate. Industrial production in these three regions is expected, in the low-demand scenario, to increase by over 150% by 2030 and by almost 300% by 2050 compared to 2007. OECD countries are expected to show relatively flat demand or only modest increases as consumption levels for materials in these countries are already mature and population growth is expected to be relatively flat or declining.

Scenario results

In the Baseline scenario, total direct and indirect emissions from industry rise between 2007 and 2050 by 74% in the low-demand case and by 91% in the high-demand case, reaching 19.9 Gt CO₂ and 21.9 Gt CO₂ respectively (Figure 5.5). In the BLUE scenarios, total industrial emissions would be 40% lower in 2050 than in 2007. Compared to the Baseline scenarios, industry emissions in the BLUE scenarios would be 66% lower in 2050 in the low-demand case and 68% lower in the high-demand case.

Direct process and energy emissions from industry are expected to reach 11.0 Gt CO₂ in the Baseline low-demand case and 12.5 Gt CO₂ in the high-demand case in 2050. In the BLUE scenarios, direct emissions fall from 7.6 Gt CO₂ in 2007 to 5.7 Gt CO₂ in 2050, a 24% reduction.

Indirect emissions from electricity use represent the largest increase between 2007 and 2050 in the Baseline scenarios, rising from 3.9 Gt CO₂ in 2007 to 8.8 Gt CO₂ (low-demand case) and 9.3 Gt CO₂ (high-demand case) in 2050. In the BLUE scenarios, as the power sector progressively decarbonises, indirect emissions show the largest decline, falling by 2050 to just 1.1 Gt CO₂ in low-demand case and 1.2 Gt CO₂ in the high-demand case.

The decarbonisation of the power sector accounts for the largest share (45% in the low-demand case and 42% in the high-demand case) of the reductions in total emissions in industry by 2050 in both BLUE scenarios (Figure 5.6). Energy efficiency, including electricity demand reductions, makes the next largest contribution, amounting to 34% and 32% of total reductions in the BLUE low- and high-demand scenarios respectively. The fitting of CCS to industrial applications, which accounts
Figure 5.4  Materials production under the Baseline and BLUE scenarios

The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Note: Materials production is the same in the Baseline and BLUE scenarios.

Key point

Growth in industrial production will be strongest in India, other developing Asia and Africa and the Middle East.
for 13% and 17% of the total direct and indirect emissions reductions in the BLUE low- and high-demand scenarios respectively, will also be needed.

**Figure 5.5**  ▶ Total industry CO₂ emissions in the Baseline and BLUE scenarios

![Bar chart showing total industry CO₂ emissions in the Baseline and BLUE scenarios](chart)

**Key point**

Total direct and indirect CO₂ emissions in industry fall by 40% in the BLUE scenarios compared to 2007 levels.

**Figure 5.6**  ▶ Contribution to total direct and indirect CO₂ emissions reductions in the industry sector in the BLUE scenarios compared to Baseline scenarios

**BLUE low 13 Gt CO₂**
- Energy efficiency 19%
- Fuel switching 8%
- CCS (energy and process) 13%
- Electricity demand reduction 15%
- Electricity supply-side measures 45%

**BLUE high 15 Gt CO₂**
- Energy efficiency 20%
- Fuel switching 9%
- CCS (energy and process) 17%
- Electricity demand reduction 12%
- Electricity supply-side measures 42%

**Key point**

Measures in the electricity sector account for the largest reduction in total direct and indirect CO₂ emissions in industry.
Energy use

Total final energy use in the Baseline low-demand scenario increases from 3,017 Mtoe in 2007 to 5,308 Mtoe in 2050. It increases in the Baseline high-demand scenario to 6,021 Mtoe. Fossil fuels currently constitute 70% of the total final energy used in industry. In all scenarios, fossil fuel use will continue to dominate (Figure 5.7). But its share of final energy use will decline to 57% in the BLUE low-demand scenario and to 55% in the BLUE high-demand scenario. The remaining energy and feedstock will come from heat, biomass and waste and electricity. Coal currently accounts for over a quarter of total final energy use. In the BLUE scenarios, coal’s share of final energy use falls to 20% by 2050.

Figure 5.7 Share of industrial energy use by fuel in the Baseline and BLUE scenarios

![Bar chart showing energy use by fuel type in different scenarios.](image)

Note: Numbers at the top of the bars show total energy use in Mtoe.

Key point

The share of fossil fuels will decline significantly in the BLUE scenarios, offset by higher biomass and electricity use.

In the Baseline scenarios, the share of biomass and waste use remains similar to current levels. It increases sharply in the BLUE scenarios, rising from 6% of energy used in 2007 to 14% in the low-demand case and to 16% in the high-demand case by 2050. The switch from fossil fuels to biomass makes a significant contribution to CO₂ emissions reductions in all sectors except in aluminium production where electricity provides most energy. Applying CCS to biomass combustion will result in net emissions reductions as CO₂ from the atmosphere, initially captured in biomass, is sequestered. Industrial applications will have to compete with power generation for the available biomass. Significant improvements will be needed in agricultural yields if costs are to be contained and the negative impacts of land-use change and food availability are to be minimised.
In the BLUE scenarios, higher levels of energy efficiency will significantly reduce energy intensity, but total final energy use in 2050 will still rise by 31% in the BLUE low-demand scenario and by 48% in the BLUE high-demand scenario compared to 2007. This will be driven by strong production growth. The use of CCS in the BLUE scenarios to reduce CO₂ emissions increases energy consumption, offsetting some of the savings from higher energy efficiency that would otherwise be achieved.

Biomass use

In the BLUE scenarios, industry’s use of biomass and waste increases from 190 Mtoe in 2007 to 556 Mtoe in the low-demand case or to 734 Mtoe in the high-demand case in 2050. The largest increase comes from the chemical and petrochemical sector, followed by the cement and iron and steel sectors (Figure 5.8). In the pulp and paper sector, biomass already represents 33% of total energy use and this share rises to about 60% in the BLUE scenarios in 2050. In the iron and steel sector, the use of biomass and waste rises to 36 Mtoe and 66 Mtoe in 2050 in the BLUE low- and high-demand scenarios respectively. Bio-based feedstock and biomass used as energy in the chemical and petrochemical sector represent between 8% and 10% of total energy used by the sector in 2050. In the cement sector, about 40% of the biomass and waste used in 2050 is assumed to come from combustible biomass, with the use of tyres, rugs and other waste accounting for the remainder.

Figure 5.8 Use of biomass and waste in the industrial sector

Sources: IEA (2009b and 2009c); IEA analysis.

Key point

Use of biomass and waste in industry will be three to four times higher in 2050 than in 2007.

Achieving the high shares of biomass use in industry outlined in the BLUE scenarios will be challenging. The industrial sector will have to compete with other sectors of the economy for limited biomass resources. Growing demand could increase biomass
prices, making fuel switching options in industry less economic. To assess whether or not the increased use of biomass by industry and other sectors is sustainable, it will be necessary to analyse at global, national and sub-national levels the use of biomass throughout the economy through a full life-cycle analysis.

Carbon capture and storage

Emissions reductions of between 1.7 Gt CO₂ and 2.5 Gt CO₂ need to be achieved through the application of CCS in industry in the BLUE low-demand and high-demand scenarios respectively, accounting for between 33% and 37% of the total direct emissions reductions needed as compared with the Baseline scenarios in 2050. Without CCS, direct CO₂ emissions in the industrial sector in 2050 come back to 2007 levels in the low-demand case; they would be 8% higher in 2050 than in 2007 in the high-demand case.

In the BLUE scenarios, CCS technology is applied in the iron and steel, pulp and paper, chemical and petrochemical and cement sectors. In the iron and steel sector, CO₂ is captured from blast furnaces, smelting reduction and direct reduced iron production plants. Capture in the cement sector is from rotary kilns for clinker production. In the chemical and petrochemical sector, capture is mainly in ammonia production and from large combined heat and power (CHP) units. In the pulp and paper sector, CO₂ is captured from large CHP units and black liquor gasifiers in pulp production (Figure 5.9).

Figure 5.9  Industrial CO₂ emissions reductions from CCS compared to the Baseline equivalent scenarios by sector, 2050

- **BLUE low 1.7 Gt CO₂**
  - Iron and steel: 52%
  - Chemicals: 15%
  - Cement: 31%
  - Pulp and paper: 2%

- **BLUE high 2.5 Gt CO₂**
  - Iron and steel: 45%
  - Chemicals: 13%
  - Cement: 39%
  - Pulp and paper: 3%

Key point

*There are important CO₂ reduction opportunities for CCS in the iron and steel and cement sectors.*

Developing countries account for the bulk of the economic activity and for two-thirds of the CO₂ emissions in the Baseline scenarios in 2050. Spreading CCS
technology to these countries will require international co-operation to maximise the impact of CCS as an abatement option.

If CCS is cost-effectively to play the role it needs to play in a number of sectors, the development of a CO$_2$ pipeline transportation and storage infrastructure will need to be actively co-ordinated between sectors. As CCS builds from demonstration to commercialisation, CO$_2$ transportation networks will need to be developed at regional, national and international levels to optimise infrastructure development and to lower costs.

The iron and steel and cement sectors have made some progress in advancing demonstration of CO$_2$ capture in industry. The United States government is providing USD 1.1 million to support the demonstration of a dry sorbent CO$_2$ capture technology at one of Cemex’s cement plants in the United States. Discussions are currently under way between the cement industry and the European Commission to fund a CO$_2$ capture project in Europe. The Ultra-Low CO$_2$ Steelmaking (ULCOS) project, which is a joint public-private partnership in the steel industry in Europe, will soon move to the demonstration phase and a CO$_2$ capture demonstration plant at an ArcelorMittal plant in France is expected to be commissioned in 2015.

**Industrial electrification**

The decarbonisation of the power sector offers an attractive opportunity to reduce CO$_2$ emissions in industry through greater electrification, for example through the wider use of heat pumps instead of boilers (Box 5.1). R&D is needed to develop new electricity-based manufacturing processes. The widespread use of electricity in recycling suggests that increases in recycling rates would lead to higher levels of electrification in industry. There remains potential in many sectors to increase recycling, especially in developing countries. In the iron and steel sector, CO$_2$-free electricity could make production from hydrogen an attractive option. Research is also under way to produce iron by molten oxide electrolysis (MOE).

**Box 5.1  Heat pump applications in industry**

Heat pumps are already widely used in households and buildings. Recent technological advances that have enabled efficiency improvements, increases in capacity and output at higher temperatures offer the opportunity to replace boilers with heat pumps in a range of industrial applications. Heat pumps supplying heat at temperatures over 100°C are being commercialised. Additional R&D could help to make this technology more suitable for wider adoption in industry.

In the food and beverage sector, operating temperatures are often relatively low and, therefore, particularly appropriate to the use of heat pumps. An analysis of the CO$_2$ reductions from applying heat pumps with electric-drive compressors in the food and beverage industry in 11 countries has estimated that 40 Mt of CO$_2$ per year could be avoided (Table 5.2). This amounts to about 1.3% of CO$_2$ emissions in the industrial sector in the 11 countries analysed.
Energy and CO₂ emissions reduction from heat pump application in the food and beverage sector

<table>
<thead>
<tr>
<th>Country</th>
<th>Energy savings (Mtoe)</th>
<th>CO₂ savings (Mt CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>3.57</td>
<td>3.0</td>
</tr>
<tr>
<td>France</td>
<td>0.47</td>
<td>2.0</td>
</tr>
<tr>
<td>Germany</td>
<td>0.53</td>
<td>1.3</td>
</tr>
<tr>
<td>Italy</td>
<td>0.44</td>
<td>2.2</td>
</tr>
<tr>
<td>Japan</td>
<td>0.57</td>
<td>0.5</td>
</tr>
<tr>
<td>Netherlands</td>
<td>0.18</td>
<td>0.1</td>
</tr>
<tr>
<td>Norway</td>
<td>0.04</td>
<td>0.8</td>
</tr>
<tr>
<td>Spain</td>
<td>0.24</td>
<td>0.2</td>
</tr>
<tr>
<td>Sweden</td>
<td>0.04</td>
<td>1.1</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.42</td>
<td>13.7</td>
</tr>
<tr>
<td>United States</td>
<td>4.17</td>
<td>15.4</td>
</tr>
</tbody>
</table>


Heat pump technology could be applicable to a range of other manufacturing processes in which relatively low temperatures are required, such as for washing, drying, air-conditioning and in the agricultural sector for horticulture and storage processes, etc. that are fundamental to the food sector. Using heat pumps can also cut energy costs, improve product quality and in some industries even shorten production periods.

The potential decarbonisation of the power sector in the future, combined with improvements in the efficiency of heat pumps, will also help to increase the CO₂ benefits of industrial heat pump applications. Heat pumps are a promising technology for industrial application and additional R&D is needed to allow for heat pump use at higher temperatures to enable wider adoption among industry sectors.

Recycling

The recycling of materials conserves energy, landfill space and raw materials. The use of recycled materials by industry, where appropriate, reduces energy needs and associated CO₂ emissions. Recycling is a particularly attractive option for the aluminium, iron and steel, paper and chemical and petrochemical industries. Although recycling rates could be increased in many sectors, achieving high rates of recycling might not be cost-effective. Many countries have already achieved high levels of recycling in some sectors and there is limited room for additional growth.

The proportion of recycled material relative to overall production is expected to increase by six percentage points (p.p.) in the aluminium sector, 19 p.p. in the iron
and steel sector and three p.p. in the paper sector in 2050 compared to 2007, reducing energy use in these sectors by between 181 Mtoe and 240 Mtoe. The use of recycled materials will have an important contribution to make in achieving the 24% reduction in industrial direct energy use and process CO$_2$ emissions in the BLUE scenarios in 2050.

**Sectoral results**

Industry can significantly reduce emissions by 2050 only if all industrial sectors make a contribution. The projected direct emissions reductions between 2007 and 2050 in the BLUE low- and high-demand scenarios differ according to sector (Figure 5.10).

The aluminium sector shows an increase in direct emissions of 100%, offset by significant indirect emissions reductions from decarbonisation in the power sector. The iron and steel sector reduces its direct emissions by between 35% and 37%. Compared to the Baseline scenarios, total emissions fall in the BLUE low- and high-demand scenarios in 2050 in all five sectors.

In the BLUE low-demand scenario, the share of total CO$_2$ emissions from the chemical and petrochemical sector rises from 17% in 2007 to 21% in 2050 (Figure 5.10). The iron and steel sector, which is currently the largest emitter, shows the largest potential for reduction. The cement sector, which is currently the second-largest emitter, becomes the largest, accounting for 28% of total direct industrial emissions in 2050.

**Figure 5.10** Direct energy and process CO$_2$ emissions in industry by sector

![Figure 5.10](image)

**Key point**

All sectors have the potential significantly to reduce emissions.
Iron and steel

The iron and steel sector is the second-largest industrial user of energy, consuming 616 Mtoe in 2007 and the largest industrial source of CO₂ emissions. The five most important producers — China, Japan, the United States, the European Union (EU) and Russia — account for over 70% of total world steel production.

Steel is produced through a dozen or so processing steps, which can take various configurations depending on the product mix, available raw materials, energy supply and investment capital. There are three principal modern processing routes:

- Blast furnace (BF)/basic oxygen furnace (BOF). This uses between 70% and 100% of iron ore, the balance being made up from scrap.
- Scrap/electric arc furnace (EAF). This uses between 70% and 100% scrap material, with the balance being made up by ore-based materials.
- Direct reduced iron (DRI)/EAF. This uses DRI ore and scrap.

The scrap/EAF route is much less energy-intensive (using 4 GJ to 6 GJ per tonne of iron produced when using 100% scrap) than the BF/BOF route (which uses 13 GJ to 14 GJ per tonne of iron produced). For EAFs using higher levels of ore-based iron, energy use is higher. Significant energy savings can be achieved by switching from BF/BOF to scrap/EAF production, but such changes may be limited by barriers such as the availability of scrap and the demand for higher grades of steel. In China, India and other emerging industrial economies, the BF/BOF route will continue to dominate production.

Energy efficiency and CO₂ reduction potentials

Individual countries offer different technological efficiency potentials (Figure 5.11). The total potential energy saving in the iron and steel industry is 133 Mtoe, equivalent to 421 Mt CO₂ on the basis of current production levels. These potentials are technical and the economic potentials are significantly below these levels as achieving these savings will require re-build or major refurbishments. In some regions with small-scale production and low-quality indigenous coal and iron ore, the reduction potential will be particularly difficult to achieve. China accounts for 55% of the potential energy saving, although a number of other countries have higher potential in terms of energy reductions per unit of steel produced. The average global potential is 4.1 GJ per tonne of crude steel, equivalent to 0.3 tCO₂/tonne of steel produced.

The extensive use of BATs could result in energy and CO₂ reductions of around 20%. This is considerably less than the expected growth in energy demand that will result from production almost doubling in the low-demand case between 2007 and 2050. A net reduction in energy demand and emissions will, therefore, be dependent on significant innovation strategies bringing new technological solutions on stream well before 2050.
Figure 5.11 Energy savings potential in 2007 for iron and steel, based on BATs

Notes: OHF: open-hearth furnace; COG: coke-oven gas; CDQ: coke dry quenching.

Key point

The potential exists to save approximately 130 Mtoe of energy, with country-specific savings potentials of 1.4 to 9.0 GJ/t of crude steel.

Scenario results

Improvements in materials flow management focus on the increased recovery of steel scrap, the development of new steel types and the design of new steel products. For example, more steel can be recovered from municipal solid waste through mechanical waste separation. For new steel types, significant developments will be needed in the design of alloys and testing procedures.

Crude steel production is estimated to increase from 1 351 Mt in 2007 to 2 408 Mt and 2 857 Mt in 2050 in the low- and high-demand cases respectively. In both cases, China will remain the main crude steel producer, accounting for about 30% of world production. India, other developing Asia, and Africa and Middle East will have the strongest growth rates, with the result that between 32% and 35% of all production in 2050 will be from those countries/regions.

Total direct CO$_2$ emissions in the iron and steel sector in the BLUE scenarios reach about 1.5 Gt CO$_2$ in both the low- and high-demand cases in 2050. This represents a decrease of about 35% to 37% in direct emissions compared...
to 2007. CO₂ intensity decreases by 63% to 70% between 2007 and 2050 in the BLUE scenarios, largely as a result of technological innovation, the introduction of CCS and efficiency gains (including recycling). Initially, recycling dominates (Figure 5.12). From 2020 onwards, fuel switching and CCS start to play a more important role. Total direct emissions reductions amount to 1.6 Gt CO₂ a year in the low-demand case and to 2.1 Gt CO₂ in the high-demand case in 2050. About 55% of this total reduction can be attributed to CCS and about 17% to 21% to increased recycling. Recycling levels in the BLUE scenarios are expected to rise from 444 Mt in 2007 to 1 200 Mt of steel in the low-demand case and to 1 470 Mt in the high-demand case in 2050.

Figure 5.12 Direct emissions reduction by technology option for iron and steel

Key point

Energy efficiency, recycling and CCS are the main options for emissions reduction in the iron and steel sector.

In the Baseline scenarios, energy use almost doubles to 934 Mtoe in the low-demand case and 1 045 Mtoe in the high-demand case. In the BLUE scenarios, energy use rises only to 757 Mtoe in the low-demand case and to 844 Mtoe in the high-demand case. This is 23% and 37% more than in 2007, with production growth being offset by the stronger uptake of energy efficiency measures and more efficient technologies. Coal use in the BLUE scenarios in 2050 is more or less the same as in 2007. All the growth in energy demand in the BLUE scenarios is met by other energy forms such as natural gas, electricity, biomass and waste. Compared to the Baseline scenarios, electricity, natural gas, biomass and waste use increases significantly in relative terms in the BLUE scenarios in 2050. These changes are underpinned by a range of structural changes (Box 5.2). For example, an increase in the use of natural gas for DRI production is offset by significant gas savings attributable to efficiency gains in steel finishing.
Box 5.2  Impacts of gas availability on use of gas-based direct reduced iron (DRI)

The results of the modelling are based on several assumptions on the production route that will be used to produce steel. Since in the BLUE scenarios the power sector is decarbonised, the model assumes a large increase in production from EAFs. As scrap availability is limited, large increases in gas-based DRI production are assumed in countries with large natural gas resources such as Russia, the Middle East and some South American countries. The increase is more moderate in regions where natural gas availability is more limited. Production from gas-based DRI increases from 51 Mt in 2007 to 329 Mt in 2050 in the BLUE high-demand scenario.

Recognising that the DRI option might be attractive only in locations with cheap stranded gas, a further analysis has been undertaken which limits production from gas-based DRI to no more than a doubling between 2007 and 2050. Initial analysis of the implication of this low growth in gas-based DRI, and the consequently lower levels of production of steel from EAFs, indicates that the large CO₂ savings implicit in the BLUE scenarios could only be achieved if there was particularly strong and fast technology development and deployment.

All new and refurbished units would need to be equipped with carbon capture starting in 2020 and new CO₂-free technologies, or a significant increase in the use of biomass and plastic waste would need to be implemented from 2020. Breakthrough technologies which are currently at the research stage, such as MOE, would need to be commercially available earlier than expected.

Preliminary analysis suggests that the incremental investment cost under this alternative scenario would be between USD 400 billion and USD 500 billion, compared to an investment of USD 300 billion to USD 400 billion if gas-based DRI were to be used, excluding any increased investment needed for the development and deployment of breakthrough technologies.

Technology options

A number of technology options need to be developed and deployed in the iron and steel sector (Table 5.3).

Natural gas-based DRI production enables the complete replacement of coal. It is a well-established technology. Such plants can use relatively small gas reserves, including those which may not be large enough to justify the development of liquefied natural gas (LNG) projects. New DRI projects should be equipped with CCS, the cost of which is highly sensitive to the price of natural gas. Biomass, plastic waste, CO₂-free electricity and hydrogen are other future energy source options. Gas can also be injected into blast furnaces, but volumes are limited by process conditions.
### Technology options for the iron and steel industry

<table>
<thead>
<tr>
<th>Technology</th>
<th>R&amp;D needs</th>
<th>Demonstration needs</th>
<th>Deployment milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smelting reduction</td>
<td>Improve heat exchange in FINEX*</td>
<td>Demonstration plants already operational for FINEX and Hlsmelt</td>
<td>Share rise from 3% in 2015 to 18% in 2030 and 31% in 2050</td>
</tr>
<tr>
<td></td>
<td>New configuration of Hlsmelt** to lower coal consumption</td>
<td>Demonstration plant for producing reduced pellets operational by 2015</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Integration of Hlsmelt and Isarna*** processes (Hisarna). Pilot due to start in 2010</td>
<td>Demonstration plant with smelter by 2020</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paired straight hearth furnace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top-gas recycling blast furnace</td>
<td>Demonstration plants already operational for FINEX and Hlsmelt</td>
<td></td>
<td>Deployment in 2020</td>
</tr>
<tr>
<td></td>
<td>Research needs to focus on improving the mechanical stability of charcoal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of charcoal and waste plastic</td>
<td>Proven technologies</td>
<td>Commercial scale demonstration – small blast furnace – by 2014</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Research needs to focus on improving the mechanical stability of charcoal</td>
<td>Full scale demonstration plant by 2016</td>
<td></td>
</tr>
<tr>
<td>Production of iron by MOE</td>
<td>Assessment of technical feasibility and optimum operating parameters</td>
<td>If the laboratory-scale project is successful, demonstration may start in the next 15 to 20 years</td>
<td>Deployment after 2025</td>
</tr>
<tr>
<td>Hydrogen smelting</td>
<td>Assessment of technical feasibility and optimum operating parameters</td>
<td>If the laboratory-scale project is successful, demonstration may start in the next 15 to 20 years</td>
<td>Deployment after 2025</td>
</tr>
<tr>
<td>CCS for blast furnaces</td>
<td>Research focusing on reducing the energy used in capture</td>
<td>2015-2020</td>
<td>2030 all new large plants to be equipped with CCS</td>
</tr>
<tr>
<td>CCS for DRI</td>
<td></td>
<td>2015-2020</td>
<td>2030 all new large plants to be equipped with CCS</td>
</tr>
<tr>
<td>CCS for smelt reduction</td>
<td></td>
<td>2020-2030</td>
<td>2035 all new large plants to be equipped with CCS</td>
</tr>
</tbody>
</table>

Notes: * FINEX is a smelting reduction process developed by POSCO which consists of a melting furnace with a liquid iron bath where coal is injected and a cascade of fluidised bed reactors for the pre-reduction of iron fines.
** Hlsmelt (high-intensity smelting) is an iron bath reactor process.
***Isarna is a smelting reduction technology under development by ULCOS. It is a highly energy-efficient iron making process based on direct smelting of iron ore fines using a melting cyclone in combination with a coal-based smelter. All process steps are directly hot-coupled, avoiding energy losses from intermediate treatment of materials and process gases.

CCS can play an important role in reducing CO₂ emissions in the iron and steel industry. If 1.1 Gt CO₂ emissions are to be avoided through CCS in the iron and steel sector by 2050, significant deployment would need to be achieved by 2030. This requires that the technology has been demonstrated at plant level by 2020. Urgent action will be needed in the next ten years to demonstrate CCS for blast furnaces, smelting reduction plants and DRI. Government support for CCS, which has focused on the power sector, should also be extended to demonstration projects in the iron and steel sector.
Investment costs

Table 5.4 provides a breakdown of the investment needs implicit in the Baseline and BLUE scenarios. Total investments in the Baseline scenarios amount to between USD 2.0 trillion and USD 2.3 trillion between now and 2050. In the BLUE scenarios, these rise to between USD 2.3 trillion and USD 2.7 trillion. Total incremental costs for the iron and steel sector to reach the BLUE scenario outcomes are approximately USD 300 billion to USD 400 billion, roughly 15% to 20% higher than Baseline investment needs.

Table 5.4  Additional investment needs in the iron and steel sector to 2050: BLUE scenarios compared to Baseline scenarios

<table>
<thead>
<tr>
<th>USD bn</th>
<th>China</th>
<th>OECD Europe</th>
<th>India</th>
<th>United States</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>130 to 160</td>
<td>20 to 25</td>
<td>90 to 115</td>
<td>10 to 15</td>
<td>300 to 400</td>
</tr>
</tbody>
</table>

Cement

China is by far the largest cement producer with 49% of world production in 2007. India, the second-largest producer, accounts for only 6% of global cement production.

Cement production uses about 240 Mtoe of energy, equivalent to 80% of all energy used in non-metallic minerals production. The average final energy intensity for cement production for those countries with available data ranges from 2.9 GJ/t to 4.7 GJ/t cement, including electricity. The thermal energy needed ranges from around 3.2 GJ to 4.5 GJ/t of clinker produced. The cement industry has made significant strides in reducing energy consumption, with China reducing its thermal energy intensity per tonne of clinker by a quarter since 1990. The cement industry also uses significant amounts of electricity, equivalent to around 310 terawatt-hours (TWh) in 2007.

The industry is a significant source of CO₂ emissions. Coal accounts for around 60% of the fuel burned in cement kilns. Total direct CO₂ emissions from cement production amounted to 2.0 Gt CO₂ in 2007, with around 0.8 Gt CO₂ emitted from fuel combustion and 1.2 Gt CO₂ from processes.

Energy efficiency and CO₂ reduction potentials

The thermal energy consumption of the cement industry is strongly linked to the type of kiln used. The relatively efficient dry process with pre-heaters and pre-calciners is the technology of choice for new plants as shown by trends in the stock of plants in operation. The increasing share of dry-process kilns with pre-heaters and pre-calciners has had a clear impact on energy consumption in clinker production. The average thermal energy consumption per tonne of clinker has fallen by approximately 15% since 1990. The current average global intensity is 3.9 GJ per tonne of clinker.
Figure 5.13 ▶ Energy savings potential in 2007 for cement, based on BATs

Key point

China has the largest absolute potential for energy savings, but other countries have larger energy savings potential per unit of output.

A wet kiln can use between 5.9 GJ and 6.7 GJ/t clinker. Current BATs for six-stage pre-heater and pre-calciner kilns is in the range of 2.9 GJ to 3.3 GJ/t clinker. If all plants were BATs, assuming an average fuel need of 3.2 GJ/t clinker, 42 Mtoe a year of energy could be saved, equivalent to around 20% of current consumption. Shifting to BATs for electricity consumption would achieve savings of around 60 TWh (equivalent to around 5.2 Mtoe). The availability of clinker substitutes is sufficient to allow the cement-to-clinker ratio to be reduced to 0.7 globally, theoretically enabling a saving of a further 15 Mtoe of thermal energy. Taking into account all these potentials, the global intensity of cement production could be reduced by 0.9 GJ/t of cement produced, with significantly higher savings possible in many countries and regions (Figure 5.13).

CO₂ savings in cement production tend broadly to reflect the levels of energy saving. Shifting to BATs, maximising the use of clinker substitutes and increasing the proportion of alternative fuels could result in CO₂ savings of around 520 Mt CO₂ a year globally, including savings in process emissions.

Scenario results

Cement demand is assumed to grow from around 2 774 Mt in 2007 to 3 817 Mt in the low-demand case or 4 586 Mt in the high-demand case in 2050. Demand in China peaks between 2015 and 2030 in both cases as per-capita cement consumption nears the levels in more developed countries. China’s consumption is lower in both cases in 2050 than the 1 354 Mt it consumed in 2007, at 1 000 Mt in the low-demand case or 1 200 Mt in the high-demand case. Between 2007 and
2050, more than 95% of the growth in cement demand will come from non-OECD countries, reflecting the fact that many OECD countries are projected to experience declining populations between 2030 and 2050.

Total final energy consumption in the cement sector grows from 240 Mtoe in 2007 to 273 Mtoe in 2050 in the Baseline low-demand scenario and to 327 Mtoe in the Baseline high-demand scenario. In the BLUE scenarios, energy use is approximately 5% to 14% higher at 287 Mtoe in the BLUE low-demand case and 372 Mtoe in the BLUE high-demand case as an estimated 48 to 85 Mtoe of additional energy is needed for CCS.

The shift to BATs, the increased use of clinker substitutes and alternative fuels and the application of CCS reduce direct CO₂ emissions from the cement industry by around 20% below 2007 levels in the BLUE low- and high-demand scenarios (Figure 5.14). This represents a reduction from the Baseline level in 2050 of 0.85 Gt CO₂ in the BLUE low-demand scenario and 1.3 Gt CO₂ in the BLUE high-demand scenario. CCS is expected to contribute most of the savings, saving 0.5 Gt CO₂ in the BLUE low-demand scenario and 1.0 Gt CO₂ in the BLUE high-demand scenario. In both scenarios, CCS is essential to reduce emissions below today’s levels. CCS dominates total savings by 2050, accounting for more than half the reduction below the Baseline scenarios by that time.

**Figure 5.14** Direct emissions reduction by technology option for cement

<table>
<thead>
<tr>
<th>Technology Option</th>
<th>BLUE low</th>
<th>BLUE high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other fuel switching</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Alternative fuels</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Clinker substitutes</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>CCS process</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>CCS energy</td>
<td>1.4</td>
<td>1.4</td>
</tr>
</tbody>
</table>

**Key point**

CCS represents the largest share of CO₂ savings in the cement sector.

**Technology options**

A number of technology options need to be exploited to reduce emissions in the cement sector (Table 5.5). The four main options for the sector are increased energy efficiency and improvements in BATs; higher shares of alternative fuel use; the use of greater volumes of clinker substitutes; and CCS.
Cement companies should deploy existing BATs in new cement plants and retrofit energy efficiency equipment where economically viable. There is also a need to close down the remaining wet kilns which are almost twice as energy-intensive as current BATs. The use of less carbon-intensive fossil fuels and of more alternative fossil and biomass fuels also offers the possibility of reducing CO₂ intensity. Stronger policy support will be needed to reach the levels outlined in the BLUE scenarios. Further reductions in cement-to-clinker ratios will require additional R&D to assess substitution materials and to evaluate regional availability. The development and implementation of international standards for blended cements would also support greater use of clinker substitutes.

<table>
<thead>
<tr>
<th>Technology</th>
<th>R&amp;D needs</th>
<th>Demonstration needs</th>
<th>Deployment milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy efficiency and shift to BATs</td>
<td>Fluidised bed technology</td>
<td>Ongoing further improvements to BATs</td>
<td>Phase-out of wet kilns International standard for new kilns</td>
</tr>
<tr>
<td>Alternative fuels</td>
<td>Ongoing identification and classification of suitable alternative fuels</td>
<td></td>
<td>Share to rise from 5% in 2010 to 12% in 2020, 23% in 2030 and 37% by 2050</td>
</tr>
<tr>
<td>Clinker substitutes</td>
<td>Analyse substitution material properties and evaluate regional availability Develop and implement international standards for blended cements</td>
<td></td>
<td>Cement-to-clinker ratio falling from 77% in 2010 to 74% in 2020, 73% in 2030 and 71% by 2050</td>
</tr>
<tr>
<td>CCS post-combustion</td>
<td>Pilot plant needed by 2012</td>
<td>2015-2020</td>
<td>From 2020 for large new plants and retrofits</td>
</tr>
<tr>
<td>CCS oxyfuelling</td>
<td>Gas cleaning</td>
<td>2020-2030</td>
<td>All large new plants to be equipped with CCS from 2030</td>
</tr>
</tbody>
</table>

The widespread application of CCS is essential if the cement sector is to reduce CO₂ emissions below today’s levels. In the BLUE low- and high-demand scenarios, 0.5 Gt and 1.0 Gt of CO₂ respectively are sequestered annually in 2050. Reaching these levels implies that CCS needs to be demonstrated at cement plants from around 2015 in order to ensure that a number of technology platforms are tested as early as possible. This would be an essential precursor to the beginning of commercial deployment in 2020 to 2025.

Such a rapid expansion of CCS will require between 20% and 30% of new plants to be equipped with CCS by 2030 and some retrofitting of post-combustion technology to existing plant. As with other sectors, this implies that there is a 10-year window in which CCS needs to be demonstrated if it is to be deployed at its lowest possible cost. If CCS were not commercially available until 2030, achieving the BLUE scenarios would require greater retrofitting of CCS to large or medium-scale plants after 2030 in order to ensure that between 26% and 40% of the stock of cement kilns in 2050 are fitted with CCS. This would significantly increase the marginal cost in the BLUE scenarios.
Investment costs

The additional investment needed to achieve the CO₂ reduction outlined in the BLUE scenarios is in the range of USD 350 billion to USD 840 billion (Table 5.6). Much of the additional investment will be needed in developing countries where CO₂ policies are now emerging. Overcoming the barriers in developing economies posed by limited capital and multiple demands for its use will be critical.

Investment needs for the cement industry are dominated by the additional upfront costs of CCS installations at cement plants. In Europe, CCS could double the capital cost of a cement plant (ECRA, 2009), as well as increase energy use and operating costs. The total investment needs and marginal abatement costs for the cement industry are critically sensitive to the future costs of CCS. In the short term, CCS development and demonstration will require strong government support as industry cannot bear these costs alone. An estimated USD 2 billion to USD 3 billion is required to fund CCS demonstration projects in the cement industry and an additional USD 30 billion to USD 50 billion will be needed by 2030 for deployment.

Table 5.6 Additional investment needs in the cement sector to 2050: BLUE scenarios compared to Baseline scenarios

<table>
<thead>
<tr>
<th>USD bn</th>
<th>China</th>
<th>Europe</th>
<th>India</th>
<th>United States</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>50 to 130</td>
<td>35 to 100</td>
<td>50 to 150</td>
<td>30 to 80</td>
<td>350 to 840</td>
</tr>
</tbody>
</table>

Chemicals

The chemical and petrochemical sector is by far the largest industrial energy user, accounting for almost 30% of all industrial final energy demand. It accounts for roughly 10% of total worldwide final energy demand, equivalent to 879 Mtoe/yr, and is responsible for 7% of global CO₂ emissions. In 2007, the process energy requirements of the chemical and petrochemical sector emitted approximately 1 280 Mt CO₂, excluding indirect emissions from power use and from the treatment of post-consumer waste, e.g. from the incineration of plastics. Fossil fuels are used in the sector both for energy production and as feedstocks for the production of organic chemicals and a number of inorganic chemicals, including ammonia.

Energy efficiency and CO₂ reduction potentials

The global chemical and petrochemical sector has significant potential to improve its energy intensity through the implementation of best practice technology (BPT) in core chemical processes (121 Mtoe) and other opportunities for energy

---

2. Final process energy is the total of demand of fuel (excluding feedstock energy), steam use and electricity. Final energy is the sum of final process energy and feedstock energy. Primary energy use is the sum of final energy and the conversion losses for producing steam and electricity.

3. In the chemical and petrochemical sector, given the scale of most plants, it is more appropriate to analyse potentials by reference to the most advanced technologies that are currently in use at industrial scale. This is known as best practice technology (BPT) as distinct from the best available technology (BATs) reference points used in other contexts.
saving (Figure 5.15). Process intensification/integration, CHP, recycling and energy recovery all offer opportunities for reducing the industry’s energy use and CO₂ emissions. The total worldwide potential saving from these measures is approximately 235 Mtoe/yr in final energy and approximately 290 Mtoe/yr in primary energy use. The largest regional potential is in the United States.

**Figure 5.15** Energy savings potential in 2007 for chemicals, based on BPT

<table>
<thead>
<tr>
<th>Region</th>
<th>Process intensification</th>
<th>CHP</th>
<th>Recycling and energy recovery</th>
<th>Electricity savings potential</th>
<th>BPT (process heat savings potential)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>250</td>
<td>200</td>
<td>150</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>United States</td>
<td>200</td>
<td>150</td>
<td>100</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Japan</td>
<td>150</td>
<td>100</td>
<td>50</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td>China</td>
<td>100</td>
<td>50</td>
<td>25</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>50</td>
<td>25</td>
<td>12</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Benelux, FR, UK, DE, IT</td>
<td>25</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Korea</td>
<td>25</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Canada</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Brazil</td>
<td>10</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>India</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>China Taipei</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Key point**

The current technical potential for global energy savings in the chemical and petrochemical sector is estimated at 235 Mtoe.

**Scenario results**

Worldwide production of high-value chemicals (HVCs) is projected to grow by 8 Mt to 14 Mt a year from 2007 to 2050. This is similar to the 10 Mt a year growth from 1990 to 2005. HVC production between 2007 and 2050 increases by 330 Mt to 600 Mt in the Baseline scenarios. It grows by a smaller amount, around 245 Mt to 340 Mt, in the BLUE scenarios as higher recycling rates reduce the need for HVC production. Ammonia production rises at a higher rate between 2007 and 2050 than in the last decade, increasing by 63% (100 Mt) in the low-demand case and almost doubling (increasing by 140 Mt) in the high-demand case. Methanol production is also projected to increase at a higher rate between 2007 and 2050 than in the last decade, more than tripling in both the high- and low-demand cases. Global growth in the chemical sector will be fuelled by China, the Middle East and other developing Asia, with production relatively flat in both North America and Europe.

In the Baseline scenarios, total final energy use increases by between 119% and 163% by 2050 compared to 2007. In the same period, the BLUE scenarios show an increase in final energy use of 59% to 75%. In the Baseline scenarios, total energy use in 2050 reaches 1 925 Mtoe in the low-demand case and 2 310 Mtoe...
in the high-demand case compared to 880 Mtoe in 2007. Energy use in 2050 in the BLUE scenarios rises much less, reaching 1 400 Mtoe and 1 540 Mtoe in the low- and high-demand cases respectively as greater levels of energy efficiency help to reduce energy intensity.

Figure 5.16 Direct emissions reduction by technology option for chemicals and petrochemicals

![Graph showing direct emissions reduction by technology option for chemicals and petrochemicals.]

Key point

Energy efficiency offers the largest opportunities for CO₂ savings in the chemical and petrochemical sector.

Worldwide direct CO₂ emissions in the Baseline low- and high-demand scenarios are projected to more than double by 2050, increasing from 1.3 Gt in 2007 to 2.5 Gt and 2.9 Gt respectively in 2050. Worldwide direct CO₂ emissions by 2050 in the BLUE scenarios at around 1.2 Gt are about 7% lower than 2007 emissions and 52% (low-demand case) and 59% (high-demand case) lower than the Baseline scenario levels for 2050.

In the BLUE scenarios, the largest reductions in direct emissions come from energy efficiency improvements (Figure 5.16). These save an estimated 735 Mt CO₂ in the low-demand case and 935 Mt CO₂ in the high-demand case in 2050. In the BLUE high-demand scenario, fuel switching contributes emissions reductions of 200 Mt CO₂ in 2050, although in the BLUE low-demand scenario it contributes savings of only 85 Mt CO₂. CCS accounts for savings of 265 Mt CO₂ and 310 Mt CO₂ in 2050 in the BLUE low- and high-demand scenarios respectively.

Technology options

Developments in the last fifty years have seen the products of this sector, such as plastics, increasingly substitute for other engineering materials such as steel and glass.
Major productivity increases and improvements in material and process performance in other sectors, for example yields in the agricultural sector, have been enabled to a substantial extent by chemical products. The chemical and petrochemical sector continues to be very innovative. But it is unclear how it will develop in future, for example if the need to pass on substantially higher oil and gas prices slows down the demand for products of the industry. Even so, a growing world population is likely to require more fertilisers for food production and to help meet increased demand for biomass as a fuel and a feedstock. The chemical and petrochemical sector is also likely to play an important role in developing and supplying the materials needed to support growth in renewable energy and to enhance energy efficiency, such as lightweight materials for vehicles and more powerful batteries, and more effective agents for the removal of CO₂ from flue gases.

The implementation of BPT in the short term and of new technologies in the long term would enable the sector significantly to reduce both its energy needs and its CO₂ intensity. A wide range of technology options needs to be applied in order to reach the emission levels implicit in the BLUE scenarios. Ambitious R&D, spanning from basic to applied research, followed by strong and effective technology development is needed to reach these goals. New developments in catalysts, membranes and other separation processes, process intensification and bio-based chemicals could bring about very substantial energy savings. All countries should strive to achieve BPT levels by 2025. New technologies will need to be brought on stream from 2020 onwards. A number of technology goals will need to be met if the chemical and petrochemical sector is to contribute its full potential CO₂ emission savings (Table 5.7).

CCS can make an important contribution to reducing emissions in the sector. Early deployment should focus on implementation in ammonia plants. CCS in combination with large-scale CHP and in HVC production will also need to be developed for the sector to realise its full potential.

New investments are likely to remain in use for many decades. As companies make new investments in coming years, they will be making fundamental and in many cases irreversible choices about feedstocks. First-of-a-kind large-scale plants for the production of bio-based chemicals and plastics are currently being built. The experience gained by these plants and their products in the next 10 to 20 years will determine to a large extent the success or failure of bio-based chemicals and plastics. Policy support needs to extend over relatively long periods in order to be successful. Designing suitable and affordable policies for bio-based chemicals and plastics is a challenge given the complexity of the sector and its products, international trade agreements and the need to avoid displacing food production.

R&D on materials development and adapted design techniques that can, for example, maximise material efficiency and facilitate disassembly and separation is required to enable the potential of recycling fully to be exploited. Strong policy support is needed in order to expand collection schemes. Recycling can be optimised through the use of a portfolio of mechanical and chemical recycling steps, followed by highly efficient incineration with energy recovery.
Table 5.7 Technology options for the chemical industry

<table>
<thead>
<tr>
<th>Technology</th>
<th>R&amp;D needs</th>
<th>Demonstration needs</th>
<th>Deployment milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>New olefin production technologies</td>
<td>Improve methanol-to-olefin (MTO) processes and oxidative coupling of methane (OCM)</td>
<td></td>
<td>Currently under way with greater penetration from 2020</td>
</tr>
<tr>
<td>Other catalytic processes</td>
<td>Improve performance and further reduce gap to thermodynamically optimal catalytic process by 65% to 80%</td>
<td>Under way</td>
<td>Starting in 2020 to 2025</td>
</tr>
<tr>
<td>Membranes</td>
<td>Develop other novel separation technologies</td>
<td>Expand use of membrane separation technologies</td>
<td></td>
</tr>
<tr>
<td>Bio-based chemicals and plastics</td>
<td>Develop bio-based polymers</td>
<td>Bio-based monomers</td>
<td>Wider use of bio-based feedstocks from 2025</td>
</tr>
<tr>
<td>CCS for ammonia</td>
<td>Two plants by 2012</td>
<td></td>
<td>20 plants by 2020 and 50 plants by 2030</td>
</tr>
</tbody>
</table>

Investment costs

In ETP 2010, the BLUE scenarios bring into effect technologies that are cost-effective with a carbon price of up to USD 175/tCO₂. Cumulative investment needs up to 2050 are estimated at USD 4.1 trillion in the Baseline low-demand case and USD 4.7 trillion in the Baseline high-demand case. In the same period, additional investment of USD 0.4 trillion is needed in the BLUE low-demand case and USD 0.5 trillion in the BLUE high-demand case (Table 5.8), resulting in cumulative investments of USD 4.5 trillion and USD 5.2 trillion respectively.

If successfully developed, membrane technology and catalysts could be implemented at very low or even negative additional cost. This may also be the case for some process-intensification processes. Additional investment costs could, however, be substantial for process integration and for CCS, especially in smaller plants. The capital cost of new olefin technologies could be substantially larger than that of current technologies because of the increase in the process steps involved. Additional investment costs for bio-based plastics and chemicals could also be substantial although some products are likely to be significantly less expensive to produce than others.

Table 5.8 Additional investment needs in the chemical sector to 2050: BLUE scenarios compared to Baseline scenarios

<table>
<thead>
<tr>
<th>USD bn</th>
<th>China</th>
<th>Europe</th>
<th>India</th>
<th>United States</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>60 to 100</td>
<td>50 to 70</td>
<td>15 to 25</td>
<td>60 to 80</td>
<td>400 to 500</td>
</tr>
</tbody>
</table>

Pulp and paper

The pulp and paper sector is the fourth-largest industrial sector in terms of energy use, consuming 164 Mtoe of energy in 2007, 5% of total global industrial energy
consumption. The primary input for pulp and paper manufacture is wood. The industry, therefore, usually has ready access to biomass resources and it generates from biomass approximately a third of its own energy needs. It also produces energy as a by-product. The majority of the fuel used in pulp and paper making is used to produce heat. Just over a quarter is used to generate electricity.

Its large use of biomass makes the sector one of the least CO₂-intensive, although large variations exist between different countries depending on biomass availability and industry structure. The sector emitted 183 Mt of CO₂ in 2007, representing 2% of direct emissions from industry.

**Energy efficiency and CO₂ reduction potentials**

The main production facilities are either pulp mills or integrated paper and pulp mills. An integrated mill is more energy-efficient than the combination of a stand-alone pulp mill and paper mill because pulp drying can be avoided. But integrated plants require grid electricity as well as additional fuel.

Most of the energy efficiency improvement that has so far been achieved has come from integrated pulp and paper mills in which recovered heat is used in the production process, for example to dry the paper. Investment in heat recovery systems in stand-alone mechanical pulp mills is not economically viable.

**Figure 5.17** Energy savings potential in the pulp and paper sector in 2007, based on BATs

![Energy savings potential chart](chart.png)

**Key point**

Global technical potential for energy savings in the pulp and paper sector is estimated at 35 Mtoe with the largest savings potential in Canada and the United States.
The application of BATs would yield total energy savings of 14% for heat and electricity use, equivalent to nearly 16 Mtoe of heat and 6.8 Mtoe of electricity (Figure 5.17). If global recycling was increased to the current EU level of 60%, another 6 Mtoe of energy could be saved. Higher CHP use could achieve an additional saving of approximately 6 Mtoe. Total savings for the sector are estimated at approximately 35 Mtoe, equivalent to 21% of total current energy use.

Scenario results

Paper and paperboard consumption is assumed to continue to grow most strongly in non-OECD countries, especially in Asia where demand from China is expected to increase fivefold from current levels by 2050 in the high-demand cases. As a consequence, the global share of paper and paperboard consumption shifts significantly from OECD to non-OECD countries with the share from the former falling from 65% today to between 32% and 24% by 2050. Consumption in China and India could match that of all OECD countries by 2050 in the high-demand case. World paper production is estimated to reach almost 800 Mt by 2050 in the low-demand case and over 1 100 Mt in the high-demand case.

Recycling levels are already relatively high with a global recycling rate of 50%. Many countries are already at or near their practical limits. But in others, especially developing countries, some growth can be expected in the future. In the Baseline scenarios, recovered paper utilisation is expected to reach 54% in 2050, while in the BLUE scenarios these levels are assumed to grow further, to 60%. Higher recycling levels can significantly reduce energy use as recovered paper pulp uses 10 GJ to 13 GJ less energy per tonne than the production of virgin pulp.

Energy use in the pulp and paper sector is expected to rise from 164 Mtoe in 2007 to 304 Mtoe in 2050 in the Baseline low-demand scenario. In the BLUE low-demand scenario, energy use will reach 270 Mtoe in 2050, 11% less than in the Baseline scenario, as higher energy efficiency reduces energy intensity. Biomass today represents 33% of total energy use. This is expected to rise to approximately 60% in 2050 in both the BLUE low- and high-demand scenarios as fuel switching takes place to reduce emissions. Electricity consumption in the sector in 2050 is expected to rise from 43 Mtoe in 2007 to 77 Mtoe in the Baseline low-demand case and to 105 Mtoe in the Baseline high-demand case scenarios and to 69 Mtoe and 94 Mtoe in the equivalent BLUE scenarios. In all regions, the share of fossil fuels will need to fall significantly to achieve the BLUE scenario outcomes, although fossil fuels will still represent a large share of total fuel use in China and India.

In the BLUE scenarios, where CCS is applied to black liquor gasifiers in regions with a high usage of biomass, the sector becomes a CO\textsubscript{2} sink, reducing overall global emissions. Total direct and indirect emissions in the BLUE scenarios fall by 56% from 405 Mt in 2007 to 175 Mt in 2050. The decrease in direct emissions is significantly less, at 30%. This reflects the extent to which the decarbonisation of the power sector impacts on overall emissions in the pulp and paper sector.
**Key point**

Energy efficiency makes the largest contribution to CO₂ savings in the pulp and paper sector.

In the BLUE low-demand case in 2050, energy efficiency represents the largest share of savings as compared to the Baseline scenario, at 54%, followed by fuel switching which represents 35% (Figure 5.18). In the BLUE high-demand case, fuel switching plays the most important role in reducing emissions, accounting for 47% of the reduction, while energy efficiency contributes 36% of the reduction. By 2050, total emissions reductions in the sector are 264 Mt CO₂ in the BLUE low-demand scenario and 418 Mt CO₂ in the BLUE high-demand case. CCS, which is a later option for the sector, begins to have an impact by 2030 and accounts for 11% of the reductions in the BLUE low-demand scenario and 17% of the reductions in the BLUE high-demand scenario.

**Technology options**

The implementation of BATs and the future implementation of newly emerging technologies would enable the sector significantly to reduce both its energy needs and its CO₂ intensity. A wide range of technology options and opportunities need to be deployed if the outcomes implicit in the BLUE scenarios are to be achieved (Table 5.9). All countries need to try to achieve BATs levels by 2025 and to improve on BATs by 15% to 20% by 2035 through the wide deployment of black liquor and biomass gasification, increased waste heat recovery and new technologies in pulping and papermaking.

RD&D priorities should focus on improving biomass conversion technologies, more efficient water-extraction technologies and reducing the use of water in pulp washing and paper making. Improved reliability and gas clean-up for gasification is needed in the short term. Early commercial biomass-integrated gasification with combined cycle (BIGCC) plants need to be deployed within the next five to ten
years and wider deployment should occur from 2015 to 2025. In addition to black liquor gasification, lignin production from black liquor and biomass gasification with synfuel production also offers attractive opportunities to increase biomass use in the sector and to raise the profitability of pulp and paper mills.

### Table 5.9 Technology options for the pulp and paper industry

<table>
<thead>
<tr>
<th>Technology</th>
<th>R&amp;D needs</th>
<th>Demonstration needs</th>
<th>Deployment milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black liquor gasification</td>
<td>Improved reliability</td>
<td>Under way</td>
<td>Beginning in 2015 to 2025</td>
</tr>
<tr>
<td></td>
<td>and gas clean-up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass conversion to fuels and chemicals</td>
<td>Efficient and low-cost</td>
<td>Under way</td>
<td>Beginning in 2015 to 2025</td>
</tr>
<tr>
<td></td>
<td>removal of tar</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Production of high-value</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>chemicals and liquid</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>fuels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced water-removal technologies</td>
<td>Enhance water-removal</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>techniques</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCS</td>
<td>Two plants by 2020 - 2025</td>
<td>Starting in 2030</td>
<td></td>
</tr>
</tbody>
</table>

In OECD countries, significant attention has been placed on developing biorefineries within the forest-based industries. The development of biorefineries within the pulp and paper industry could have positive impacts on the energy intensity, carbon intensity and profitability of the sector.

Additional CO$_2$ emissions reductions can be achieved if CCS is developed for BIGCC technology. The scenario analysis shows that an additional 30 Mt to 70 Mt of CO$_2$ can be saved in the sector with CCS. To reach this level of CCS, at least two demonstration plants would need to be on stream by 2020 to 2025, with more extensive deployment beginning by 2030. By 2050, approximately one-third of all CO$_2$ emitted from black liquor gasification would need to be captured and stored if the outcomes implicit in the BLUE scenarios were to be achieved.

### Investment costs

Total investments in the Baseline scenarios amount to between USD 1.2 trillion and USD 1.35 trillion between now and 2050. In the BLUE scenarios, the additional investment costs over Baseline investments are USD 140 billion in the low-demand scenario and nearly USD 160 billion in the high-demand scenario (Table 5.10).

### Table 5.10 Additional investment needs in the pulp and paper sector to 2050: BLUE scenarios compared to Baseline scenarios

<table>
<thead>
<tr>
<th>USD bn</th>
<th>China</th>
<th>Europe</th>
<th>India</th>
<th>United States</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>30 to 40</td>
<td>25 to 35</td>
<td>5 to 10</td>
<td>40 to 50</td>
<td>140 to 160</td>
</tr>
</tbody>
</table>
Aluminium

Final energy consumption in the global aluminium industry in 2007 was estimated to be 93 Mtoe. The industry is highly electricity-intensive. Primary aluminium smelters used just over 50 Mtoe of electricity in 2007, equivalent to about 4% of global electricity consumption. In total, the aluminium industry emits 0.4 Gt CO₂-equivalent of greenhouse gases, including process emissions and indirect emissions from electricity production, equivalent to just under 1% of total global greenhouse-gas emissions.

Energy efficiency and CO₂ reduction potentials

The industry has steadily improved its energy efficiency in recent years. Globally, the electricity consumption of smelters has improved by an average of 0.4% a year since 1980. Smelters used 15.5 MWh/t of primary aluminium produced in 2007. China and Africa have the newest and most efficient smelters. Energy consumption in alumina refineries has also been reduced over time. The world average use is now around 17 GJ/t of alumina. China has the most energy-intensive alumina refineries because of the characteristics of its bauxite deposits.

Figure 5.19 Energy savings potential in 2007 in the aluminium sector, based on BATs

Key point

Implementation of BATs in aluminium refineries and smelters offers significant opportunities for energy savings.

4. IEA estimate based on International Aluminium Institute data for 2007 on the global average specific power consumption of smelters and global production of primary aluminium.
The CO₂ impact of aluminium production depends on the fuel mix of the electricity that is used to produce it. Countries such as those in North America that use significant amounts of hydropower can produce aluminium less CO₂-intensively than countries such as China that use significant amounts of coal in their electricity mix.

BATs offers the opportunity to reduce energy use in aluminium production by 10% compared with current levels (Figure 5.19). This is equivalent to final energy savings of about 9.7 Mtoe a year and direct and indirect emissions savings of 47 Mt CO₂.

Scenario results

Demand for aluminium is assumed to grow substantially up to 2050 because of higher consumption across a wide range of sectors, especially transport, buildings and engineering. World average per-capita demand almost doubles in the Baseline low-demand scenario and grows by more than 2.5 times in the Baseline high-demand scenario. To meet this increased demand, primary aluminium production reaches 95 Mt by 2050 in the Baseline low-demand scenario and increases to 127 Mt in the high-demand case. In both scenarios, most growth is outside the OECD, with strong increases in Asia, the economies in transition, and Africa and the Middle East.

Aluminium recycling is also expected to increase strongly. In the Baseline scenarios, recycled production rises to 47 Mt in 2050 in the low-demand case and to 63 Mt in the high-demand case, continuing to represent around one-third of finished products. In the two BLUE scenarios, total aluminium production is assumed to be the same as in the corresponding Baseline scenarios, but the recycled production increases to 56 Mt and 76 Mt in 2050 in the low- and high-demand BLUE scenarios respectively, representing about 40% of finished products.5

In the BLUE scenarios, energy use in 2050 is 14% (low-demand case) to 28% (high-demand case) lower than in the equivalent Baseline scenarios. In the BLUE low-demand scenario, these energy efficiency gains are largely achieved through further development of existing technology together with some deployment of new technologies. In the BLUE high-demand scenario, the widespread introduction of wetted drained cathodes and inert anodes from 2015 and of carbothermic reduction technologies from 2030 is assumed to reduce the global average electricity intensity of smelting in 2050 to 10.9 MWh/t of primary aluminium.

In the Baseline scenarios, total direct and indirect CO₂ emissions grow from around 0.4 Gt in 2007 to 1.0 Gt (low-demand case) and 1.3 Gt (high-demand case) by 2050.6 Emissions grow less than final energy use as a result of the lower CO₂ intensity of the fuel mix in 2050 resulting from fuel switching. In the BLUE scenarios, total CO₂ emissions fall by 63% in the low-demand case or 72% in the high-demand case compared to the equivalent Baseline scenario cases, reaching 0.4 Gt in 2050, around 21% lower than current levels. Most of the CO₂ emissions reductions come from the use of low-carbon electricity rather than from the adoption of more

5. Production of aluminium is higher than demand as some of the aluminium is returned for recycling by customers before being made into finished products, and a small percentage is lost during the recycling process.
6. As indirect emissions account for 75% of total emissions in the aluminium industry it is important to look at total direct and indirect emissions for this sector.
expensive measures to reduce direct emissions from the aluminium industry itself. This suggests that an important part of the strategy for reducing emissions in this industry may lie in locating smelters close to sources of CO$_2$-free electricity such as hydro or nuclear power stations.

**Figure 5.20** Direct emissions reduction by technology option for aluminium

![Graph showing direct emissions reduction by technology option for aluminium](image)

**Key point**

Achieving deep cuts in CO$_2$ emissions in the high-demand scenario, requires significant reductions in direct emissions.

However, the decarbonisation of the power sector will not be sufficient to achieve the emissions reduction required in the BLUE scenarios. Additional CO$_2$ savings that are needed will have to come from direct emissions reductions. Reductions in direct emissions are, therefore, significantly greater in the BLUE high-demand scenario than in the BLUE low-demand scenario (Figure 5.20). In the BLUE low-demand scenario, about 65% of the direct emissions reductions come from recycling. In the BLUE high-demand scenario, recycling makes a much smaller contribution, with the largest share of reduction coming from improved energy efficiency.

**Technology options**

Reducing CO$_2$ emissions in the generation of the electricity that is used in smelters is the single largest opportunity for long-term emissions reduction in the aluminium sector. Currently, around 40% to 50% of the total electricity used by the aluminium industry comes from zero-carbon hydroelectric sources, often in remote locations where there are few competing uses for the electricity. Measures to create a global carbon price would encourage new aluminium plants to be sited where they have access to cheap, low-carbon electricity. In the longer term, the average CO$_2$ intensity of grid electricity is likely to decrease substantially in many countries so that by 2050 low-carbon grid electricity may become the norm.
Increasing the share of recycling in total production can help reduce energy use and CO₂ emissions. But given the long lifetime of aluminium in some markets and products, over three-quarters of the aluminium ever produced is still in use. Globally, recycled production accounts for around one-third of total aluminium production. In the BLUE scenarios, it is assumed that by 2050 this can be increased to 40% of total production. Although this is a relatively small percentage increase, in absolute terms it is very significant.

Future technological developments could also offer opportunities to reduce the direct emissions of CO₂ from aluminium smelting (Table 5.11). But although the two most promising technological developments — inert anodes and carbothermic reduction — have both been the subject of research for many years, neither has yet reached commercial scale. An alternative would be to combine conventional cell technologies with CCS, but this option is also still only at the research stage.

<table>
<thead>
<tr>
<th>Technology</th>
<th>R&amp;D needs</th>
<th>Demonstration needs</th>
<th>Deployment milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetted drained cathodes</td>
<td>Ready for demonstration</td>
<td>Deployment to start by 2015 with full commercialisation by 2020</td>
<td></td>
</tr>
<tr>
<td>Inert anodes</td>
<td>Extensive testing at laboratory and batch scale</td>
<td>Ready to be demonstrated at plant level</td>
<td>Deployment to start in 2015-2020 with full commercialisation by 2030</td>
</tr>
<tr>
<td>Carbothermic reduction</td>
<td>Extensive research under way</td>
<td>2020 - 2025</td>
<td>Deployment to start between 2030 and 2040 with full commercialisation by 2050</td>
</tr>
<tr>
<td>Kaolinite reduction</td>
<td>Research under way</td>
<td>2025 - 2030</td>
<td>Deployment to start between 2035 and 2045</td>
</tr>
</tbody>
</table>

**Table 5.11** Technology options for the aluminium industry

**Investment costs**

Total investment costs over the period 2007 to 2050 in the Baseline scenarios are USD 840 billion in the low-demand case and USD 1 150 billion in the high-demand case. For the BLUE scenarios, the net additional investment costs are USD 60 billion in the low-demand case and USD 95 billion in the high-demand case, around 7% to 8% more than in the equivalent Baseline scenarios (Table 5.12). This takes account of the additional investment costs of more efficient refinery and smelter technologies, plus some investment savings in anode production as carbon anodes are replaced by inert anodes.

<table>
<thead>
<tr>
<th>USD bn</th>
<th>China</th>
<th>Europe</th>
<th>India</th>
<th>United States</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>20 to 30</td>
<td>7 to 10</td>
<td>3 to 6</td>
<td>5 to 6</td>
<td>60 to 95</td>
</tr>
</tbody>
</table>

7. The investment calculation excludes the additional costs of low- or zero-carbon electricity generating capacity.
Industry-wide regional implications

A significant reduction in CO₂ emissions in industry will only be possible if all regions contribute. Actions in OECD countries alone, where emissions today represent 33% of total industrial emissions, would not be enough. Industrial production growth will continue to be strongest in non-OECD countries, with over 80% of total industrial emissions in 2050 expected in developing countries in the Baseline scenarios as compared to 66% today.

The BLUE scenarios examine the implications of a policy objective to halve global energy-related CO₂ emissions in 2050 compared with today’s level. In the BLUE scenarios, all regions need to show a sharp decrease in emissions by 2050, ranging from 44% to 54% lower than in the Baseline scenarios (Figure 5.21). If industry is to contribute the 24% reduction in emissions that it needs to contribute to the achievement of the overall 50% reduction in emissions, all regions will need significantly to reduce the CO₂ intensity of their industrial operations.

In the Baseline scenarios, regional emissions grow fastest in India, other developing Asia and in Africa and the Middle East where current levels of industrial development are significantly below current global levels and where industrial production is expected to grow at the fastest rates. China’s emissions will continue to rise rapidly in the next 20 years but then rise only moderately as the country’s consumption of the most CO₂-intensive products, such as cement and iron and steel, begins to level off after 2030.

**Figure 5.21** Direct CO₂ emissions in industry by region in the Baseline and BLUE scenarios, 2007-50

![CO₂ emissions by region](image)

**Key point**

In the BLUE low-demand scenario, all regions will need significantly to reduce future emissions.

In the Baseline scenarios, emissions are expected to continue to rise year on year in all regions through to 2050. In the BLUE scenarios, emissions peak between 2015
and 2020 and then begin to decline as more efficient and cleaner technology is introduced. The largest contributor to the emissions reduction in the BLUE scenarios is expected to be China, given its dominant position in industry today.

Emissions from OECD countries decrease significantly in the BLUE scenarios, falling by more than half by 2050. With lower rates of production growth than China’s, the OECD will contribute smaller reductions than China in all scenarios in 2050. Although it is important that OECD countries take the lead in terms of technology deployment and diffusion, measures in the OECD alone will not be sufficient to reduce global emissions from industry. Non-OECD countries also need to contribute.

As domestic consumption feeds demand, India’s industrial CO₂ emissions in the Baseline scenarios grow the most of all countries. In the BLUE scenarios, India’s emissions rise at a slower rate, but still almost double from today’s levels by 2050. Industrial production in other developing Asia and in Africa and the Middle East is also expected to grow strongly. These three regions account for 23% of total global industry emissions by 2050, significantly surpassing total OECD industry emissions. Effort will also be required in these regions to reduce the CO₂ intensity of industrial production if global industry is to achieve significant reductions in emissions. Strong support for the poorest regions will be needed to promote technology transfer and deployment.

Table 5.13  Direct CO₂ reductions in industry by region in the Baseline and BLUE low-demand scenarios

<table>
<thead>
<tr>
<th>Region</th>
<th>2007 Mt CO₂</th>
<th>Baseline low 2050 Mt CO₂</th>
<th>BLUE low 2050 Mt CO₂</th>
<th>Reduction Baseline 2050 vs BLUE 2050</th>
<th>Reduction BLUE 2050 vs 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>2 650</td>
<td>3 545</td>
<td>1 981</td>
<td>-44%</td>
<td>-25%</td>
</tr>
<tr>
<td>India</td>
<td>413</td>
<td>1 563</td>
<td>828</td>
<td>-47%</td>
<td>100%</td>
</tr>
<tr>
<td>OECD Europe</td>
<td>932</td>
<td>648</td>
<td>316</td>
<td>-51%</td>
<td>-66%</td>
</tr>
<tr>
<td>OECD North America</td>
<td>906</td>
<td>884</td>
<td>404</td>
<td>-54%</td>
<td>-55%</td>
</tr>
<tr>
<td>OECD Pacific</td>
<td>635</td>
<td>480</td>
<td>229</td>
<td>-52%</td>
<td>-64%</td>
</tr>
<tr>
<td>Economies in transition</td>
<td>620</td>
<td>827</td>
<td>421</td>
<td>-49%</td>
<td>-32%</td>
</tr>
<tr>
<td>Other developing Asia</td>
<td>566</td>
<td>1 183</td>
<td>576</td>
<td>-51%</td>
<td>2%</td>
</tr>
<tr>
<td>Africa and Middle East</td>
<td>539</td>
<td>1 409</td>
<td>717</td>
<td>-49%</td>
<td>33%</td>
</tr>
<tr>
<td>Latin America</td>
<td>310</td>
<td>485</td>
<td>271</td>
<td>-44%</td>
<td>-13%</td>
</tr>
<tr>
<td>Total</td>
<td>7 573</td>
<td>11 025</td>
<td>5 742</td>
<td>-48%</td>
<td>-24%</td>
</tr>
</tbody>
</table>

Note: In the high-demand scenario, emissions reductions show a similar pattern.

**Investment costs**

The additional investment needs to achieve the results in the BLUE scenarios by 2050 are estimated to be between USD 2 trillion and USD 2.5 trillion higher than in the Baseline scenarios, with most investment being needed in the cement, iron and steel and chemical sectors (Table 5.14). These sectors account for the largest share...
of emissions in industry. Total additional investments in industry represent just 4% of the total incremental costs needed across all sectors to halve global CO₂ emissions. With the exception of cement, where investment needs in the BLUE scenarios are more than 50% higher than in the Baseline scenarios, investments in the other sectors are estimated to be 10% to 15% higher than in the Baseline scenarios.

The investment in new technologies will yield significant savings in fossil fuel consumption, but lead to increased biofuel and feedstock costs. Many of the energy efficiency investments are already competitive on the basis of life-cycle costs: total cumulative undiscounted fuel savings are estimated at USD 22 trillion. These savings are calculated on the basis of the difference between fuel costs in the Baseline and BLUE scenarios over the 2010 to 2050 period. If the fuel savings are discounted at 10%, the cumulative fuel savings fall to just USD 2.3 trillion and discounted additional investment costs fall to USD 0.3 trillion, making the net savings for industry under the BLUE scenarios USD 2.0 trillion. These estimates do not include the extra costs of achieving a near-decarbonised power sector in the BLUE scenarios.

Table 5.14  
Investment needs in industry in the Baseline and BLUE scenarios  
(USD bn)

<table>
<thead>
<tr>
<th></th>
<th>Total investment needs Baseline 2010-2050</th>
<th>Total investment needs BLUE 2010-2050</th>
<th>Additional investment needs (BLUE scenarios compared to Baseline)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron and steel</td>
<td>2 000 – 2 300</td>
<td>2 300 – 2 700</td>
<td>300 – 400</td>
</tr>
<tr>
<td>Cement</td>
<td>760 – 970</td>
<td>1 200 – 1 640</td>
<td>440 – 670</td>
</tr>
<tr>
<td>Chemicals and petrochemicals</td>
<td>4 100 – 4 700</td>
<td>4 500 – 5 200</td>
<td>400 – 500</td>
</tr>
<tr>
<td>Pulp and paper</td>
<td>1 220 – 1 350</td>
<td>1 360 – 1 510</td>
<td>140 – 160</td>
</tr>
<tr>
<td>Aluminium</td>
<td>660 – 910</td>
<td>720 – 1 000</td>
<td>60 – 90</td>
</tr>
<tr>
<td>Total industry</td>
<td>2 000 – 2 500</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Industry measures to reduce CO₂ emissions have different marginal abatement costs. Many energy efficiency options, for example, are cost-effective on a life-cycle basis provided they are introduced during the regular capital stock turnover cycle. For the most part, these options have negative or low marginal costs as the additional investment costs are largely or completely offset by fuel savings.

The industrial use of CCS is generally more expensive than CCS for coal-fired power plants, but is essential for deep emissions reductions in industries such as cement and iron and steel. CCS in industry falls within the range of USD 50/tCO₂ to USD 100/tCO₂ saved. Other more expensive options, costing up to USD 175/tCO₂ saved, include higher levels of recycling, and fuel and feedstock substitution, including switching to biomass feedstock in the chemical and iron and steel sectors.

8. In the Baseline scenario, Baseline fuel prices are used and in the BLUE scenario, BLUE fuel prices are used.
Policy changes needed to support technology transition in industry

Bringing about the technology transition that is needed to reduce emissions in industry will not be easy. It will require both a step change in policy implementation by governments and unprecedented investment in best practices and new technologies by industry. Engaging developing countries and their industries in this transition will also be vital, since most of the future growth in industrial production and, therefore, CO₂ emissions, will happen in countries outside the OECD region.

Given these considerations, a global system of emissions trading could eventually be crucial to create the conditions for global action to reduce CO₂ emissions from industry. But a worldwide carbon market is unlikely to emerge immediately. In the short to medium term, in order to encourage the urgent action that is required to stimulate the deployment of new technologies while addressing concerns about competitiveness and carbon leakage, it may be necessary as a first step to seek to secure international agreements covering some of the main energy-intensive sectors. Meanwhile, national energy efficiency and CO₂ policies will need to address specific sectors or particular barriers through standards, incentives and regulatory reform, including the removal of energy price subsidies.

Governments collectively and individually need to adopt challenging but achievable long-term greenhouse-gas mitigation goals and to allow flexibility to enable these goals to be met at least cost. This will facilitate and encourage the innovation of least-cost technologies to reduce greenhouse-gas emissions. Policy instruments can include market mechanisms, fiscal policies, regulatory measures and information schemes. Policies that foster increased recycling and/or changes in materials use can also play an important role.

To complement policies that generate market pull, many new technologies will need government support while in the RD&D phases before they become commercially viable. There is an urgent need for a major acceleration of RD&D in breakthrough technologies that have the potential to change industrial energy use or reduce greenhouse-gas emissions. Support for demonstration projects will be particularly important. This will require greater international collaboration and will need to include mechanisms to facilitate the transfer and deployment of low-carbon technologies in developing countries. Policy support to secure public acceptance of certain new technologies may also be important if they are to achieve more widespread deployment.

From sectoral agreements to global emissions trading

In any effective global emissions trading system, crediting mechanisms will need to encourage investments in emissions reductions where they are least expensive. In a number of cases, this will be in developing countries. The design of such approaches should ensure that in the long term they do not become a subsidy to developing countries at the expense of countries with carbon constraints.
The challenge for policy makers is to turn current concepts for sectoral agreements into effective international policy instruments which will foster the rapid, cost-effective deployment of BATs and provide a strong signal to make greenhouse-gas mitigation a priority for innovation.

**Improving industrial data coverage should be a priority**

The establishment of national sector-wide baselines requires statistical data that may not exist or be readily available in most developing countries. Even in the areas where international industry federations have been active, coverage is often limited to member countries and/or companies. In other cases, sectoral statistics may exist but they may need to be evaluated to establish confidence that they could form the basis of emission baselines and of measures of performance that could be used to determine emission credits on the international market. The collection of such data also raises issues of data confidentiality at the plant level.

Industry initiatives have also shown the importance of establishing clear sectoral boundaries. Major progress has been achieved, including through the Asia-Pacific Partnership on Clean Development and Climate (APP), to strengthen existing performance measurement practices (CCAP et al., 2008). But there is also a need to allow for some flexibility in terms of the application of sectoral boundaries. One forum in which such methodological issues could be discussed with a view to developing standardised approaches is the International Organization for Standardization (ISO). The World Steel Association, for example, has already launched an initiative to standardise statistical approaches in the steel industry in co-operation with the ISO.

More work is also needed to establish the data that should underpin sectoral baselines. Countries may not be prepared to negotiate baselines without some knowledge of their own potential to reduce emissions and of the cost of achieving such reductions. Much is already known about mitigation technologies and best practices. But the cost of avoiding CO₂ emissions depends very heavily on national circumstances. Japan’s submission to the United Nations Framework Convention on Climate Change (UNFCCC) illustrates how an inventory of existing practices and technologies, in addition to robust performance measurements, needs to be established if governments and/or sectors are to set ambitious but achievable targets.

Achieving significant reductions in greenhouse-gas emissions from industry will require costs to be attached to those emissions through policy measures. Existing schemes suggest that the system of caps and flexibility mechanisms embedded in the Kyoto Protocol architecture is not sufficient to trigger effective mitigation action. Sectoral agreements, which provide a means to engage effort in developing countries more effectively, could offer the promise of a “new deal” that would result in a more effective regime to reduce global greenhouse-gas emissions.

**Pathway to the next Industrial Revolution**

The implementation of current BATs could reduce industrial energy use by up to between 10% and 26%. This should be the first priority in the short term. But this will
be nowhere near enough to achieve absolute reductions in CO₂ emission levels as production is expected to double or triple in many sectors. Continued improvements in energy efficiency offer the largest and least expensive way of achieving CO₂ savings over the period to 2050 (Figure 5.22). Energy efficiency gains will need to increase to 1.2% a year, double the rate seen in the Baseline scenarios. This will require the development of new energy-efficient technologies. Many new technologies which can support these outcomes, such as smelting reduction, new separation membranes, black liquor and biomass gasification, regenerative burner systems and advanced CHP, are currently being developed, demonstrated and adopted by industry.

**Figure 5.22** Options for reducing direct CO₂ emissions from industry to 2050

New low-carbon fuels and technologies will also be needed, together with increased recycling and energy recovery. The use of biomass and electricity as CO₂-free energy carriers will make a significant contribution to industry’s reductions in emissions. Although the technologies required are often sector-specific, the development and deployment of CCS will be critical for achieving deep emissions reductions in a number of sectors, particularly in the iron and steel and cement sectors.

Additional RD&D is needed to develop breakthrough process technologies that allow for the CO₂-free production of materials and to advance understanding of system approaches such as the optimisation of life cycles through recycling and the use of more efficient materials. These longer-term options will be needed in the second half of this century to ensure sustainability of industrial processes to the end of the century and beyond.

Technology development is fraught with uncertainties. Some of the technologies identified may never come to fruition, but future research may also deliver new technologies or breakthroughs that are not currently foreseen. A portfolio approach to the necessary RD&D can help to spread risks and help reduce the uncertainty of outcomes.
Key findings

- In the Baseline scenario, global final energy demand in buildings increases by 60% between 2007 and 2050. Carbon dioxide (CO₂) emissions from the sector, including those associated with electricity use, nearly double from 8.1 gigatonnes (Gt) of CO₂ to 15.2 Gt CO₂. This is driven by a 67% increase in the number of households, a near tripling of the service building area, higher ownership rates for existing energy-consuming devices, and increasing demand for new types of energy services.

- The BLUE Map scenario shows the part that the buildings sector can play in securing a more sustainable energy future. In this scenario, CO₂ emissions are 83% lower than in the Baseline scenario in 2050. Most of this saving comes from the decarbonisation of the electricity used in the sector (6.8 Gt CO₂), from energy efficiency and from the switch to low- and zero-carbon technologies (5.8 Gt CO₂).

- The additional investment needs to transform the buildings sector in the BLUE Map scenario are estimated to be USD 7.9 trillion in the residential sector and USD 4.4 trillion in the service sector. These investments achieve significant fuel savings, totalling USD 51 trillion between 2010 and 2050 at wholesale prices. Discounting the investment and fuel savings at 3% reduces the net saving to USD 18.6 trillion. Even at a 10% discount rate, these measures save USD 5.3 trillion net by 2050.

- The implementation of currently available low-cost energy efficiency options is essential to achieve cost-effective CO₂ emissions reductions in the short run. This will buy time to develop and deploy those technologies that are either currently more expensive, or not commercialised, and that can significantly improve efficiency or help decarbonise energy consumption in buildings in the longer term. These include highly efficient heat pumps for heating and cooling, solar thermal space and water heating, and combined heat and power (CHP) systems with hydrogen fuel cells.

- The main barriers are higher initial costs, lack of consumer awareness of technologies and their potential, split incentives and the low priority placed on energy efficiency, as well as the fact that the true costs of CO₂ emissions are not generally carried by consumers. Overcoming these barriers will require a comprehensive, sequenced policy package. This must target specific barriers with effective policy responses. These may include information campaigns, fiscal and financial incentives, and minimum energy performance standards. They must address financial constraints, develop industry capacity and boost investment in research and development (R&D).

- The policy challenge in the OECD and the economies in transition (EITs) is very different from that in developing countries. In the OECD and EITs, space heating in the residential sector results in very significant CO₂ emissions, while much of the current building stock is likely to remain in use for many decades. Most of the savings potential, therefore, lies in retrofitting technologies in existing buildings. In developing countries, where new building growth will be very rapid, opportunities exist to improve efficiency standards relatively strongly and quickly.
In the service sector, improvements in the building shell of new buildings, together with highly efficient heating, cooling and ventilation systems will be needed to achieve the CO₂ emissions reductions in the BLUE Map scenario. Significant policy measures to improve the efficiency of energy use in lighting and other electrical end uses, such as office equipment, information technology equipment and refrigeration, will also be required given their larger share of total use compared to the residential sector.

Reducing heating and cooling loads through building shell measures is not enough on its own to achieve the BLUE Map scenario outcomes. The deployment of low- and zero-carbon technologies, such as heat pumps, solar thermal, CHP and on-site electricity generated from renewables will also be required to improve efficiency and reduce CO₂ emissions.

Overview of the residential and service sectors

Residential, service sector and public buildings use a wide array of technologies. They are used in the building envelope and its insulation, in space heating and cooling systems, in water heating systems, in lighting, in appliances and consumer products, and in business equipment. From an energy perspective, buildings are complex systems in which the interaction of technologies almost always has an influence on energy demand. Occupancy profiles, the behaviour of occupants and the local climate all affect overall energy demand in a building.

Most buildings last for decades. Some last for centuries. More than half of the current global building stock will still be standing in 2050. In the OECD, this will be closer to three-quarters. Buildings are much more frequently refurbished than replaced. This has significant implications for policy makers. The very low retirement rate of the residential building stock in OECD countries is a significant constraint, particularly on reducing heating and cooling demand in the more ambitious CO₂ reduction scenarios. Service sector buildings are generally less constrained in this respect, as they are subject to much earlier retirement or to significant refurbishment.

Energy-consuming technologies and appliances are changed much more frequently than buildings. Heating, ventilation and air-conditioning (HVAC) systems are generally changed every 15 to 20 years. Roofs, facades and windows need renovation periodically. Office equipment is often changed after three to five years. Household appliances are changed every 5 to 15 years. Consumables such as light bulbs are changed in much shorter timeframes. Choosing the best available technology (BAT) at the time of renovation or purchase is important in reducing energy demand in buildings. It also has an impact on the costs and benefits associated with energy savings.

Buildings emissions are growing rapidly with the rapid expansion of both the built environment and the ownership of energy-consuming equipment. In the service sector, architectural trends are also increasing the energy intensity of new buildings.

1. These are collectively referred to as the “buildings sector” in this chapter. It comprises residential buildings, plus those of the service sector. The service sector includes activities related to trade, finance, real estate, public administration, health, food and lodging, education and commercial services (ISIC codes 50-55 and 65-93). This is sometimes also referred to as the commercial and public service sector.
as large window surfaces become the norm. Policies to improve energy efficiency in new and existing buildings need to be designed to ensure that new structures are built to the highest standards of efficiency. Policies should foster new technologies both in buildings themselves and in the energy-using equipment inside them. Ensuring that these technologies are integrated into the smart energy network of the future will facilitate energy saving opportunities and unlock energy security benefits.

A wide range of technologies are already available that can significantly reduce CO₂ emissions in new and existing buildings. Many of these technologies are already economic on the basis of total life-cycle costs. But non-economic barriers can significantly slow their penetration. Government policies need to target these barriers. Additional R&D effort is also needed to expand the range of applications in which technologies can be deployed and to optimise their performance in a wider range of operating and climate conditions. Ensuring that these technologies are taken up will require strong policy action and integrated strategies on the part of the construction industry, developers, building owners, policy makers and building occupants (WBCSD, 2009).

Building stock turnover and heating and cooling

Achieving significant energy and CO₂ emissions reductions in the buildings sector is technically possible, but a challenging policy goal. Three fundamental issues need to be addressed by specific policies:

- Population, household numbers and service sector activity will grow significantly faster in developing countries to 2050, than in the OECD and EITs.
- Residential buildings, particularly in OECD countries, have very long life spans.
- Heating loads are large in the OECD and the EITs, while cooling loads are much more important in most developing countries.

The implications for policy makers of these issues are significant. The achievement of the deep emission cuts envisaged in the BLUE Map scenario will require a transformation of the current building stock in OECD countries by 2050. This is already technically achievable. But making it happen will require consumers to invest in technologies with potentially higher investment costs. And it will require unprecedented and well targeted policy direction and support. Policy efforts will need to be well tuned to local circumstances. For example, space heating is predominantly an issue for OECD countries. The issue for non-OECD countries will, more often, be to come to grips with the potentially very large growth in the energy demand for cooling.

Current building stock and energy consumption

Households: the residential building stock and its characteristics

The world’s population was 6.6 billion in 2007 (World Bank, 2009). OECD countries had an estimated 425 million occupied households in 2005, although the total number of dwellings is around 10% higher than this. Data for non-OECD
countries are not always available and household numbers have been estimated as a basis for the projection of future energy consumption. China had an estimated 373 million households in 2005, with 190 million being in urban areas (LBNL, 2008). In India, total household numbers were estimated to be 219 million in 2006/07 with 58 million urban households (NSSO, 2008).

Even in OECD countries with very modest population growth rates, household numbers increased between 1990 and 2005. The G7 countries accounted for around two-thirds of all households in OECD countries in 2005, down from around 70% in 1990.

The share of single-family buildings and multi-family buildings varies by country and region. Single-family buildings dominate in Brazil, India and the United States, whereas in Europe, China and India around 50% are multi-family buildings (WBCSD, 2009). In Europe, average area per dwelling is greater in single-family buildings, such that they account for around two-thirds of total built area.

The average number of persons per household in the IEA countries for which data are available was 2.9 in 1990 and 2.6 in 2006, a decline of 12%. In Finland, the number of persons per household dropped below two in 2006. In Korea, occupancy rates fell from 5.8 to 3.6 persons per household in 2006. In India, the average number of people per urban household dropped from 5.3 in 1990 to 4.3 in 2005, with a similar reduction from 5.6 to 4.9 people per rural household in the same period (de la Rue du Can et al., 2009). In China, the average number of persons per household has fallen from 4.8 to 4.1 in rural areas and from 3.5 to 3 in urban areas between 1990 and 2006 (LBNL, 2008).

Since 1990, the average size of individual dwellings has generally increased in the countries for which IEA data are available, except in Greece, Italy, Korea and Sweden. Average dwelling size increased on average by eight square metres (m²), or 9%, between 1990 and 2006. In OECD countries, the largest increase in absolute terms was in the United States, where the average dwelling size increased from 147m² to 172m² (17%). In China, urban households increased in size from 48m² in 1990 to 77m² (60%) in 2005, with the increase in rural households being from 86m² to 121m² (41%) over the same period.

Although building shells have a significant effect on energy consumption, the total energy consumption of buildings is also determined by the appliances, fittings and heating and cooling systems inside them. These systems have very different, and generally much shorter, economic life spans than the buildings in which they are used (Figure 6.1).

The age of a building has a significant impact on its heating requirements. Data from Germany suggest that energy consumption per square metre for pre-1970s homes can be between 55% and 130% higher than that for more modern buildings. In the OECD countries, a significant share of the building stock was built before 1970 (Figure 6.2). It is only retired very slowly, with as little as 0.1% a year being retired in some OECD countries. Developing countries tend to have a higher building stock turnover rates, with average life spans often in the range of 25 to 35 years.

2. Analysis conducted in 2004 on the basis of UN Habitat data suggested that the estimated 1.56 billion households in the year 2000 would grow to 3.3 billion in 2050 according to 2002 population projections (Jennings Lloyd-Smith and Ironmonger, 2004).
3. Data in this section are based on the IEA’s Energy Indicators Database, unless otherwise noted.
**Figure 6.1**  
Economic life spans of energy-consuming equipment and infrastructure

- Light bulbs: incandescent
- Light bulbs: fluorescent
- Computers, printers, faxes, copiers...
- Consumer electronics: TVs, VCRs, stereos...
- Consumer appliances: stoves, fridges, washers...
- Residential water heating equipment
- Residential space heating and cooling equipment
- Commercial heating and cooling equipment
- Electric transm. and distrib., telecom, pipelines
- Power stations
- Building stock

Source: Based on Philibert and Pershing (2002).

**Key point**

As the building stock is very long lived, action on appliances, fittings and systems is the key to achieving early low-cost CO₂ emissions reductions in the short run.

**Figure 6.2**  
Share of residential building stock in selected countries by vintage

Notes: Final year varies by country. Some data sources are for slightly different periods.
Sources: Norris and Shiels (2004); NRCan (2007); Energy Information Administration (2007); UNECE (2004).

**Key point**

In many OECD countries, more than half of the housing stock was built before 1970.
The service sector building stock

Energy use in the service sector is primarily a factor of the level of economic activity in that sector. Between 1990 and 2005, the rate of growth in service sector value added in 20 IEA countries for which data are available exceeded 2% per year in all countries except Finland, Italy and Sweden (Figure 6.3). The fastest growth occurred in Korea and Luxembourg, which averaged 5.1% and 5.2% a year, respectively.

**Figure 6.3**  Service sector value added by country

Service sector economic activity has grown rapidly in many OECD countries.

Reliable data on service sector floor area are only available for a smaller number of countries. At over 7 billion m², the United States has more service sector floor area than all of the other ten OECD countries for which data are available. Japan has the next largest area at 1.8 billion m². China is estimated to have around 11 billion m² of service sector floor area, while India is estimated to have anywhere between 400 million m² and 815 million m².

The relationship between floor area and value added has been relatively stable in most OECD countries since 1990. In 2005, the range for the OECD countries for which data were available was between 0.7m² and 1.2m² per USD 1 000 of service sector value added.

---

4. Value added of output expressed in constant USD (2000 prices) at purchasing power parity.
Global trends in buildings sector energy consumption

Between 1971 and 2007, total energy consumption in the buildings sector grew by 1.6% a year from 1 535 million tonnes of oil equivalent (Mtoe) to 2 759 Mtoe (Figure 6.4). Overall growth has slowed over time, with energy consumption growing by 1.1% a year between 1990 and 2007. Energy consumption in the service sector grew more rapidly, at 2.2% a year, between 1990 and 2007 than for the overall period. Growth in energy consumption in the residential sector was 1.4% a year between 1990 and 2007. The residential sector remains the largest consumer of energy in the buildings sector, although the service sector has increased its share of the total slightly since 1990.

**Key point**

The residential sector dominates total buildings sector energy consumption at a global level.

The OECD countries’ share of total energy consumption in the buildings sector has declined from 55% in 1971 to 44% in 2007. China’s share of total energy consumption has increased from 13% to 14% over that period.

**Residential sector**

Global energy use in the household sector increased by 28% between 1990 and 2007 to 1 941 Mtoe. As is the case in the other major end-use sectors, energy consumption in households since 1990 has grown more in non-OECD countries (34%) than in OECD countries (17%).

---

5. In the presentation of the historical data for the buildings sector, the residential, “services” or “commercial and public service” sectors (these terms are used interchangeably in this chapter), and “non-specified (other)” sectors are presented separately. In the scenario analysis, however, the data for “other non-specified” (159 Mtoe in 2007), are included with services. This is in line with the treatment in WEO 2009 (IEA, 2009a).
Natural gas is the fuel used most in OECD countries, providing 265 Mtoe (38%) of household energy requirements in 2007 (Figure 6.5). Electricity use has been rising rapidly in OECD countries, largely because of the increased penetration of many different appliances. Electricity consumption increased from 169 Mtoe in 1990 to 248 Mtoe in 2007. In non-OECD countries, renewables, particularly traditional biomass, remain the largest source of energy, with consumption of 706 Mtoe in 2007.\(^6\) Electricity use is by far the fastest growing energy commodity, its use increasing by 175\(^7\) since 1990 to reach 11\% of total energy consumption. In Russia, district heating remains important in the household sector with heat consumption of 53 Mtoe in 2007, or 47\% of total household energy consumption.\(^8\)

**Figure 6.5**  Household energy use by energy commodity

<table>
<thead>
<tr>
<th>Energy Commodity</th>
<th>OECD Europe</th>
<th>OECD Pacific</th>
<th>United States and Canada</th>
<th>Mexico</th>
<th>China</th>
<th>India</th>
<th>Brazil</th>
<th>South Africa</th>
<th>Russia</th>
<th>Rest of the world</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>26%</td>
<td>24%</td>
<td>32%</td>
<td>40%</td>
<td>35%</td>
<td>28%</td>
<td>36%</td>
<td>23%</td>
<td>20%</td>
<td>21%</td>
</tr>
<tr>
<td>2007</td>
<td>34%</td>
<td>32%</td>
<td>38%</td>
<td>46%</td>
<td>38%</td>
<td>31%</td>
<td>42%</td>
<td>28%</td>
<td>25%</td>
<td>24%</td>
</tr>
</tbody>
</table>

**Key point**

Electricity, natural gas, oil products, district heat and biomass are of varying importance in different regions.

**The service sector**

In 2007, final energy consumption in the service sector was 658 Mtoe, 46\% higher than in 1990. In OECD countries, service sector energy consumption grew by 32\%. It grew by 93\% in non-OECD countries. Despite the slower increase in service sector energy use in OECD countries, in 2007 these countries accounted for 71\% of global energy consumption in this sector.

---

\(^6\) The efficiency with which this biomass is used is typically very low (8\% to 15\% for traditional cook stoves is common). It has a wide range of negative impacts such as degraded indoor air quality and deforestation. Switching to alternatives will require a fraction of the energy, as alternatives are much more efficient, and have significant co-benefits.

\(^7\) The falling share of inefficient traditional biomass use in favour of electricity and commercial fuels is one of the main factors that has restrained the growth in energy use in non-OECD countries.

\(^8\) In IEA statistics for the residential and service sectors, “heat” refers only to purchased heat. It is not the total energy consumed for heating purposes.
Electricity is the largest energy commodity used in the service sector. Its use has increased by 91% since 1990. Its share of global service sector energy consumption increased from 38% in 1990 to 50% in 2007. This reflects the growing importance of electrical devices such as lighting, office equipment and air conditioning. Increased access to electricity and rising incomes have also played a role in the growth in electricity consumption in some developing countries.

There are substantial differences in the service sector energy mix between countries and regions (Figure 6.6). Electricity and natural gas are the dominant final energy commodities in many OECD countries, with oil also an important fuel in the OECD Pacific region, Mexico and China. Biomass is still heavily used in India, accounting for 47% of total final consumption in services. Direct coal use retains a significant share in both China and South Africa. In Russia, 46% of the service sector’s energy demand is met by district heating.

Figure 6.6  Service sector energy use by energy commodity

Key point

Electricity is generally the largest source of energy in the service sector.

Buildings sector CO₂ emissions

The buildings sector’s CO₂ emissions, including non-specified (other) and upstream emissions attributable to electricity consumption, grew by 2.2% a year between

---

9. Oil appears currently to account for 53% of final energy use in China, but this share may be inflated by a statistical convention that includes some commercial transportation in the service sector.
10. Some uncertainty surrounds service sector energy consumption statistics in India and these values should be treated with caution.
1995 and 2007. CO₂ emissions from the service sector grew by 3.1% a year, while those from the residential sector grew by 1.5% a year. The service sector’s share of total buildings sector CO₂ emissions has grown from 32% in 1995 to 35% in 2007, while the residential sector’s share has declined from 63% to 57%. Direct CO₂ emissions from fossil fuels accounted for 34% of the buildings sector’s emissions in 2007 (2.768 Mt CO₂), with the upstream emissions attributable to electricity and heat consumption accounting for the remaining 66%. Household sector CO₂ emissions were around 4.7 Gt CO₂ in 2007, while they were around 2.9 Gt CO₂ in the service sector.

Global average emissions in the household sector were 0.7 tonnes (t) of CO₂ per person in 2006, slightly lower than in 1990. Per-capita emission levels differ widely between countries, being on average more than five times higher in OECD countries than in non-OECD countries. This results from a combination of lower per-capita household energy use and a higher share of renewable energy used in non-OECD countries, and from the very significant heating loads in OECD countries.

Demand drivers in the scenario analysis

Energy demand in the buildings sector is driven by population, climate, incomes, service sector value added and cultural factors. These factors have an impact on the number and size of households, the heating or cooling load, the number and types of appliances owned and their patterns of use.

The world’s population will increase by around 40% to 9.1 billion in 2050 (UN, 2009), with Asia and Africa growing most. The population of the G8+511 countries will drop from 56% of the world’s population today to 48% in 2050. Today, slightly more than half of the world’s population lives in urban areas in developing countries (UN, 2008). By 2050, almost 85% of the world’s urban population will be in developing countries.

The global number of households is projected to grow by 67% between 2005 and 2050. This is larger than population growth because of the continuing trend of fewer people per household. The recent trend towards larger floor areas per household is likely to continue, although this will be weak in many mature economies.

Service sector floor area is expected to continue to grow rapidly, with a projected increase of 195% between 2005 and 2050. In 2050, the global average per-capita service sector floor area will be around today’s per-capita level in France, Japan and the United Kingdom. After rising initially, the global average floor area in the service sector per unit of GDP will decline slightly by 2050, as floor area growth begins to slow in the sector. Floor area is projected to expand most rapidly in developing countries, driven by the higher rates of growth in their economies and their service sector value added.

11. The G8+5 is defined as Canada, France, Germany, Italy, Japan, Russia, the United Kingdom and the United States, plus Brazil, China, India, Mexico and South Africa.
The Baseline scenario

Energy consumption by fuel and by sector

Total energy demand in the buildings sector increases from 2,759 Mtoe in 2007 to 4,407 Mtoe in 2050 in the Baseline scenario (Figure 6.7). The residential sector accounts for 59% of this growth and the service sector for around 41%. The service sector grows the most rapidly at 1.4% a year between 2007 and 2050, with the residential sector growing by 1.0% per year. As a result, the service sector’s share of energy consumption increases from 30% in 2007 to 34% in 2050, and that of the residential sector declines from 70% to 66%.

Figure 6.7  Buildings sector energy consumption in the Baseline scenario by sector and by energy commodity

Key point
The share of buildings sector energy consumption accounted for by electricity increases by 2050.

Non-biomass renewables use, predominantly solar, grows the most rapidly in the buildings sector as a whole, by 4.5% a year between 2007 and 2050, although it still only represents 2% of the sector’s energy consumption in 2050. The demand for biomass increases only slightly by 2050 compared to today, thanks to the improved efficiency of its use and the continued switch to fossil fuels in developing countries. Electricity demand grows by 2.1% a year. As a result, it not only remains the largest single source of energy, but also increases its share from 27% to 42% of total energy use in the sector by 2050. Heat consumption increases by 0.5% a year.

---

12. In line with the treatment in the World Energy Outlook, in this section the service sector total includes the projections for “non-specified (other)”.  
13. Unless explicitly noted, “solar” in this chapter refers to solar thermal energy.
gas consumption by 1.1% a year and oil consumption by 0.6% a year. Coal is the only fuel to experience a decline in use (of 0.2% a year) between now and 2050.

In the residential sector, total energy consumption grows by 1% a year between 2007 and 2050 to 2,920 Mtoe. Electricity demand in the residential sector continues to grow strongly, by 2.2% per year on average, increasing its share of consumption from 20% to 34% between 2007 and 2050. Non-biomass renewables, predominantly solar, grow rapidly by 5.4% a year on average. But this is from a low base, and they account for only 2% of total energy consumption in the residential sector by 2050. Gas consumption grows by 1.1% per year and oil consumption by 0.7% per year. Coal consumption is roughly flat between 2007 and 2050.

In the service sector, energy demand is projected to almost double between 2007 and 2050, growing by around 1.4% per year to 1,488 Mtoe in 2050. Non-biomass renewables, predominantly solar, are projected to grow the most rapidly, by 3.1% a year, between 2007 and 2050, albeit from a low base. In the Baseline scenario, the demand for electricity grows by 1.9% a year and remains the single most important source of energy in the service sector. The demand for biomass grows by 1.3% a year, gas by 1.0% a year, heat by 0.9% a year and oil by 0.5% a year. Coal demand declines by 0.8% a year.

**Energy consumption and CO\textsubscript{2} emissions by region and by sector**

Energy consumption in the residential sector is dominated by the three OECD regions, China and Africa. Together these account for around two-thirds of all energy consumption in the residential sector. The OECD regions are expected to have only moderate growth in energy consumption before 2015 as a result of energy policies to tackle climate and energy security concerns. But growth picks up again after 2015 as the effect of currently enacted policies taper off, for example as already announced retrofit programmes reach a conclusion. The Middle East will experience the most rapid growth in residential sector energy consumption of 2.2% per year between 2007 and 2050 (Figure 6.8).

Energy consumption in the residential sector in India and China will grow by 1.7% and 1.1% per year respectively. The largest absolute increase in residential sector energy consumption will occur in China, where consumption will increase by 208 Mtoe from 2007 levels to 524 Mtoe in 2050. In the residential sector in non-OECD countries, there is a marked increase in the share of fossil fuels and electricity as traditional biomass becomes a relatively less important energy source. Distributed heat remains an important source of energy in the EITs, although significant improvements in the heat distribution network and renovations that improve building envelopes will mean that its share of energy consumption declines.

In the service sector, China is projected to experience the most rapid growth in energy consumption, with consumption growing by 3.3% a year between 2007 and 2050. India and the Middle East are also projected to experience rapid growth in energy consumption, by 3.1% and 2.9% a year respectively. OECD Europe and North America experience more modest growth rates, but their service sectors continue to consume the most energy, despite China’s very rapid growth (Figure 6.9).
**Figure 6.8** Residential sector energy consumption by fuel and by region in the Baseline scenario

Residential sector energy consumption grows by around 50% in the Baseline scenario.

**Figure 6.9** Service sector energy consumption by fuel and by region in the Baseline scenario

Even by 2050, OECD regions still dominate service sector energy consumption.
Buildings sector CO₂ emissions increase by 87% between 2007 and 2050 in the Baseline scenario to around 15.2 Gt CO₂ in 2050. Service sector CO₂ emissions grow by 85% between 2007 and 2050, and residential sector emissions grow by 88%. The total buildings sector CO₂ emissions attributable to electricity consumption grow the fastest, by 2.1% a year between 2007 and 2050, while those of gas grow by 1.1% a year, purchased heat by 0.8% a year and oil by 0.7% a year. CO₂ emissions from coal are virtually unchanged between 2007 and 2050.

The BLUE Map scenario

The buildings sector has an important role to play in the BLUE Map scenario’s overall goal of a 50% reduction in CO₂ emissions by 2050. Energy efficiency options are available in the buildings sector that can reduce energy consumption and CO₂ emissions from lighting, appliances and heating and cooling rapidly and at low cost. But achieving deep cuts in energy consumption and CO₂ emissions in the buildings sector is a challenge. The implementation of these technologies will require much more ambitious policies, particularly in relation to building shells in the existing stock of buildings in OECD countries, as well as decarbonising the energy sources used. These outcomes will be much more expensive to secure and their achievement will face significant barriers.

The most cost-effective approach to the transition to a sustainable buildings sector will involve three steps:

- First, the rapid deployment of existing low-cost technology options for energy efficiency and low-carbon fuel sources, while boosting R&D into new technologies and optimising existing technologies for new applications in the buildings sector.

- Second, the deployment of existing technologies into less economic end uses, efforts to address the existing building stock in OECD countries, and the deployment of emerging technologies at a modest scale.

- Third, maximising the deployment of energy-efficient technologies, substantially renovating 60% of today’s OECD building stock by 2050 and ensuring the widespread deployment of new technologies, particularly those that decarbonise the fuel supply in the buildings sector.

Energy efficiency will not, by itself, be sufficient to meet ambitious climate change goals. It will need to be followed by significant fuel switching to low- or carbon-free fuel sources, including electricity and hydrogen after 2030 in the BLUE Map scenario. The low carbon content of gas, the high efficiency of gas-condensing boilers and the low cost of this incumbent technology means that fuel switching away from gas is likely to be expensive in many cases.

To achieve the transformation that is needed in the BLUE Map scenario will require significant policy action over a range of technologies and end uses (Table 6.1). Balancing the availability of technologies and their current costs with the rate of capital stock turnover means that some changes are more urgent than others. Some will achieve greater savings, over different time scales, than others.
The policy challenge facing OECD countries and the EITs is very different from that facing developing countries. OECD countries, and EITs to a lesser extent, are characterised by a large stock of residential buildings that is not growing quickly and that will be retired only slowly. So most of the CO₂ reduction potential is in the current stock of buildings. OECD countries and EITs also have significant heating loads, as does China. It is essential in OECD countries and EITs to achieve significant reductions in these heating loads in existing buildings through insulation and heating system retrofit packages. These actions are potentially expensive and are only likely to make economic sense during the scheduled refurbishments or maintenance activities which occur only every 20 to 30 years on average.

### Table 6.1 Priority policy actions needed to deliver the outcomes in the BLUE Map scenario

<table>
<thead>
<tr>
<th>Energy efficiency</th>
<th>Overall savings potential</th>
<th>Policy urgency</th>
<th>Bulk of savings available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>Medium</td>
<td>Average</td>
<td>Quickly</td>
</tr>
<tr>
<td>Appliances</td>
<td>Large</td>
<td>Average</td>
<td>Short- to medium-term</td>
</tr>
<tr>
<td>Water heating systems</td>
<td>Medium to large</td>
<td>Urgent</td>
<td>Short- to medium-term</td>
</tr>
<tr>
<td>Space heating systems</td>
<td>Medium to large</td>
<td>Urgent</td>
<td>Short- to medium-term</td>
</tr>
<tr>
<td>Cooling/ventilation systems</td>
<td>Medium to large</td>
<td>Urgent</td>
<td>Short- to medium-term</td>
</tr>
<tr>
<td>Cooking</td>
<td>Small</td>
<td>Average</td>
<td>Quickly</td>
</tr>
</tbody>
</table>

| Fuel switching                |                           |                |                          |
| Water heating systems         | Medium to large           | Urgent/average | Short- to long-term     |
| Space heating systems         | Medium to large           | Urgent/average | Short- to long-term     |
| Cooking                       | Small                     | Average/urgent | Short- to medium-term    |

| Building shell measures       |                           |                |                          |
| New residential buildings     | Medium to large           | Average/urgent | Medium- to long-term    |
| Retrofit residential buildings| Large                     | Urgent         | Medium- to long-term    |
| New commercial buildings      | Large                     | Urgent         | Medium- to long-term    |
| Retrofit commercial buildings | Medium to large           | Average        | Medium- to long-term    |

*Note: Overall savings potential is relative to their contribution to total savings in the buildings sector. Where two policy urgency ratings are given, it is for OECD/non-OECD.*

In developing countries, buildings have much shorter life spans, commonly of 25 to 35 years. The rate of growth of the overall building stock is also very rapid. The priority for developing countries is, therefore, to address the energy consumption of new buildings, especially in respect of cooling loads, through building standards and codes. Building codes that reduce the cooling load of buildings through better design and building shell performance need to be implemented rapidly to avoid the building of very large numbers of high CO₂ emissions buildings in the short- to medium-term which will be around for decades to come.

The energy consumption of appliances and lighting can be reduced relatively quickly given their short economic lives. A wide range of technologies have lower life-cycle costs than the incumbent systems. But shifting to BAT can be an expensive abatement option until wider deployment begins to help to reduce costs.
**Box 6.1** Recent trends in low-carbon technologies for buildings

There are some possibly encouraging signs of a shift in consumer behaviour in recent years towards new technologies which can reduce CO₂ emissions.

For example, the sales of heat pumps in a number of major European markets experienced double-digit growth from 2007 to 2008. In France, sales grew even more significantly, by 127%, and surpassed annual sales in Sweden, one of the most mature heat pump markets in Europe. Total annual sales in Austria, Finland, France, Germany, Italy, Norway, Sweden and Switzerland reached 576 000 in 2008, almost 50% more than in 2005 (EHPA, 2009). With estimated sales of 7.1 million boiler units (VHK, 2007a) and of 10.8 million dedicated water heaters in the European Union (VHK, 2007b), these data suggest that heat pumps may be beginning to achieve a critical mass for space and water heating in a number of European countries.

In addition, recent growth in sales of solar thermal systems, that can provide low-temperature heat for cooling and space and water heating, also highlights a growing shift towards renewable energy sources in buildings. Installed capacity of such systems in 2007 was 147 GWₑₚ, 32% higher than in 2005. The number of systems installed each year is growing rapidly, increasing by 37% between 2005 and 2007: 19.9 GWₑₚ of capacity was installed in 2007 alone (Weiss, Bergmann and Faninger, 2009).

---

**Energy consumption in the BLUE Map scenario**

In the BLUE Map scenario, energy consumption in the buildings sector is reduced by around one-third of the Baseline scenario level in 2050. Energy consumption in 2050 is only 5% higher than in 2007, despite an increase in households of 67% and in service sector floor area of 195% over that time. The energy consumption of fossil fuels declines significantly, as well as that of traditional biomass. The residential sector accounts for 63% of the buildings sector’s energy savings from the Baseline scenario in 2050.

The consumption of electricity, heat and solar is higher in 2050 than in 2005 in the BLUE Map scenario (Figure 6.10 and Table 6.2). Solar grows the most, accounting for 11% of total energy consumption in the buildings sector, as its widespread deployment for water heating (30% to 60% of useful demand depending on the region) and, to a lesser extent, space heating (10% to 35% of useful demand depending on the region) helps to improve the efficiency of energy use in the buildings sector and to reduce CO₂ emissions.

The level of energy savings and the percentage reduction below the Baseline vary significantly between regions (Figure 6.11). The largest percentage reductions occur in China (38%), the EITs (38%) and OECD Europe (37%). China’s reduction in 2050 is a result of both improved efficiency and switching away from the inefficient use of traditional biomass to modern bioenergy (biofuels, biogas and bio-dimethyl ether) and commercial fuels. The smallest percentage reduction below the Baseline occurs...
in India and is due to a rebound effect in which some increased consumption is triggered by some of the energy efficiency measures in the period to 2050. The largest absolute reductions occur in China (286 Mtoe), OECD Europe (244 Mtoe) and OECD North America (230 Mtoe). In OECD regions and the EITs, it is projected that, with an abatement cost of USD 175/tCO2, energy demand can be reduced below 2007 levels by 2050.

**Figure 6.10** Buildings sector energy consumption by fuel and by scenario

![Figure 6.10](image)

**Key point**

Energy consumption in the buildings sector is 5% higher in 2050 than in 2007 in the BLUE Map scenario.

**Table 6.2** Buildings sector energy consumption by fuel in the Baseline and BLUE Map scenarios

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th></th>
<th></th>
<th>BLUE Map</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2007</td>
<td>2015</td>
<td>2030</td>
<td>2050</td>
<td>2015</td>
<td>2030</td>
</tr>
<tr>
<td>Coal</td>
<td>96</td>
<td>104</td>
<td>94</td>
<td>88</td>
<td>97</td>
<td>66</td>
</tr>
<tr>
<td>Oil</td>
<td>336</td>
<td>344</td>
<td>382</td>
<td>439</td>
<td>321</td>
<td>283</td>
</tr>
<tr>
<td>Gas</td>
<td>608</td>
<td>661</td>
<td>796</td>
<td>958</td>
<td>597</td>
<td>502</td>
</tr>
<tr>
<td>Electric</td>
<td>758</td>
<td>914</td>
<td>1 270</td>
<td>1 837</td>
<td>852</td>
<td>1 004</td>
</tr>
<tr>
<td>Heat</td>
<td>149</td>
<td>175</td>
<td>186</td>
<td>188</td>
<td>181</td>
<td>208</td>
</tr>
<tr>
<td>Biomass</td>
<td>799</td>
<td>779</td>
<td>787</td>
<td>816</td>
<td>721</td>
<td>586</td>
</tr>
<tr>
<td>Solar/other renewables</td>
<td>12</td>
<td>24</td>
<td>49</td>
<td>81</td>
<td>73</td>
<td>184</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2 759</strong></td>
<td><strong>3 001</strong></td>
<td><strong>3 565</strong></td>
<td><strong>4 407</strong></td>
<td><strong>2 841</strong></td>
<td><strong>2 834</strong></td>
</tr>
</tbody>
</table>
The largest energy savings by end use in the BLUE Map scenario in the residential sector come from space heating. In the service sector, the largest savings come from lighting and miscellaneous energy use (Figures 6.12 and 6.13). In each sector, solar energy consumption for space and water heating is higher in the BLUE Map scenario in 2050 than in the Baseline scenario. Solar thermal energy is a particularly cost-effective abatement option in many countries. In addition, the projected availability of low-cost compact thermal storage systems enables a greater proportion of the annual space and water heating demand to be met by solar thermal systems in countries outside the tropics.

In the residential sector, total energy demand is reduced by 956 Mtoe. Globally, energy consumption for space heating is reduced by 374 Mtoe below the Baseline scenario in 2050, with a significant increase in the share of solar thermal and micro and small-scale CHP. Increased efficiency in space heating accounts for 39% of the total residential sector’s energy savings with cooking (16%), water heating (18%), appliances and miscellaneous end uses (16%), cooling and ventilation (7%) and lighting (4%) all making significant contributions.

In the service sector, energy demand in the BLUE Map scenario is reduced by 553 Mtoe compared to the Baseline scenario in 2050. The pattern of savings is different from that in the residential sector. Space and water heating are still
important sources of energy savings, but electrical end uses are just as important. Lighting and miscellaneous end uses account for 40% of the savings and cooling and ventilation for 19%. Space and water heating account for 27% and 14% of the savings, respectively.

**Figure 6.12** Change in residential sector energy demand by end use in the BLUE Map scenario compared to the Baseline scenario, 2050

**Key point**

The BLUE Map scenario achieves significant savings in fossil fuels.

The total energy savings in the buildings sector in the BLUE Map scenario amount to 1 509 Mtoe in 2050 (Figure 6.14). Energy savings in residential space heating account for around a quarter of the savings. Space and water heating in the residential sector account for 36% of the total energy savings, and in the service sector for 15% of the total savings. End uses where the savings are dominated by electricity represent 39% of the savings. These will contribute an even larger share of the CO₂ emissions reductions as much of the savings occur in countries where electricity generation is CO₂-intensive.
Figure 6.13 Change in service sector energy demand by end use in the BLUE Map scenario compared to the Baseline, 2050

Key point
In the service sector, savings in electrical end-uses are just as important as space and water heating.

Figure 6.14 Buildings sector energy savings by sector and by end use, 2050

Key point
Two-thirds of the energy savings in the BLUE Map scenario come from the residential sector.
In the Baseline scenario, the buildings sector emits 15.2 Gt CO₂ in 2050, a 87% increase over 2007 levels. The BLUE Map scenario reduces CO₂ emissions from the buildings sector by 12.6 Gt CO₂ from the Baseline scenario level in 2050, with 6.8 Gt CO₂ of this reduction being attributable to the decarbonisation of the electricity and heat sectors. As a result, buildings sector CO₂ emissions are 83% lower than the Baseline level in 2050. This reduces the direct and indirect CO₂ emissions attributable to the buildings sector to 2.6 Gt CO₂ in 2050, one-third of the 2007 level (Figure 6.15).

**Figure 6.15** Buildings sector CO₂ emissions by scenario and by fuel

The BLUE Map scenario is based on the large-scale deployment of a number of technology options for the buildings sector, including:

- **Tighter building standards and codes for new residential and commercial buildings.** Regulatory standards for new residential buildings in cold climates are tightened progressively to between 15 and 30 kWh/m²/year for heating purposes, with little or no increase in cooling load. In hot climates, cooling loads are reduced by around one-third. For commercial buildings, standards are introduced which halve consumption for heating and cooling compared to 2007. This will enable the downsizing of heating and cooling equipment.

---

14. Note that CO₂ emissions savings from electricity in this chapter have been calculated using the global CO₂ emissions factor for electricity. This is consistent with the approach taken in Chapter Two.

15. This is the useful energy demand. The actual energy consumption is a function of the fuel mix and the efficiency of the technology used.
Large-scale refurbishment of residential buildings in the OECD. Around 60% of today’s residential dwellings in the OECD which will still be standing in 2050 will need to be refurbished to a low-energy standard (approximately 50 kWh/m²/year), which also enables the downsizing of heating equipment. This represents the refurbishment of around 210 million residential dwellings in the OECD between 2010 and 2050.

Highly efficient heating, cooling and ventilation systems. Heating systems need to be both efficient and cost-effective. The coefficient of performance (COP)\textsuperscript{16} of installed cooling systems doubles from today’s level.

Improved lighting efficiency. Notwithstanding recent improvements, many driven by policy changes, there remains considerable potential to reduce lighting demand worldwide through the use of the most efficient options.

Improved appliance efficiency. Appliance standards are assumed to shift rapidly to least life-cycle cost levels, and to the current BAT levels by 2030.

The widespread deployment of CO\textsubscript{2}-free technologies, including:

- **Heat pumps** for space and water heating. This occurs predominantly in OECD countries, and depends on the relative economics of different abatement options.

- **Solar thermal** for space and water heating. Often cost-effective today, further cost reductions for systems and the likely availability of low cost, compact thermal energy storage systems in the near future help increase deployment, especially in OECD countries.

- **Micro- and mini-CHP** for space and water heating, and electricity generation. CHP can be an effective abatement option where power generation is CO\textsubscript{2}-intensive. In the BLUE Map scenario in the buildings sector, all CHP deployed after 2030 is CO\textsubscript{2} free.

The CO\textsubscript{2} emissions savings that need to be delivered by the buildings sector in the BLUE Map scenario can only be achieved by undertaking all of these measures. Early improvements in the thermal envelope of buildings and other building shell improvements account for 22% of the total savings of 5.8 Gt CO\textsubscript{2} attributable to the buildings sector in 2050 (Figure 6.16) and enable the downsizing of heating and cooling equipment. Lighting and appliances, given the importance of electrical end-use growth and energy efficiency improvements in non-OECD countries, account for 32% of the total reduction.

The increased deployment of heat pumps for space and water heating, as well as the deployment of more efficient heat pumps for cooling account for 22% of the savings. Solar thermal systems for space and water heating account for around 12% of the savings. CHP plays a small but important role in reducing CO\textsubscript{2} emissions, as well as assisting in the balancing of the renewables-dominated electricity system in the BLUE Map scenario.

\textsuperscript{16} The COP of a heat pump is the ratio of useful energy output (heat or cold) to energy input (typically electricity).
**Key point**

*Improvements in the building shell and energy savings in electrical end uses dominate total CO₂ reductions in the BLUE Map scenario.*

**Investment requirements in the BLUE Map scenario**

Additional investment needs in the BLUE Map scenario are estimated to be USD 12.3 trillion (constant 2007 USD), made up of USD 7.9 trillion in the residential sector and USD 4.4 trillion in the service sector.¹⁷ The investment is required to ensure that new buildings meet more stringent building codes, to refurbish around 60% of the OECD building stock still standing in 2050 to a low-energy standard, and for additional investments in heat pumps, solar thermal systems, CHP systems, lighting systems and appliances.

The investment required in building shells, particularly in OECD countries for refurbishment of the existing building stock, dominates the total additional investment needs in the BLUE Map scenario over and above the Baseline by 2050 (Figure 6.17). The incremental investment needs for space heating are modest, because equipment size is reduced as a result of the building shell measures implemented, thus offsetting the shift to more capital-intensive options such as heat pumps, solar thermal and CHP.

In the residential sector, improvements in building shells account for just over half of the incremental investment needs. In the service sector, around 31% of all investment is required for this purpose. In the service sector, the electrical end uses of lighting, cooling and ventilation and miscellaneous plug loads dominate the incremental investment needs (Figure 6.18).

¹⁷. This is the total incremental investment over and above the Baseline scenario.
Figure 6.17 Incremental investment needs in the buildings sector in the BLUE Map scenario

USD 12.3 trillion

- Appliances and miscellaneous: 23%
- Demolition/early retirement: 5%
- Lighting: 2%
- New building shell measures: 14%
- Water heating: 8%
- Cooling and ventilation: 19%
- Refurbishment of building shell in OECD: 24%
- Space heating: 5%
- New building shell measures: 14%
- Demolition/early retirement: 5%
- Appliances and miscellaneous: 23%
- Lighting: 2%
- Water heating: 8%
- Cooling and ventilation: 19%
- Refurbishment of building shell in OECD: 24%
- Space heating: 5%

Note: Miscellaneous includes appliances, IT and office equipment, pumps and other small plug loads in the residential and service sectors. It also includes cooking in the residential and service sectors.

Key point

Investments in the building shell account for 43% of the additional investment.

Taken together, this investment of USD 12.3 trillion achieves fuel savings (including electricity) totalling USD 51 trillion between 2010 and 2050 when evaluated at wholesale prices. The net savings, undiscounted, are therefore around USD 39 trillion. Using a 3% discount rate reduces the net savings to USD 18.6 trillion; while at a 10% discount rate, the net savings are USD 5.3 trillion. On this basis, the net cost of investing in efficiency improvements in the buildings sector is relatively low.

Figure 6.18 Incremental investment needs in the residential and service sectors in the BLUE Map scenario, 2007-50

Key point

Additional investment needs in the residential sector are 80% higher than in the service sector.
BLUE scenario variants

Developing scenarios for the future is an inherently uncertain exercise. To explore the sensitivity of the results to different input assumptions, several variants of the BLUE Map scenario have been analysed. They are:

- **BLUE Heat Pumps**: this scenario looks at ultra-high efficiency heat pump air conditioners (COP of 9) for cooling and humidity control, and faster cost reductions for space and water heating applications.

- **BLUE Solar Thermal**: this scenario explores the situation where low-cost compact thermal storage is deployed on a large scale from 2025 and system costs come down more rapidly in the short term.

- **BLUE Buildings CHP**: this scenario explores the impact of more rapid declines in the cost assumptions for fuel-cell CHP units using hydrogen and their potential contribution to a higher penetration of distributed generation.

The main distinction between these scenarios is that in each case a specific technology is assumed to achieve significant cost reductions earlier than in the BLUE Map scenario. This technology, therefore, gains a higher share of installations than competing options. By 2050 this has a significant impact on the share of space and water heating demand that is met by the technology in question. In the BLUE Solar Thermal and BLUE Heat Pumps scenarios, each of these technologies becomes the dominant technology in 2050 for space and water heating. In addition, in the BLUE Heat Pumps scenario, heat pumps achieve higher efficiencies than in BLUE Map for cooling. In the BLUE Buildings CHP scenario, the share of useful energy for space and water heating provided by small-scale CHP in the buildings sector doubles.

In each of the buildings sector BLUE scenario variants, additional savings are achieved below the Baseline scenario in 2050 compared to the BLUE Map scenario. These additional savings are modest because the BLUE Map scenario is already very efficient and has already resulted in a significant switch away from fossil fuels for space and water heating by 2050.18

In the BLUE Solar Thermal variant, total CO₂ reductions in the buildings sector are 5% greater than in the BLUE Map scenario. They reach around 6 083 Mt CO₂ (Figure 6.19). In this scenario variant, solar thermal accounts for 44% of the CO₂ reduction below the Baseline scenario from space and water heating in 2050. In the BLUE CHP variant, CO₂ emissions reductions are 4% more than in the BLUE Map scenario. CHP increases its share of CO₂ emissions reductions in space and water heating from 7% in the BLUE Map scenario to 19% in the BLUE CHP variant.

In the BLUE Heat Pumps variant, CO₂ emissions reductions are 7% higher than in the BLUE Map scenario. Heat pumps’ share of the savings from space and water heating increases from 23% in the BLUE Map scenario to 40% in the BLUE Heat Pumps variant in 2050. In addition, highly efficient heat pumps for air-conditioning save an additional 155 Mt CO₂.

18. These BLUE scenario variants assume the same economy-wide marginal abatement cost of USD 175/tCO₂, and hence result in greater emissions reductions. An alternative approach would have been to keep the same abatement level as the BLUE Map scenario and to analyse the reduction in the marginal abatement cost for the sector of each scenario variant.
Figure 6.19 Direct CO₂ emissions reduction below the Baseline scenario in the buildings sector BLUE scenario variants, 2050

Key point

A range of outcomes are possible for the buildings sector depending on the rate at which technologies improve and reduce their costs.

Technology options in the BLUE Map scenario

Buildings are complicated systems and a wide range of factors affect their energy use. In OECD countries and the EITs, the biggest opportunities to improve energy use and reduce CO₂ emissions arise in the areas of space and water heating, lighting and appliances. In developing countries, lighting and cooking are relatively more important, and cooling will grow in importance. Other than in China, space heating is less significant for developing countries.

A number of technologies offer opportunities to significantly reduce energy use and emissions at low cost. Reductions in electricity consumption may be a higher priority than reductions in the direct use of fossil fuels in countries with CO₂-intensive electricity generation. In the buildings sector, the greatest opportunities for cost-effective CO₂ reductions will come from:

- **Intelligent building design** that makes the most of solar gains in the heating season and limits those gains in the cooling season.

- **High-performance building envelopes** that reduce heating and cooling loads, e.g. through shading, reflective surfaces and light coloured roofs, high levels of insulation and air tightness, and high-performance windows.
• **Highly efficient heating, ventilation and air-conditioning systems.** HVAC systems such as heat pumps for heating and cooling, ventilation systems, gas-condensing boilers and CHP need to be as efficient as is cost-effective.

• **Highly efficient water heating systems.** These may be dedicated systems or combined (integrated) with the space heating system and/or cooling system. Options include integrated heat pumps, solar thermal, CHP, and gas-condensing boilers.

• **Highly efficient appliances and lighting.** A rapid shift to least life-cycle cost standards and then to BAT is required.

• **Efficient cook stoves.** In developing countries, the use of more efficient biomass stoves and switching to commercial fuels will reduce energy consumption and deforestation and improve indoor air quality.

• **CO₂-free technologies.** The deep emission cuts envisaged in the BLUE Map scenario require not only efficiency improvements but also fuel switching. By 2030, increased electrification using electricity from decarbonised generation sources is an abatement option. Solar thermal is an important abatement option for space and water heating. Depending on technology developments, hydrogen in fuel-cell CHP units could also be an important option.

The BLUE Map scenario requires large contributions from all of these sources if energy consumption and CO₂ emissions are to be reduced.

### The building envelope and good design

The building envelope and the design\(^\circ\) of a building play a substantial role in determining the heating and cooling load for a desired indoor temperature. It is estimated that, in 2007, 39% of the residential sector’s and 35% of the service sector’s global CO₂ emissions stemmed from space and cooling needs. The largest total savings potential to 2050 is in new buildings in developing countries, because of the rapid growth in the building stock, and in existing buildings in the OECD.

In new buildings, significant savings are possible compared to common new building practices and codes in many countries (IEA, 2008a). Current codes and standards are in many cases a long way from being sufficient to achieve least life-cycle costs if energy savings are taken into account. Significant reductions can be achieved at relatively low CO₂ abatement costs.

In cold climates (predominantly in the OECD, EITs and China), the BLUE Map scenario envisages building standards for new residential buildings being progressively tightened. They reach between 15 and 30 kWh/m²/year of useful energy for heating and cooling by 2030 for those countries with standards furthest from this level (greater than 150 kWh/m²/year) and the same level by 2020 for those that currently have more stringent codes. This is similar to the passive house standard for Central Europe of around 15 kWh/m²/year when normalised for climate. At the same time, building design will also need to evolve to more readily

---

\(^{19}\) The term design is used here to encompass all of the architectural issues involved in buildings, as well as the integration of the building with its energy-using systems where appropriate.
incorporate solar thermal and photovoltaic (PV) systems. Governments will also need to do more to ensure compliance with building standards.

In OECD countries, most of the building stock was constructed before the 1970s and has very high space heating requirements (Figure 6.20). Refurbishment or renovation of these buildings will offer the largest abatement potential, given current low rates of retirement of the existing stock and modest additions of new buildings. But although many measures are cost-effective, comprehensive energy refurbishment to standards similar to those in new buildings will require significant upfront costs, and their economics will depend heavily on fuel prices.

The BLUE Map scenario assumes that this investment will only be economic when major scheduled refurbishments are undertaken, typically every 20 to 30 years, but sometimes after much longer periods. These measures are also relatively expensive in terms of their costs per tonne of CO₂ saved. The refurbishment of 60% of the existing OECD stock by 2050, as implied in the BLUE Map scenario, will only happen if urgent policy action is taken to make it happen.

Figure 6.20  Yearly primary space heating use per dwelling in selected European countries


Key point

The existing building stock in many European countries requires significantly more energy for space heating than could be achieved with today’s technology (e.g. a passive house design).

Achieving these more rigorous standards for new buildings currently increases initial construction costs by around 2% to 7% on average, although higher values are possible in the early stages of deployment. This will decline over time as this standard becomes the norm and the required components such as high-performance windows and insulation achieve mass market deployment. Reducing the heating and cooling loads of new commercial buildings will be more difficult to achieve.
Building shell technologies and design

Building shells, including the external walls, floors, roofs, ceilings, windows and doors, are a critical factor in determining heating and cooling demand. Building heating loads constitute the largest energy end use in OECD countries.

Reducing heat losses in winter and heat gains in summer offers large opportunities to reduce energy consumption. The most important heat losses occur through roofs (30% to 35%), walls (25% to 30%), windows (15%) and ventilation (25%).\(^{20}\) For renovations, these areas provide the best opportunities to reduce heating needs at least cost. In new buildings, they are the areas requiring most attention in energy-efficient design.

Energy-efficient designs are optimised to reduce heating and cooling needs and make the most use of the sun. Passive solar designs maximise the benefits of free solar radiation and light in cold climates to reduce heating and lighting needs. Similarly, in hot climates, the use of thermal mass, insulation, shading and reflective surfaces, and convection ventilation can help minimise heat gains in summer and, by providing naturally assisted ventilation, reduce energy needs for cooling and ventilation. Having significant thermal mass can also help reduce temperature fluctuations. Minimising heating and cooling loads generally requires the following to be incorporated into the building design:

- High levels of insulation in the walls, roof and floor in order to reduce heat losses in cold climates.
- Minimisation of design components that easily conduct heat/cold (known as thermal bridges).
- Use of high-performance windows with low U-values,\(^{21}\) with low-emissivity coatings or even switchable coatings appropriate to the prevailing climate.
- Air tightness to reduce heat losses and latent cooling loads. This often then requires a mechanical system to ventilate the building. Such systems can also be used for heat recovery. In hot climates, air tightness may not be as important, and can even have a negative impact.
- Good passive solar design, including natural ventilation.

Existing standards offer minimum measures for efficient building. Guidance is often readily available to achieve designs that significantly exceed minimum standards (such as the ASHRAE Advanced Energy Design Guide series). Taking these design principles into account can significantly reduce heating and cooling loads in a new building at little or no additional cost when life-cycle costs are taken into account.

Building shell technologies: walls, floors, roofs and windows

Walls, floors and roofs represent the largest external area of most residential and commercial buildings. It is through these elements of the shell that most of the heat losses from the building occur. There are many types of insulating materials, including mineral wool, cellulose, polystyrene and polyurethane. Insulation is

\(^{20}\) Significant variations can occur depending on the design and construction of the home. These values are indicative only.

\(^{21}\) The U-value is the overall heat transfer coefficient for a given building element. It measures, for a given area (usually one m\(^2\)), the rate at which heat is transferred through a given building component under standardised conditions.
available for all parts of the building shell. Building insulation performance has more than doubled over the past 25 years. But super-insulation technologies that are already or will soon be on the market will be even more effective than today’s technology. These include vacuum-powder-filled panels, gas-filled and vacuum-fibre-filled panels, structurally reinforced beaded vacuum panels, and switchable evacuated panels.

The IEA’s Implementing Agreement on Energy Conservation in Buildings and Community Systems has a specific work programme on high-performance thermal insulation systems. Considerable attention is being paid to improving insulation quality as standards for buildings become more rigorous.\(^{22}\)

Different types of insulation perform differently for a given level of thickness. If space is not a constraint, the cheapest and simplest solution to improve building envelope performance is to increase the thickness of the insulation installed as the additional material cost is usually only a fraction of the overall construction cost.

Although windows take up less area than the rest of the building shell in most cases, they have been an important source of heat losses because of the poor energy performance of conventional window systems compared to well-insulated walls. For windows, the resistance to heat flow is affected by a number of factors including the tightness of the window installation, the type of glazing material, the number of layers of glazing, the size of the air space between layers, the filling between the layers, the coating (if any), and the thermal resistance of the frame. In general, multiple layers of small areas of glass will typically perform better than larger windows with fewer layers.

Windows are available with heat losses of only 0.7 to 0.8 W/m\(^2\) per degree Kelvin (K). This is around 30% to 35% less than coated double-glazed windows. The improvement in the thermal performance of windows is due to the use of multiple glazing layers, the use of low-conductivity gases such as argon between glazing layers, applying low-emissivity coatings on one or more glazing surfaces, and using very low-conductivity framing materials such as extruded fibreglass or PVC. Coatings that allow the inner glass layer to have a temperature much closer to that of the room also help improve indoor comfort. It is important that glazing with low-conductivity gases is well maintained, as a loss of filling can result in performance deterioration of up to 60%.

In hot climates, it is particularly important to keep heat out. Coatings on the glazing that reflect or absorb a large fraction of the incident solar radiation while maximising the transmission of visible sunlight can reduce solar heat gain by up to 75%. This reduces the need for cooling, particularly when combined with shutters or shading. The cost of glazing and windows, even with these technological improvements, has remained constant or even dropped in real terms (Jakob and Madlener, 2004).

### Barriers to greater market penetration

A number of market and non-economic barriers mean that the building shells of new buildings are generally not designed to least life-cycle cost levels. Cost-effective refurbishments are also often not undertaken, even when other renovations are

---

22. For more information, see [www.ecbcs.org](http://www.ecbcs.org)
under way. Research, development and demonstration (RD&D) is needed to improve the cost and performance of current materials, and to develop their optimisation and integration into new building design and refurbishment designs. This RD&D is essential if large-scale reductions in energy consumption, particularly from existing residential buildings and new commercial buildings, are to be achieved.

Savings potential and abatement costs

The technical scope for energy efficiency improvements in the existing residential building stock is large. It is also large from an economic perspective. Some industry studies indicate that energy consumption in existing buildings in Europe could be reduced by more than 50%, more than three-quarters of which in some types of buildings could be achieved with increased insulation (European Mineral Wool Manufacturers Association, EURIMA). In new buildings, BATs could halve or quarter heating requirements compared to standard practice. This could be achieved at a cost of only a few per cent of the total cost of residential buildings, and at little or no net incremental cost in new service sector buildings (Demirbilek et al., 2000; Hamada et al., 2003; Hastings, 2004). In countries that have mild winters but still require heating, modest amounts of insulation can readily halve heating requirements, as well as substantially reducing indoor summer temperatures (Taylor et al., 2000; Florides et al., 2002; Safarzadeh and Bahadori, 2005). This includes many developing countries.

Retrofitting high-rise residential buildings with energy efficiency improvements when they are refurbished can yield energy savings of up to 80% and negative life-cycle costs. The economics of retrofitting detached or terraced houses can vary widely. In the United Kingdom, for example, retrofitting ceilings and cavity walls with insulation has been estimated to range from a cost of USD 1 310/tCO₂ saved where insulation is already thick to a net saving of as much as USD 444/tCO₂ saved where this is not the case (Shorrock and Henderson, 2005). For new houses in Canada, moving to a more energy-efficient design standard (the Canadian R-2000 standard) rather than the minimum standard can save significant amounts of energy at abatement costs in the range of net savings of USD 36/tCO₂ to costs of USD 228/tCO₂ depending on circumstances (Seeline Group, 2005 and IEA analysis). In the United States, the average abatement cost for building shell measures such as the tightening of new building standards and retrofits is estimated to be around a net saving of USD 42/tCO₂ abated (McKinsey, 2007a). In Germany, renovation to a low-energy standard is expected to have negative abatement costs, while renovation to passive house standards is currently estimated to be very expensive, with an abatement cost of at least USD 800/tCO₂ (McKinsey, 2007b).

Heat pumps for heating and cooling

Heat pumps are highly efficient technologies for providing cooling and space and water heating. They use renewable energy from their surroundings (ambient air, water or ground) and “high-grade” energy (e.g. electricity or gas) to raise the...
temperature for heating, or lower it for cooling. They achieve efficiencies greater than 100%, that is to say they provide more useful cold or heat (in energy terms) than the energy input. The potential energy and CO₂ savings from the wider use of heat pumps are substantial, given their high efficiency and relatively low market penetration for space and water heating. Most air conditioners are heat pumps. The efficiency of today’s BAT for air conditioners is considerably higher than average installed efficiencies, offering further scope for CO₂ emission savings. When combined with thermal storage, to enable load to be shifted out of peak periods, heat pumps could also help reduce the costs in the BLUE Map scenario of integrating a high share of intermittent renewables into the grid.

In OECD countries, most energy in the buildings sector is used for space and water heating. The energy consumption for cooling is generally modest. For example, in the residential sector in the United States, a mature air-conditioning market, energy consumption for cooling is only around 8% of the total energy consumption in the residential sector. In commercial buildings in the United States, cooling and ventilation accounts for around 13% of the total energy consumption for space and water heating.

Air-conditioning systems, which are predominantly heat pumps, cool, ventilate, humidify and dehumidify buildings. Space conditioning, including controlling humidity, is an integral requirement of many buildings for human comfort, productivity and even safety, for example in hospitals and rest homes. In humid countries, the energy required for dehumidification can be as high as that for cooling. In the BLUE Map scenario, the buildings sector deploys heat pumps widely for space and water heating and very high-efficiency heat pumps for cooling. This, together with the decarbonisation of the electricity sector, results in very significant savings as against the Baseline scenario.

Heat pump technology and performance

Heat pumps for heating and cooling buildings can be described by the source of renewable energy they use (air, water or ground) and by the heat transport medium they use (air or water). They can also be described by the service that they provide, i.e. cooling, or space and/or water heating. The European Union, depending on certain criteria being met, credits heat pumps as using renewable energy.

The performance of heat pump systems has improved over time with the advances made in individual heat pump components (such as the use of inverters) and with efforts to achieve better overall system integration and performance. The efficiency of a heat pump depends on a number of different factors, specifically:

- the technical specifications of the heat pump;
- whether the heat pump is operating at full load or not;

---

25. The European Union credits the heat pumps use of “aerothermal”, “hydrothermal” and “geothermal” energy as part of its Directive to promote the use of renewable energy (EU, 2009).
26. Heat pump efficiencies can be described by the “coefficient of performance” (COP). For example, a heating COP of three is equivalent to 300% efficiency, i.e. three units of useful heat for one unit of energy input.
27. United States Energy Information Administration's Residential Energy Consumption Survey (RECS) and Commercial Building Energy Consumption Survey (CBECS) (see www.eia.doe.gov).
whether temperature is being increased or decreased;

- the desired indoor temperature and the existing or planned heat distribution system temperature;

- the temperature difference between the heat source and heat sink to be bridged by the heat pump.

The most critical factor is the temperature differential that is required to be bridged, i.e. the temperature lift or reduction that is being sought. The higher this is, the lower is the efficiency of the system. On a like-for-like basis, ground-source heat pumps (GSHPs) tend to have higher efficiencies than air-source heat pumps (ASHPs)\(^{28}\) or air-to-air heat pumps, as ground temperatures are more constant throughout the year. The higher efficiency of GSHPs has to be considered in light of their higher installation costs. Typical COP values for air-to-air heat pumps are in the range of 2.5 to 3.5, while for ASHPs the range is similar. GSHPs tend to have COPs in the range of 3.5 to 5.\(^{29}\) However, the best systems available can exceed these values by a significant margin.

Significant improvements in the average efficiency of new air conditioners have been achieved. The United States minimum energy performance standards and Energy Star programmes, the European labelling schemes, and Japan’s Top Runner Programme have helped to raise COPs. The Japanese programme has resulted in impressive improvements in COPs. The COP of heat pump air conditioners in Japan increased from around 4.3 in 1997 to around 6.6 in 2008. Some air conditioners have achieved COPs of 9.0. In the United States, the minimum standard for new central air conditioners in the residential sector is a seasonal COP of 3.8, while models with a COP greater than six are available.\(^{30}\)

Heat pumps for space heating can either use air or water as the distribution method. In hot climates, the availability of units that can both heat and cool offer a potentially very cost-effective means of producing hot water, heating it from the waste heat produced in the cooling cycle. If combined with thermal storage, this could dramatically reduce energy consumption for water heating. This technology is also suitable for buildings with simultaneous space heating and cooling loads, particularly in the commercial sector.

ASHPs are capturing an increasing share of the space and water heating market. They can operate down to temperatures of around -25°C and, by avoiding the need for ground or water loops, have significantly lower installation costs than GSHPs. Significant improvements in efficiency have also been achieved, with the COP of Japanese heat pump water-heating systems rising from around 3.5 in 2001 to around 5.1 in 2008. But they tend to be around 10% to 30% less efficient than GSHPs in cold climates.\(^{31}\)

---

\(^{28}\) In this chapter, ASHPs are defined as air-to-water heat pumps to distinguish them from air-to-air heat pumps.

\(^{29}\) It should also be noted that in inter-country comparisons of heat pumps, higher COPs do not necessarily imply more efficient technology. Differences can be due to different climate and operating conditions.

\(^{30}\) The COPs of Japan and the United States are not directly comparable owing to different test standards.

\(^{31}\) This is due to the rapid fall in capacity and performance with decreasing outdoor temperature, the relatively high temperature difference in the evaporator and the energy needed for defrosting the evaporator and to operate the fans.
Barriers and R&D priorities

Heat pump technologies are proven and mature. But to achieve the goals in the BLUE Map scenario will require a number of current market and non-economic barriers to be overcome as well as additional R&D to improve overall system performance, particularly in a wider range of applications and climates.

For example, although there are many air-conditioning products on the market, users often lack an understanding of the most appropriate technology for a specific use. Some more efficient systems have high initial capital costs although they may be cheaper to run on a lifetime basis. The installation and operation of more advanced systems can be difficult as well, adding to costs. There has been a lack of good comparative information to help the consumer. Improvements in control systems have the potential to achieve additional savings by ensuring that coolers only run when necessary.

Similarly, more efficient heating systems suffer from relatively high first costs, a lack of consumer awareness of the often lower life-cycle costs and the lack of good comparative information and financing packages to help overcome these barriers.

The main R&D priorities for the future are:

- **Components**: More efficient components and systems for heating and cooling applications. Reduce costs and increase reliability and performance.

- **Systems/applications**: Optimise component integration and improve heat pump design and installations for specific applications.

- **Control and operation**: Develop intelligent control strategies to adapt operation to variable loads and optimise annual performance. Develop automatic fault detection and diagnostic tools.

- **Integrated and hybrid systems**: Develop integrated heat pump systems that combine multiple functions (e.g. space conditioning and water heating) and hybrid heat pump systems that are paired with other energy technologies (e.g. storage, solar thermal and other energy sources) in order to achieve very high levels of performance.

Integrated systems, such as those that integrate solar thermal technologies and heat pumps, have significant potential and would result in very high efficiency/low-carbon hybrid systems.

Heat pump system and abatement costs

Investment costs and delivered energy costs depend heavily on the system selected and the cost of electricity. In many cases, heat pump investment costs are higher than those of conventional boiler systems. Heat pump systems with borehole heat exchangers are expensive. Horizontally installed heat pump circuits are cheaper and can cost around the same as oil-fired boilers. In large systems in commercial buildings,
the use of thermal ground storage offers the possibility of very low-cost cooling once the installation is paid for. Air-to-air systems have very low capital costs.

Systems that can be reversed, for heating or for cooling purposes, are economically attractive in temperate climates which may require both applications at different times of the year. The incremental cost of giving the possibility to reverse the cycle is very modest compared to the cost of installing separate heating and cooling systems.

Different regions deploy residential heat pumps with very different specifications and costs, as a result of the often very different sizing systems, local standards and consumer preferences (Table 6.3). GSHPs tend to be the largest and most expensive systems to install.

**Table 6.3** Technology and cost characteristics of heat pumps for heating and cooling, 2007

<table>
<thead>
<tr>
<th></th>
<th>Single-family dwelling</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North America</td>
<td>China and India</td>
</tr>
<tr>
<td>Typical size (kWth)</td>
<td>2-19</td>
<td>1.5-40</td>
</tr>
<tr>
<td>Economic life (years)</td>
<td>15-20+</td>
<td>15-20</td>
</tr>
</tbody>
</table>

**Costs**

<table>
<thead>
<tr>
<th></th>
<th>Installed cost: air-to-air (USD/kWth)</th>
<th>Installed cost: ASHP (USD/kWth)</th>
<th>Installed cost: GSHP (USD/kWth)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>475-1 250</td>
<td>720-1 250</td>
<td>905-1 700</td>
</tr>
<tr>
<td></td>
<td>180-225</td>
<td>347</td>
<td>439-600</td>
</tr>
<tr>
<td></td>
<td>400-536</td>
<td>560-1 333</td>
<td>1 000-1 400</td>
</tr>
<tr>
<td></td>
<td>558-1 430</td>
<td>607-3 187</td>
<td>1 170-2 267</td>
</tr>
</tbody>
</table>

**Cost of delivered energy**

<table>
<thead>
<tr>
<th></th>
<th>(USD/GJ) range for all</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16-29</td>
</tr>
<tr>
<td></td>
<td>7-11</td>
</tr>
<tr>
<td></td>
<td>18-49</td>
</tr>
<tr>
<td></td>
<td>18-64</td>
</tr>
</tbody>
</table>

Note: The cost of delivered energy is an average for heating and cooling combined where appropriate; COPs used for calculating delivered energy costs are based on typical values provided by the IEA Heat Pump Programme. Economic life varies by technology.

Sources: IEA Heat Pump Programme; Navigant Consulting; VHK (2007c) and McNeil et al. (2005).

The cost of abating CO₂ through the use of heat pumps varies widely depending on the country and application (Figure 6.21). A number of options in the United States for the residential sector would deliver cost savings alongside emissions savings. Advanced unitary compressors for central air-conditioning units would save USD 95/tCO₂ abated. In humid climates, systems would save USD 80/tCO₂ abated (Sachs et al., 2004). For the service sector, an advanced roof-top air conditioner unit could save over 4 000 kWh a year with a saving of USD 72/tCO₂ abated. In the European Union, the wider use of split air conditioners would reduce electricity consumption by 38% at a saving of between USD 117/tCO₂ and USD 600/tCO₂ abated (Riviere et al., 2008).

In many cases, modest energy and CO₂ savings can be achieved with negative costs of abatement. But larger energy and CO₂ savings can only be achieved at a cost, and one which tends to become progressively larger for higher levels of abatement.
**Figure 6.21** CO₂ abatement costs for heat pumps in heating applications

Note: “Gas new” and “Oil” denote a comparison to a gas and oil boiler respectively for a new installation. “Retrofit” denotes a comparison to a boiler replacement in an existing home. “SFD” is single-family dwelling and “MFD” is multi-family dwelling. Analysis undertaken for typical residential dwellings in North America, Europe, China and OECD Pacific.

Sources: Based on data in Table 6.3 and IEA databases and analysis.

**Key point**

Heat pumps are already an attractive abatement option in many applications and countries.
For example, in India today the electricity consumption of room air conditioners could be cut by around 10% at a saving of between USD 14/tCO₂ and USD 65/tCO₂ saved. But increasing the electricity saving to around 30% would result in costs of between USD 120/tCO₂ and USD 170/tCO₂ saved. This latter cost range could fall to between USD 50/tCO₂ and USD 100/tCO₂ saved by 2030, but will still even then be a cost rather than a saving (McNeil et al., 2005 and IEA analysis).

For large service-sector buildings, GSHPs systems are likely to be economic and have negative abatement costs where they provide space and water heating as well as cooling in summer (Sachs et al., 2004).

**Combined heat and power in buildings**

CHP technologies can reduce CO₂ emissions in the buildings sector today in a wide range of applications. CHP can also potentially improve energy security and the reliability of energy supplies. It is a mature technology, capable of providing electricity, heat, cooling (using absorption cycles) and dehumidification. Newer CHP technologies that are not yet mature, such as fuel cells and stirling engines, are beginning to be deployed. In the BLUE Map scenario, given the decarbonisation of electricity generation, CHP will need to depend on carbon-free or largely carbon-free fuel sources if it is to avoid increasing CO₂ emissions. Building-scale CHP systems using fuel cells powered by CO₂-free hydrogen play a part in the BLUE Map scenario after 2030. But achieving such an outcome will depend on cost reductions, improved performance and durability improvements in the next 20 years.

Building-scale CHP can meet space and water heating demands, as well as cooling demands. In recent years, the use of CHP in commercial buildings and multi-residential complexes has increased steadily. This is due largely to technical improvements and cost reductions in smaller-scale, often pre-packaged, systems that can meet a wide range of thermal and electrical loads. Previously, CHP has been confined mostly to large institutional-type organisations that have large heat loads, or that need secure electricity supplies in the event of grid failure, such as hospitals, hotels, education facilities and large campus-style service parks. Installation in residential buildings is still at an early stage of deployment.

Selecting a CHP technology for a specific application depends on many factors, including:

- the annual electricity load profile;
- the annual thermal load profile;
- the relative timing of thermal and electric loads;
- despatch choice (either thermal or electric load following);

---

32. This chapter only discusses building- and “campus”- or “service park”-scale CHP technologies. Large-scale CHP and the distribution of heat to buildings through district heating networks is taken into account “upstream” in the modelling of electricity and heat generation and distribution.
space constraints, if any;
- emission regulations;
- fuel availability;
- utility prices for electricity and other fuels;
- interconnection regimes/protocols with local electricity utilities for sale of surplus electricity;
- first cost and the cost of financing; and
- complexity of installation and operation.

The complexity of the design and operation of CHP systems is a significant obstacle to the exploitation of the potential of CHP to reduce costs and energy consumption. The development of small-scale CHP technologies with lower costs and improved performance and reliability means that their potential for deployment in the near future should grow, as building-scale CHP applications become attractive. Even so, there remain serious challenges to the widespread uptake of CHP technologies in the residential sector.

The most significant constraint is the wide variation in seasonal heat demand. For example, sizing for generally more constant water heating loads limits the benefits of CHP systems in the residential sector, while grouping water heating loads from several residential buildings is often difficult to manage. But the reduction of the relative importance of space heating in the BLUE Map scenario will allow a greater proportion of space heating needs to be met by CHP, as will the growing availability of low-cost compact thermal storage. In the service sector, many subsectors have proportionately larger and more stable water and space heating, and cooling loads. This significantly improves the competitiveness of CHP solutions.

CHP technologies

A number of technological developments are being explored that offer the possibility of expanding the range of potential applications for CHP in buildings. These include the use of reciprocating engines including stirling engines, gas turbines, fuel cells, microturbines and fuel-cell/turbine hybrids.33

Most service sector applications demand 50 to 500 kW. In the residential sector, demand can be as low as 1 to 30 kW in an individual household. Gas turbines are available up to around 30 MW. Fuel cells could possibly reach up to 10 MW. Reciprocating engines and microturbines are available from around 5 kW and 25 kW respectively. Fuel cells and microturbines are commercially available, but are still in their infancy in terms of market deployment.

33. Other options not discussed in detail in this section include organic rankine cycles and steam boilers with heat capture downstream.
Reciprocating engines

Reciprocating engines in the form of spark- or compression-ignited internal combustion engines (ICE) are the most common CHP type. They are technically mature and often the most cost-effective small-scale CHP technology. They are used in a variety of applications because they have low costs, take up little space, have a useful thermal output and are available in a wide range of sizes from as little as 5 kW, to as large as 7 MW. The efficiency of reciprocating engines for electricity generation is in the range of 25% to 45%, with the most advanced natural gas-fired engines reaching 48%. The total efficiency of reciprocating engines is between 70% and 80%. Reciprocating engines have a rapid start capability and a high tolerance of start/stop operations. Like car engines, they emit a range of local air pollutants, depending on the fuel used.

Stirling engines are external combustion engines, as opposed to ICEs. They are not yet widely available and still need development. They can use a wide range of fuel sources such as natural gas, biomass and solar energy. They are closed systems, so they require heat exchangers to transfer the heat to a working fluid. Stirling engines can have high overall efficiencies, low maintenance costs, and are quieter than reciprocating engines. However, they have relatively low electrical efficiency. Depending on development, stirling engines could become a potentially attractive technology for the buildings sector, but their low electrical efficiencies make their economics challenging.

Gas turbines

Gas turbines use high-temperature, high-pressure hot gases to produce electricity and heat. The combustion of natural gas or liquid fuels causes high-pressure, high-temperature gas to rush out of the combustor and rotate a set of turbine blades that can be used to run a generator. They can produce heat and/or steam as well as electricity. Their electrical efficiency ranges from 20% to 45%, while overall efficiency can range from 70% to 80%. Above an 80% load factor, gas turbines can operate within one or two percentage points of their design efficiency. They are among the cleanest fossil-fuelled generation equipment available. They are also quick starting, compact (relative to their output), lightweight, simple to operate and have high reliability and availability. But their output declines with altitude and with higher ambient air temperatures.

Microturbines

Microturbines have been around since the 1990s, but have not been widely deployed and are not currently a mature technology. They are similar to gas turbines although smaller, and they use recuperators to preheat combustion air. They are generally in the 25 kW to 500 kW power range, with the majority in the 30 kW to 100 kW range. Microturbines are lightweight and compact in size. They are generally designed to use natural gas but they can also use other fuels such as liquid petroleum gas and industrial waste gases if they are relatively pure. They are generally less efficient than their larger counterparts. Recuperated microturbines in the 30 kW to 100 kW capacity range typically achieve electrical efficiencies of about 23% to 27%, and overall efficiencies of between 64% and 74%. Simple-cycle
microturbines achieve electrical efficiencies some 12% to 13% lower, with little change in overall efficiencies.

**Fuel cells**

Fuel cells use an electrochemical process which releases the energy stored in a natural gas or hydrogen fuel to create electricity. Heat is a by-product. Fuel cells that include a fuel reformer can utilise the hydrogen from any hydrocarbon fuel, including natural gas, methanol and gasoline. Local pollutant emissions from this type of system would be much lower than emissions from the cleanest fuel combustion processes.

Although fuel cells are available commercially, they are only at their infancy in terms of deployment and development. They will need to tackle significant cost and performance challenges, such as cell longevity and durability, before they will become attractive CHP options in the buildings sector.

There are four main types of fuel cell: molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC), phosphoric acid fuel cells (PAFC) and polymer electrolyte fuel cells (PEMFC). Of these, the most promising for CHP may be the SOFC. These operate at high temperatures, thereby obviating the need for precious-metal catalysts and external reformers. They could be paired with gas turbines or microturbines in a hybrid configuration, potentially achieving electrical efficiencies of between 58% and 70% and overall efficiencies of up to 80% to 85%.

PEMFCs operate at relatively low temperatures (80°C), have high power density, can vary their output quickly, and are suited for applications where quick start-up is required. They are likely to be the fuel cell of choice for the automotive market and are, therefore, attracting significant R&D efforts.

If fuel cells decline in cost in line with expectations, they could become a very attractive technology as their high power-to-heat ratios make them ideal for low base-heat loads. If hydrogen production costs come down and hydrogen distribution infrastructure is available, fuel cells will also have a significant role in decarbonising heat supply as well as in improving overall efficiency.

**CHP characteristics and costs**

The overall economics of CHP systems depend on a number of factors, including the technology, system configuration, the individual characteristics of the project and relative electricity and gas tariffs (Table 6.4). Large-scale systems tend to have lower unit costs and higher electrical efficiencies, although sometimes not higher overall efficiencies. The lower installed costs for larger systems are the result of proportionally lower equipment costs and lower installation costs. Small-scale CHP applications are generally expensive today, but are expected to become cheaper over time.

---

34. See IEA (2005) for a more detailed discussion of these fuel cell types.
### Table 6.4 Technology and cost characteristics of CHP technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Reciprocating engines</th>
<th>Gas turbines/microturbines</th>
<th>Fuel cells</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size range (kW)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large-scale</td>
<td>100-3 000</td>
<td>100-3 000</td>
<td>1-100</td>
</tr>
<tr>
<td>Small-scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Economic life (years)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large-scale</td>
<td>15-20</td>
<td>15-20</td>
<td>15-25</td>
</tr>
<tr>
<td>Small-scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Electrical efficiency</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large-scale</td>
<td>30-40%</td>
<td>35-45%</td>
<td>20-40%</td>
</tr>
<tr>
<td>Small-scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total efficiency</strong></td>
<td>75-85%</td>
<td>80-88%</td>
<td>80-85%</td>
</tr>
<tr>
<td><strong>Installed cost (USD/kW)</strong></td>
<td>1 000-1 600</td>
<td>800-1 100</td>
<td>1 500-12 000</td>
</tr>
<tr>
<td><strong>Fixed O&amp;M (USD/kW/year)</strong></td>
<td>1.5-10</td>
<td>1.5-5</td>
<td>varies</td>
</tr>
<tr>
<td><strong>Variable O&amp;M (USD/kWh)</strong></td>
<td>0.008-0.017</td>
<td>0.006-0.012</td>
<td>0.011-0.017</td>
</tr>
</tbody>
</table>

**Note:** O&M refers to operation and maintenance.

**Sources:** Discovery Insights (2006); Japan Gas Association (2009); Marcogaz (2009).

---

### CHP abatement costs

The estimated CO₂ abatement costs for different CHP technologies in 2015 are shown in Figure 6.22. Stirling engines, although just being introduced to most markets, look to be an attractive small-scale technology in many regions given their cost profile. The CO₂ abatement costs of conventional gas engines and gas turbines depend significantly on the region and scale.
**Figure 6.22** CO₂ abatement costs for CHP in the buildings sector by technology, 2015

In the BLUE Map scenario, electricity generation in OECD regions is substantially decarbonised by 2030, and the carbon intensity of electricity generation in developing countries is significantly reduced. At this point, the lowest emissions will be achieved by buying electricity from the grid and producing heat separately in highly efficient gas-condensing boilers, rather than by exploiting the efficiency gains of fossil-fuelled CHP. If CHP is to play a part in the post-2030 BLUE Map scenario, it will need to move to carbon-free fuel sources.

Larger-scale CHP could be equipped with CCS, and the heat generated could be distributed to the residential and service sectors through district heating networks. Alternatively, at the building scale, biomass or possibly hydrogen could be used by conventional and fuel cell CHP technologies respectively. If the capital costs of fuel cells come down and delivered hydrogen costs can be reduced to about USD 15/GJ, then hydrogen fuel cell CHP units could be a particularly attractive abatement option in many applications in the residential and service sectors.

**Solar thermal heating and cooling**

Solar thermal technologies provide heat that can be used for any low-temperature heat application up to 250°C, including space and water heating and cooling (with sorption cooling). They are an important part of the transition to a sustainable energy profile for the buildings sector, as they offer a cost-effective, carbon-free energy source that can be used for space and water heating. But costs will need
to continue to fall and low-cost compact thermal energy storage will be required if they are to provide a significant share of space and water heating needs globally.

Active solar thermal (AST) systems collect the incoming radiation from the sun by heating a fluid (generally a liquid, but occasionally air). The heated fluid in these collectors is used either directly, for example to heat swimming pools, or indirectly with the use of a heat exchanger to transfer the heat to its final destination, for example for space heating. The amount of heat energy provided per square metre of collector surface area varies with design and location but typically can range from 300 kWh/m²/yr to 900 kWh/m²/yr.

The use of solar thermal energy varies significantly between countries depending on the maturity of markets, policy incentives and available solar resources. In 2007, China dominated total installed capacity with 79.9 GWth. The United States has 21.2 GWth installed capacity, the 27 European Union countries 17 GWth, and Japan 5.2 GWth. In China, Europe and Japan, solar thermal systems are used mainly to provide hot water and space heating, while in the United States and Canada swimming pool heating is still the dominant application.

Technology application, description and status

The majority of installed active solar thermal systems heat water for residential applications, as they are often competitive with conventional heating fuels. But they also have the potential to provide significant contributions to space heating and cooling in the buildings sector.

AST systems are either thermosiphon (natural) or pumped (forced) circulation systems. Thermosiphon systems are common in frost-free climates and rely on the fact that heated liquids are lighter than cooler ones in order to circulate the heat transfer fluid to the storage tank. Forced circulation systems allow the separation of the collector and the storage tank, but are more complicated systems with pumps and a control system to optimise operation. There are two main types of collectors: flat-plate collectors, which can be glazed or unglazed, and evacuated tubes.

Solar panels are mature technologies and at the upper end of the efficiency range for converting solar radiation into heat. Their efficiency is unlikely to improve very significantly. But design and cost parameters are complex and there can be significant differences between systems. The variation between the best and worse systems in Switzerland showed that the most effective flat-plate collectors produced more than twice as much energy as the least effective collectors for water heating (VHK, 2007c).

Thermal storage

The key to solar systems providing a larger share of a household space and water heating is the availability of low-cost compact thermal storage systems. These would enable much larger solar systems than are used today, with the surplus heat in summer months being stored until the winter, enabling 100% of space and water heating needs to be met.
The most common storage system today is a well-insulated tank containing either the working fluid or hot water. These systems are cheap and can store heat for days or even a week or two at acceptable cost. But they are bulky and not an ideal solution for long-term storage.

Current solar systems are relatively small and meet between 20% and 70% of average domestic hot water needs with a 150 to 300 litre storage tank. Solar combi-systems are larger, and with a 1 000 to 3 000 litre storage tank can meet 20% to 60% of the space heating and water heating needs of a single-family house.

The prospects for low-cost thermal storage solutions becoming available in the near future based on the latest heat-storage technologies (sorption or thermochemical heat storage) are good. The BLUE Map scenario assumes that these begin to be deployed beyond 2020 and that they enable solar thermal systems to become progressively larger to meet a growing share of space and water heating needs.

Solar thermal system and abatement costs

Solar systems can often provide space and water heating at competitive prices compared to conventional technologies using electricity or fossil fuels. Simple systems without freeze protection can provide hot water at very competitive prices. The more sophisticated flat-plate and evacuated-tube systems that characterise many markets, including the European and North American ones, are significantly more expensive. They are often more costly than conventional technologies. With wider deployment, these costs are expected to come down as solar sales grow and achieve critical mass in markets.

Solar water heating can abate emissions at very low, or even negative, costs where good insolation levels occur and cheap solar systems are available and appropriate. In China and India, for example, where systems are very cheap by OECD standards, starting from as little as USD 200 per system, the CO₂ abatement costs are often modest or negative. In Zimbabwe, solar water heating can yield discounted cost savings of USD 1 000 over 15 years (Batidzirai et al., 2008). Solar water heating is estimated to have an abatement cost of around USD 30/tCO₂ in South Africa. In Hong Kong, solar hot-water systems that replace gas-fired systems could save CO₂ at a negative cost of around USD 850/tCO₂ (Li and Yang, 2008). But in cold climates where freeze protection is necessary, abatement costs can be much higher. In the United Kingdom, for example, abatement costs could be over USD 1 000/tCO₂ (Shorrock and Henderson, 2005).

Installed system costs for solar thermal systems for water and space heating are expected to decline by 2050, at least in Europe, by around three-quarters for new multi-family buildings and by between 53% and 60% for refurbishing applications and new single-family buildings (ESTTP, 2007). Cost reductions will come from the use of cheaper materials, improved manufacturing processes, mass production, and the direct integration into buildings of collectors as multi-functional building components and modular, easy to install systems. Delivered energy costs are anticipated to decline by around 70% to 75% (Table 6.5).
<table>
<thead>
<tr>
<th></th>
<th>Single-family building</th>
<th>Multi-family building</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typical size: water heating (kWth)</strong></td>
<td>2.8-4.2</td>
<td>2.8-4.2</td>
</tr>
<tr>
<td><strong>Typical size: combi systems (kWth)</strong></td>
<td>8.4-10.5</td>
<td>8.4-10.5</td>
</tr>
<tr>
<td><strong>Useful energy: water heating (GJ/system/year)</strong></td>
<td>4.8-8</td>
<td>4.8-8</td>
</tr>
<tr>
<td><strong>Installed cost: retrofit (USD/kWth)</strong></td>
<td>1530-1730</td>
<td>1200-1300</td>
</tr>
<tr>
<td><strong>OECD North America</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Typical size: water heating (kWth)</strong></td>
<td>2.6-4.2</td>
<td>2.6-4.2</td>
</tr>
<tr>
<td><strong>Typical size: combi systems (kWth)</strong></td>
<td>8.4-10.5</td>
<td>8.4-10.5</td>
</tr>
<tr>
<td><strong>Useful energy: water heating (GJ/system/year)</strong></td>
<td>9.7-12.4</td>
<td>9.7-12.4</td>
</tr>
<tr>
<td><strong>Useful energy: space and water heating (GJ/system/year)</strong></td>
<td>19.8-29.2</td>
<td>19.8-29.2</td>
</tr>
<tr>
<td><strong>Installed cost: retrofit (USD/kWth)</strong></td>
<td>1530-2100</td>
<td>1200-2000</td>
</tr>
<tr>
<td><strong>OECD Pacific</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Typical size: water heating (kWth)</strong></td>
<td>2.1-4.2</td>
<td>2.1-4.2</td>
</tr>
<tr>
<td><strong>Typical size: combi systems (kWth)</strong></td>
<td>7-10</td>
<td>7-10</td>
</tr>
<tr>
<td><strong>Useful energy: water heating (GJ/system/year)</strong></td>
<td>6.5-10.3</td>
<td>6.5-10.3</td>
</tr>
<tr>
<td><strong>Useful energy: space and water heating (GJ/system/year)</strong></td>
<td>17.2-24.5</td>
<td>17.2-24.5</td>
</tr>
<tr>
<td><strong>Installed cost: new build (USD/kWth)</strong></td>
<td>1100-2140</td>
<td>1000-1930</td>
</tr>
<tr>
<td><strong>Installed cost: retrofit (USD/kWth)</strong></td>
<td>1400-2140</td>
<td>1300-1950</td>
</tr>
</tbody>
</table>
Barriers and research, development and demonstration needs

Solar heating technologies are mature and reliable, and are already competitive with incumbent technologies in many applications. However, their often higher capital costs can make them appear more expensive to the potential purchaser compared to conventional heating systems, even when they are competitive on full-life costs. During the last decade, capital cost reductions of around 20% have been observed for each doubling of installed capacity of solar water heaters. Solar cooling technologies are at a much earlier stage of development.

More RD&D investment can help to drive AST system costs down further. Priority areas for attention include new flat-plate collectors that can be more easily integrated into building facades and roofs, especially as multi-functional building components. Photovoltaic-thermal combined collectors that can deliver warm water as well as generate electricity and advanced systems that can meet the specific needs for heating and cooling in single-family houses. Hybrid solar thermal/heat pump systems are also a potentially interesting area of R&D. Larger-scale systems require further development if solar-assisted district heating schemes, with capacities in the megawatt scale are to be achieved. Concentrating solar heating technologies are at an early development stage, with several promising collector designs close to demonstration.

Architectural design will play a major role in the broader market penetration of solar heating and cooling options, as will the introduction of new standards, regulations and testing procedures, coupled with appropriate labelling.

Lighting and appliances

Ownership and technology status

The continuing demand for new large and small appliances, often with new functionality, is resulting in rapidly increasing electricity consumption in both the residential and service sectors. Lighting demand is also growing, although new policies on residential lighting, such as the phase-out of incandescent bulbs, will help to slow demand growth in OECD countries. Given the high CO₂ intensity of electricity generation in the Baseline scenario in developing countries, and their rapid growth, energy efficiency for lighting and appliances will be an important abatement area.

Traditional large appliances are still responsible for most household electricity consumption for appliances. But their share is falling rapidly as electronic home entertainment and information and communications equipment now accounts for more than 20% of residential electricity consumed in most countries. This rapid technology penetration offers opportunities to roll out more efficient appliances, but this effect to date has been overwhelmed by the increased uptake of new devices. For example, flat-screen televisions are more efficient than the cathode ray tube technology they replaced. But sales have quickly shifted to much larger screens, eliminating any benefits. In developing countries, current ownership levels, even
of major appliances, are often low and the potential for growth is significant. For instance, only 4% of rural households in India had refrigerators in 2002, compared to the norm of 95% to 100% in OECD countries (Figure 6.23).

**Figure 6.23** Selected appliance ownership by country

![Graph showing appliance ownership by country](image)

**Note:** Room air conditioners include “air coolers” for India. Data for India are for 1999/2000 or 2002, for other countries they are for 2005 or latest available.

**Sources:** IEA databases; LBNL (2008); National Sample Survey Organisation (2005).

**Key point**

Appliance ownership in developing countries is generally very low compared to the norms in OECD countries.

Most large household appliances, such as residential refrigerators, have become more efficient in their use of energy over recent years and at the same time have become cheaper (IEA, 2009b). But the impact of these efficiency gains has been diminished by an increase in the size of products and the increasing range of products. This is true in developed and developing countries. For example, there has been a trend in India over time for people to buy larger refrigerators. The largest sales share now is for 185 litre to 225 L refrigerators, whereas in the past 165 L refrigerators dominated. This trend is unlikely to slow for some time, as the sales of even larger refrigerators (200 L to 300 L) are rising rapidly (TERI, 2006).

The life-cycle costs of new, efficient lighting systems are often the same as or lower than existing systems. Many new lighting solutions are so cost-effective that it makes sense to prematurely retire old inefficient lighting systems and to retrofit more efficient ones. Voluntary market transformation programmes, such as the European Greenlights programme, have shown that the retrofitting of lighting systems has a generally very short payback period. Some of these programmes have shown internal rates of return on investment of over 20%.
The demand for artificial light is far from being saturated. While an average North American consumes 101 megalumen-hours each year, the average inhabitant of India uses only 3 megalumen-hours (IEA, 2006). But lighting is currently used very inefficiently. Light is routinely supplied to spaces where no one is present. This could readily be reduced by the use of time-scheduled switching, occupancy sensors and daylight-responsive dimming technologies, all of which are mature and fully proven techniques with high savings returns.

**Potentials and costs**

In developed countries, energy efficiency policies for major appliances have achieved efficiency gains of 10% to 60% in most major economies in recent years while real consumer prices have fallen by 10% to 40% at the same time (IEA, 2009b). This has been due to a combination of factors, including the availability of low-cost electronic control technologies, improved materials and reduced manufacturing costs. Experience and economies of scale have also contributed.

There is still a potential for significant further savings. The household electricity consumption of a range of information and communications technology and consumer electronics appliances could be reduced by 30% by 2030 (IEA, 2009b). Shifting to BAT would allow a 50% saving by 2030, leaving electricity consumption more or less unchanged for these appliances between 2010 and 2030. The potential savings from all types of appliances in developing countries and EITs could be even greater than in developed countries because of their ability to leapfrog to more efficient technologies (IEA, 2006; WEC, 2006 and 2007). But cost barriers need to be addressed, as consumers in these countries are much more likely to be capital constrained.

The cost of current BATs is expected to reduce as they become more widely deployed. Life-cycle costs of these technologies could even become negative. For example, shifting to BAT for fridge-freezers in OECD Europe would initially cost between USD 171/tCO₂ and USD 411/tCO₂. After deployment these costs could fall to between a saving of USD 307/tCO₂ and a cost of USD 81/tCO₂ (IEA, 2008b). Given the high CO₂ intensity of electricity generation in China and India, abatement costs are already negative for a wide range of appliances. For example, for refrigerators efficiency could be improved for a cost saving in the range of USD 30/tCO₂ to USD 50/tCO₂.

A number of already fully commercialised technologies could significantly reduce lighting demand. These include fluorescent and high-intensity discharge lamps and modern ballasts and transformers, luminaires and controls. A shift from inefficient incandescent lamps to compact fluorescent lamps (CFLs) would cut world lighting electricity demand by 18%. If owners were to install only efficient lamps, ballasts and controls, global lighting electricity demand in 2030 would be almost unchanged from 2005, and it could even be lower than that between 2010 and 2030 (IEA, 2006). This could be achieved at a global average saving of USD 161/tCO₂ saved, but it would require strong policy action.

Solid-state lighting is emerging as a promising efficient lighting technology for the near future. Over the last 25 years it has undergone sustained and significant
improvements in efficiency that hold the prospect of it outperforming today’s mainstream lighting technologies in a growing number of applications. If current progress is maintained, solid-state lighting may soon make inroads into general lighting. Solar-powered solid-state lighting already offers a robust economic solution to the needs of households reliant on fuel-based lighting.

In the service sector, the use of high-efficiency ballasts, slimmer fluorescent tubes with efficient phosphors, and high-quality luminaires produces savings that are just as impressive. For street and industrial lighting, there are large savings to be had from discontinuing the use of inefficient mercury vapour lamps and low-efficiency ballasts in favour of higher-efficiency alternatives.

**Barriers and policy options**

The bulk of this savings potential could be achieved without major technological development (McKinsey, 2007c). Achievements to date have been largely policy-led. The primary concern is to create sufficient market pull to encourage widespread deployment of the best existing technologies. The further deployment of energy-efficient appliances continues to face many barriers. R&D effort will also be needed in order to go beyond existing BATs.

In most developed countries, low energy costs and rising affluence mean that the overall running cost of appliances is a small proportion of household incomes. Electricity expenditure represented only 1.6% of average household expenditure in 2006 in the United Kingdom and only 3.1% in Japan (IEA, 2009a). And it is an expenditure that remains largely hidden. In developing countries, the first cost of more efficient products represents a significant barrier.

Energy labels have become widespread for major appliances. But there is very little available public information on the running costs and savings potential of smaller appliances. In addition, labels do not usually specify the highest efficiency potential for each type of appliance. As a result, few consumers have the ability to make informed decisions about relative life-cycle costs. For example, consumers are largely unaware of the consumption of current TV technologies, and there is little market incentive for the commercialisation of liquid crystal display (LCD) televisions with back-light modulation or organic light-emitting diodes (LEDs), technologies that could reduce consumption by approximately 50%. Such information could provide a market pull for new, more efficient appliances. This is the case in Europe, where the intention to make labelling mandatory for televisions, perhaps in 2011, has already resulted in more efficient products entering the market.

To tap into the potential for low-cost energy and greenhouse-gas savings, policies are required that provide an incentive at all stages in the supply chain to bring energy-efficient technologies to the market. A broad range of policy measures is available, including regulatory and voluntary approaches, financial incentives, fiscal measures and procurement policies. Many have been tried successfully by some countries. These need to be replicated in more countries and regions, and applied to a wider range of appliances, particularly those in the area of home entertainment and information and communications technologies.
Policies need to be developed for small electronic appliances which will remain relevant despite the rapid evolution of products. For example, the IEA has proposed that a generic approach to stand-by power requirements should be applied to the majority of appliances so that product-specific definitions become unnecessary. In general, policies need to ensure that manufacturers design all their devices with the ability to move automatically to the lowest power needed for their required functionality. This will minimise the time that appliances that no one is using continue to consume unnecessary power.
Key findings

Driven by increases in all modes of travel, but especially in passenger light-duty vehicles (LDVs) and aviation, the Baseline scenario projects a doubling of current transport energy use by 2050 and slightly more than a doubling of greenhouse-gas emissions to about 16 gigatonnes (Gt) of carbon dioxide equivalent (CO$_2$-eq).\(^1\) In a transport High Baseline scenario, CO$_2$-eq emissions increase by 150% over 2007 levels to nearly 20 Gt in 2050. Greenhouse-gas emissions increase faster than fuel use increases in the Baseline scenarios as a result of the growing use of high-carbon fuels such as unconventional oil and coal-to-liquid (CTL) fuels after 2030.

In the BLUE Map scenario, total transport fuel use rises much more slowly, reaching 30% above 2007 levels by 2050, with very low-carbon fuels such as biofuels, electricity and hydrogen (H$_2$) providing more than half of all fuel use in that year. This results in emissions reductions of 9.5 Gt CO$_2$-eq, about 60% below the Baseline scenario and nearly 20% below 2005 levels (base year for CO$_2$-eq emissions reduction target in the BLUE scenario).

A BLUE Shifts scenario is also examined in which some of the expected future growth in passenger travel and freight transport is shifted from LDVs, trucks and air travel into bus and rail travel. In this scenario, emissions in 2050 are about 3 Gt CO$_2$-eq lower than in the Baseline scenario. Combining the BLUE Shifts scenario with the BLUE Map scenario achieves an overall reduction of about 11 Gt CO$_2$-eq in 2050 against the Baseline scenario.

Both OECD and non-OECD countries reduce their greenhouse-gas emissions in 2050 by an average of about 60% in the BLUE Map scenario compared to the Baseline. This results in emissions in OECD countries on average about 60% less than in 2007. However, in non-OECD countries, emissions in BLUE Map in 2050 are still 60% higher than in 2007. Strong population and income growth in non-OECD countries will make the achievement of absolute reductions compared to today’s emission levels extremely challenging.

The prospects are good for cutting future fuel use and CO$_2$ emissions from LDVs, including via technologies to improve internal combustion engine (ICE) efficiency, through vehicle hybridisation and adoption of plug-in hybrid electric vehicles (PHEVs), electric vehicles (EVs) and fuel-cell vehicles (FCVs).

With oil at USD 120 per barrel (bbl) and using a low discount rate, virtually all incremental efficiency improvements to gasoline and diesel vehicles are paid for by vehicle lifetime fuel savings. Plug-in hybrid electric vehicles (PHEVs) can also provide

---

1. As described in IEA (2009a), the transport analysis includes three types of greenhouse-gas emissions: carbon dioxide (CO$_2$), methane (CH$_4$) and nitrous oxide (N$_2$O). Therefore, the results are expressed in tonnes of CO$_2$-equivalent emissions, on a well-to-wheel (WTW) basis, unless otherwise stated. Nearly all vehicle emissions are CO$_2$; and only for natural gas and biofuels are upstream emissions of CH$_4$ and N$_2$O significant. The transport totals reported in ETP combined results (e.g. Chapter 2) do not include CH$_4$ or N$_2$O.
relatively low-cost CO$_2$-eq reductions in the near term in areas with low CO$_2$-eq electricity generation. Pure EVs and FCVs remain relatively expensive in the near term even with oil prices at USD 120/bbl, but costs decline over time.

Advanced biofuels can also play an important role for light-duty ICE vehicles, with some cost-effective options already available and other options becoming more cost-effective over time. Demand for biofuels for LDVs in the BLUE Map scenario begins to decline after 2030 as a result of a strong shift towards electricity and hydrogen fuels. However, biofuel use continues to rise rapidly for trucks, ships and aircraft through 2050. This biofuel will slowly replace middle distillate petroleum fuels and to a large extent will need to be compatible with these fuels.

Total additional investment costs for vehicles in the BLUE Map scenario to 2050, relative to the Baseline, amount to about USD 22 trillion. This is about 10% higher than the levels of investment in the Baseline scenario of around USD 231 trillion and reflects significant cost reductions over time. At a 2050 oil price of USD 120/bbl, fuel savings in the BLUE Map scenario reduce costs by around USD 20 trillion, nearly offsetting the higher vehicle costs. At USD 70 per barrel of oil in 2050 (as assumed under BLUE Map), fuel costs are reduced by USD 47 trillion. In that case, the total vehicle and fuel costs in the BLUE Map scenario are around USD 25 trillion less than those in the Baseline scenario. With a 10% discount rate, the vehicle and fuel costs in the Baseline drop to about USD 95 trillion, with the costs in BLUE Map about USD 1 trillion higher.

Most OECD governments now have strong light-duty vehicle fuel economy standards in place that will influence LDV markets at least until 2015. Many governments have announced plans to support the wider use of EVs and PHEVs. Taken together, these commitments amount to more than 5 million EVs and PHEVs being in use by 2020. The United States and the European Union have implemented policies to encourage the greater use of more sustainable types of biofuels. But these measures constitute only initial steps towards the transport technology revolution that is needed if emission levels are to be halved by 2050. Much more effort is needed to increase research, development and demonstration (RD&D) and deployment funding and co-ordination. And measures need to be taken to encourage consumers to adopt the technologies and lifestyle choices that are the essential underpinning of a transition away from energy-intensive, fossil fuel-based transport systems.

Introduction

Transport accounted for about 26% (IEA, 2009b) of all energy-related CO$_2$ emissions in 2007 and is likely to account for a higher share in the future unless strong action is taken. As discussed in Transport, Energy and CO$_2$: Moving towards Sustainability (IEA, 2009a), reducing the global use of fossil fuels in transport will be very challenging. If a halving of global energy-related CO$_2$ emissions is to be achieved by 2050, transport must make a significant contribution, moving well below 2007 emission levels by 2050.
Worldwide, transport-sector energy use and CO\textsubscript{2} trends are strongly linked to rising population and incomes. Transport continues to rely primarily on oil. Decoupling transport growth from income growth and shifting away from oil will be a slow and difficult process. Achieving large reductions in greenhouse-gas emissions by 2050 will depend on changes happening much more quickly in the future than in the past. Improvements in vehicle and transport system efficiencies of 3\% to 4\% a year will need to replace past improvement rates of 0.5\% to 2\% a year. New technologies and fuels will need to be adopted at unprecedented rates. But if significant decoupling can be achieved, the benefits will include not only CO\textsubscript{2} reductions, but also substantial energy cost savings and increased energy security, as well as reductions in pollutant emissions, such as nitrous oxides (NO\textsubscript{x}) and particulate matter.

From 1971 to 2007, global transport energy use rose steadily by between 2\% and 2.5\% a year, closely paralleling growth in economic activity around the world (Figure 7.1). The road transport sector, including both LDVs and trucks, used the most energy and grew most in absolute terms. Aviation was the second-largest transport user of energy, and grew the most in percentage terms.

**Figure 7.1**  
World transport final energy use by mode

![Diagram showing world transport final energy use by mode](image)


**Key point**  
Transport energy use has more than doubled since 1971, and has been dominated by road transport.

Despite steady global growth, different regions and countries show very different patterns in terms both of energy use per capita and of the types of fuel used (Figure 7.2). Including the share of international transport energy use attributed to each region, some regions such as North America (except Mexico) consumed an average of over 2 300 tonnes of oil equivalent (toe) per thousand people in 2007. Others, such as parts of Africa, averaged less than 100 toe per thousand people.
Figure 7.2  Transport sector energy use by region, 2007

The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Note: The figure reports final energy (end use), including the relevant allocation of energy use by international shipping, international aviation and pipeline transport. Pipeline is excluded in the rest of Chapter 7, unless otherwise stated.


Key point

Different countries have very different patterns of energy use per capita and use very different types of energy.
These data reveal differences both in the amount of travel undertaken and in the types of vehicles and fuels used for that travel.

Transport fuel use worldwide is currently dominated by petroleum, with over 95% of fuel being either gasoline or distillate fuels such as diesel, kerosene or jet fuel. Some countries use significant amounts of natural gas, liquefied petroleum gas (LPG) or liquid biofuels such as ethanol.

Different regions use individual modes of travel to different extents (Figure 7.3). OECD countries rely on passenger LDVs (i.e. cars, sports utility vehicles and minivans) much more than non-OECD countries. People in OECD countries also undertake far more air travel per capita. Developing countries show far higher modal shares for buses and, in some regions, motorised two-wheelers, i.e. scooters and motorcycles.

**Figure 7.3** Motorised passenger travel by mode, 2007

<table>
<thead>
<tr>
<th>% of pkm</th>
<th>OECD</th>
<th>Non-OECD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td></td>
<td></td>
</tr>
<tr>
<td>United States</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>United Kingdom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other OECD Europe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia and NZ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Korea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Transition Economies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eastern Europe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Asia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle East</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Latin America</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Africa</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: IEA Mobility Model (MoMo) database estimates.

**Key point**

Passenger travel shares on a total kilometre basis in OECD regions are primarily met by passenger LDVs, while in many non-OECD regions buses provide a majority of passenger travel.

The total stock of passenger LDVs has grown steadily, reaching about 780 million worldwide in 2007. From 1990 to 2007, the stock of LDVs grew by about 60%, or about 3% per year, dominated by gasoline vehicles in most countries. In the same period, world population grew by 25%, from 5.2 billion to 6.5 billion. In wealthy countries, the rate of growth in passenger LDV stocks has declined in recent years.
This reflects a slowing in population growth. It may also signify a saturation of car ownership, reflecting the fact that in most OECD countries many families already own one vehicle per driver. In developing countries, rates of LDV ownership are growing rapidly. Many families purchase LDVs as soon as they can afford them. The emergence of low-cost LDVs such as the Tata Nano in India will probably further accelerate LDV ownership rates. The number of motorised two-wheelers also continues to grow rapidly.

In most regions, the total amount of road and rail freight has been increasing, although the rates of increase vary widely between countries (Figure 7.4). Even within Europe, growth rates vary considerably. Between 1999 and 2007, for example, road tonnage rose by 93% in Spain and fell by 7% in the Netherlands (Eurostat, 2009). Worldwide, total rail volumes are higher than total road volumes, but they are concentrated in a small number of countries, and are growing at a slower pace than road freight.

Figure 7.4  Freight activity trends by region

Freight trends for road and rail by region reveal that rail volumes are higher than total road volumes, but they are concentrated in a small number of countries.

Energy efficiency by mode

Estimates of recent average vehicle CO₂-eq intensity by mode in grammes (g) of CO₂-eq per tonne-kilometre (tkm) for freight modes and in grammes of CO₂-eq per passenger-kilometre (pkm) for passenger modes are shown in Figure 7.5. The figures reveal a wide range of values for each mode of transport. Some modes are generally less CO₂-intensive and also more efficient than other modes. For example, rail is less CO₂-intensive (more efficient) than air for both freight and passenger movement.
The energy efficiency and CO₂-eq emissions of different passenger and freight modes vary widely; shipping is least CO₂-intensive (most efficient), air is usually the most CO₂-intensive (least efficient).

Large-scale shipping is generally the most CO₂-efficient way to move freight. Rail is the next most CO₂-efficient mode. Road and air freight movements tend to be much more energy-intensive. For passenger transport, rail, buses and two-wheelers show similar levels of average efficiency, but efficiency levels range much more widely for buses and two-wheelers than for rail. Passenger LDV efficiencies range even more widely, reflecting the fact that different regions have very different vehicle...
types as well as significant differences in average load factors. Air travel shows a narrower range but on average emits more CO₂-eq than any other mode.

On the basis of the limited data available, it appears that road freight transport is more efficient in OECD countries than in non-OECD countries. Road passenger transport in non-OECD countries is more efficient than in OECD countries, as non-OECD passenger travel happens mostly in smaller vehicles and at high load factors. Current estimates also indicate that passenger aviation is more efficient in OECD countries than in non-OECD countries. This could be due to a lower average age of airplanes and higher load factors. Passenger rail transport is also thought to be slightly more efficient in OECD countries than in non-OECD countries owing to the higher levels of electrification of the rail passenger infrastructure in the former. Accurate data on rail passenger travel levels in many developing countries are not however available.

**Trends in light-duty vehicle fuel economy**

Through much of the 1980s and 1990s, new LDV fuel economy remained fairly constant in many OECD countries. It began to show steady improvements in Europe and Japan in the mid-to-late 1990s in response to new national and regional policies, thereby increasing the disparity in fuel economy between North America and the European and Pacific OECD countries. Test values, although not fully comparable one with another, indicate wide variations in the average fuel consumption rates for new LDVs in IEA countries (Figure 7.6). Korea experienced a notable jump in average fuel consumption rates after 2000 primarily because of a rapid rise in sports utility vehicle (SUV) sales.

![Figure 7.6](image)

**Figure 7.6** New LDV tested fuel economy in various OECD countries

Source: IEA MoMo database.

Note: European countries test with the New European Duty Cycle (NEDC); Canada and the United States use the CAFE test cycle; Japan uses the 10-15 test cycle; and Korea uses the US urban test cycle.

**Key point**

Steady improvements in LDV efficiency have occurred in many, but not all, OECD countries since 1995.
Transport scenarios

Five main scenarios are covered in this chapter. Two (the Baseline and BLUE Map scenarios) are consistent with the ETP-wide scenarios. Using the IEA Mobility Model (MoMo), three additional scenarios have been developed to show alternative possible futures for the transport sector. These scenarios represent just a few of many possible futures, selected to illustrate the impacts of specific assumptions and policy and technology developments. They are not predictions.

The main features of the five scenarios are:

- **Baseline:** In this scenario, vehicle ownership and travel per vehicle for LDVs, trucks and other modes are consistent with IEA (2009c) and a world oil price rising to USD 120/bbl by 2050. This scenario assumes greater urbanisation in developing countries and lower suburbanisation than in OECD countries, greater income disparities between the wealthy and the poor in non-OECD countries, and limits on the capacity of non-OECD countries to develop the infrastructure needed to support large numbers of vehicles. As a result, passenger LDV ownership is somewhat lower in the developing world at a given level of income than has occurred historically in many OECD countries. This scenario also assumes that the decoupling of freight travel growth from GDP growth that has clearly begun in OECD countries continues and that it spreads also to non-OECD countries.

- **High Baseline:** This scenario uses the same population and income assumptions as the Baseline scenario. It assumes growth in passenger LDV ownership in the developing world to levels similar to historical trends in OECD countries, and faster growth in vehicle travel and freight transport, especially trucking. This scenario results in about 20% higher fuel demand by 2050 than in the Baseline scenario and would probably require much greater use of more expensive fossil fuels such as unconventional oil and synthetic fuels such as CTL and gas-to-liquid (GTL) fuels.

- **BLUE Map:** This scenario reflects the uptake of technologies and alternative fuels across transport modes that are economic at a carbon price of up to USD 175 per tonne of CO₂-eq saved by 2050. New powertrain technologies such as hybrids, PHEVs, EVs and FCVs start to penetrate the LDV and truck markets. Strong energy efficiency gains occur for all modes. Very low greenhouse-gas alternative fuels such as hydrogen, electricity and advanced biofuels achieve large market shares.

- **BLUE Shifts:** This scenario envisages that travel is shifted towards more efficient modes and that total travel growth is restrained by better land use and the denser development of metropolitan areas, the greater use of non-motorised modes of travel and the substitution of travel by telecommunications technologies. Most of these policies will need time to be implemented and to have a wide impact. The scenario envisages that these effects reduce passenger travel in both LDVs and aircraft by approximately 25% compared to the Baseline scenario by 2050.

- **BLUE Map/Shifts:** This scenario combines the technology changes in BLUE Map with the travel pattern changes in BLUE Shifts, reaping the combined energy and CO₂-eq benefits of both. However, since in BLUE Map all vehicle types become significantly decarbonised by 2050, the benefit of modal shifting is somewhat lower than in the BLUE Shifts scenario. As a result, the combined effect of the two scenarios is much less than additive.
The specific assumptions and key results for each scenario are shown in Table 7.1.

### Table 7.1  Scenario descriptions, assumptions and key results

<table>
<thead>
<tr>
<th>Scenario definition</th>
<th>Baseline</th>
<th>High Baseline</th>
<th>BLUE Map</th>
<th>BLUE Shifts</th>
<th>BLUE Map/Shifts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Passenger LDVs</strong></td>
<td>Total vehicle travel more than doubles by 2050; fuel economy of new vehicles 30% better than in 2007</td>
<td>Non-OECD countries follow more closely OECD passenger LDV ownership trends</td>
<td>Maximum efficiency gains, greater use of advanced biofuels, deployment of EVs, FCVs</td>
<td>No advanced technology deployment, gain through modal shifting only</td>
<td>BLUE Map + BLUE Shifts</td>
</tr>
<tr>
<td><strong>Trucks</strong></td>
<td>Strong growth to 2050; 25% on-road efficiency improvement</td>
<td>Strong growth to 2050; 25% on-road efficiency improvement</td>
<td>Fuel cells reach nearly 20% of sales of large trucks by 2050; PHEVs constitute between 5% and 10%; CNG grows to about 15%</td>
<td>Baseline tkm growth between 2007 and 2050 cut by 50%, shifted to rail</td>
<td>BLUE Map + BLUE Shifts</td>
</tr>
<tr>
<td><strong>Other modes</strong></td>
<td>Aircraft 30% more efficient in 2050; other modes 5% to 10% more efficient; strong growth in air, shipping</td>
<td>Aircraft 30% more efficient in 2050; other modes 5% to 10% more efficient; strong growth in air, shipping</td>
<td>Aircraft 43% more efficient by 2050 than in 2007; improved efficiencies for other modes</td>
<td>Baseline air travel growth cut by 25% (from a quadrupling to a tripling compared to 2007); many short-distance flights replaced by high-speed rail</td>
<td>BLUE Map + BLUE Shifts</td>
</tr>
<tr>
<td><strong>Biofuels</strong></td>
<td>Reach 160 Mtoe in 2050 (4% of transport fuel) mostly 1st generation</td>
<td>Reach 230 Mtoe in 2050 (4.5% of transport fuel), mostly 1st generation</td>
<td>Reach 745 Mtoe in 2050 (27%); mostly 2nd generation biofuels growth after 2020</td>
<td>Reach 130 Mtoe in 2050 (4%); mostly 1st generation</td>
<td>Reach 600 Mtoe in 2050 (26%); mostly 2nd generation biofuels growth after 2020</td>
</tr>
<tr>
<td><strong>Hydrogen</strong></td>
<td>No hydrogen</td>
<td>No hydrogen</td>
<td>200 Mtoe in 2050</td>
<td>No hydrogen</td>
<td>150 Mtoe in 2050</td>
</tr>
<tr>
<td><strong>Electricity</strong></td>
<td>27 Mtoe (mainly for rail)</td>
<td>30 Mtoe (mainly for rail)</td>
<td>350 Mtoe in 2050 primarily for EVs and PHEVs</td>
<td>44 Mtoe (mainly for rail)</td>
<td>290 Mtoe in 2050 primarily for EVs and PHEVs</td>
</tr>
</tbody>
</table>

### Scenario results

**Energy use and greenhouse-gas emissions**

The scenarios envisage very different results for energy use over time (Figure 7.7). In the Baseline scenario and even more in the High Baseline scenario, energy use grows substantially to 2050 as efficiency improvements are outweighed by growth in transport activity. There are also important differences between scenarios in the composition of fuels used. In the Baseline and High Baseline scenarios, little non-petroleum fuel is used even in 2050, although in the High Baseline scenario substantial amounts of synthetic fossil fuels and biofuels are used. As a result, fossil fuel use doubles in the Baseline scenario and increases by almost 150% in the High
Baseline scenario. The High Baseline scenario in 2050 would require an increase of more than 40 million bbl/d in liquid fuels from today’s level just for the transport sector. That level would be very challenging from a supply perspective.

**Figure 7.7** Evolution of energy use by fuel type, worldwide

Note: Unless otherwise indicated, all material derives from IEA data and analysis.

**Key point**

The BLUE scenarios cut energy use by almost half compared to the Baseline in 2050, and cut fossil fuel use to less than 50% of energy use.

In the BLUE Shifts scenario, the changes in travel patterns cut energy use in 2050 to about 10% above the Baseline scenario in 2030, suggesting a trend towards stabilisation. In the BLUE Map scenario, which retains the Baseline mode shares but with strong efficiency improvements, energy use in 2050 drops below the Baseline 2030 level. In the BLUE Map/Shifts scenario, energy use almost returns to the 2007 level.

While in the BLUE Shifts scenario the share of different fuels is similar to the Baseline, in the BLUE Map scenario, the need for fossil energy for transport is cut by nearly half compared to 2007, given very large shifts to low-carbon alternative fuels such as low-CO₂-eq electricity, hydrogen and advanced biofuels. In the BLUE Map scenario, most conventional gasoline- and diesel-powered LDVs have been replaced by 2050, largely by hydrogen and electrically powered vehicles.

Fuels for heavier long-distance modes such as trucks, planes and ships, will continue to need to be energy-dense and to accommodate long-range travel. They, therefore, remain dominated by diesel fuel, jet fuel and heavy fuel oil (HFO) or marine diesel. Biofuels are likely to play an important role in decarbonising these modes. Biofuels reach about 27% of total transport fuel use in the BLUE Map scenario in 2050, including about 30% of truck, aircraft and shipping fuel and 24% of LDV fuel. The balance comprises nearly all electricity and hydrogen for LDVs and predominantly petroleum fuel for trucks, ships and aircraft.
Different scenarios also result in different levels of energy use by individual modes and in different regions (Figure 7.8). Passenger travel accounts for about two-thirds of total transport energy use in 2007. This proportion does not change significantly in the future in either the Baseline or the High Baseline scenarios. But in the BLUE scenarios, particularly in the BLUE Map scenario, more energy saving occurs in passenger modes than in freight modes. This is due mainly to LDVs, which achieve the biggest overall efficiency gains as a result of the increase in EVs and FCVs. So the overall balance of energy use shifts towards freight.

**Figure 7.8  Energy use by transport mode and by region**

In the BLUE scenarios, more energy saving occurs in passenger modes than in freight modes. Regionally, most of the growth in energy use occurs in non-OECD countries.
In the Baseline and High Baseline scenarios, nearly all transport growth is in non-OECD regions. In the BLUE Shifts scenario, energy use in OECD countries drops significantly below its 2007 level, although energy use in non-OECD countries still grows significantly. The levels of travel and energy use per capita in 2050 remain much higher in OECD than in non-OECD countries, but are on a trajectory to converge some time after 2050.

The CO₂ intensity of the fuels in the BLUE Map scenario is largely dependent on the manner in which they are produced. For example, the electricity generation mix in the BLUE Map scenario becomes progressively less CO₂-intensive over time as fossil fuel generation is replaced by systems equipped with carbon capture and storage (CCS) and by nuclear and renewable energy. By 2050 it is nearly completely decarbonised. If this does not happen, then the CO₂-eq benefits of shifting to EVs will be far less than shown here.

Figure 7.9 shows passenger mobility greenhouse-gas (CO₂-eq) emissions by mode and scenario. In the Baseline and High Baseline scenarios, aviation grows fastest, increasing from about 10% of passenger transport greenhouse-gas emissions in 2007 to nearly 20% in 2050. In the BLUE Map scenario, aviation greenhouse-gas emissions reach nearly 40% as emissions from LDVs are greatly reduced by the switch to non-fossil energy sources.

**Figure 7.9**  
*Well-to-wheel passenger mobility greenhouse-gas emissions by mode*

<table>
<thead>
<tr>
<th>Year</th>
<th>Baseline</th>
<th>Baseline</th>
<th>High Baseline</th>
<th>BLUE Shifts</th>
<th>BLUE Map</th>
<th>BLUE Map / Shifts</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2050</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Key point**

By 2050 in the BLUE Map scenario, passenger greenhouse-gas emissions are about 30% lower than in 2007 and are dominated by car and air travel.

In freight transport, heavy trucks will continue to emit more greenhouse gases than other modes, with a particularly high share of about 60% of all freight emissions in the High Baseline scenario (Figure 7.10). Significant efficiency improvements in all
trucks are expected. Some shift to electricity for light commercial trucks is included in the BLUE Map scenario. But only a very small amount of electricity is assumed to be used by medium and heavy trucks. For these modes, natural gas (eventually partly substituted by bio-synthetic gas, bio-SG) gains some market share by 2050, as do hydrogen fuel cells. Diesel engines and diesel fuel remain dominant, particularly for long-haul trucks. For these trucks, refuelling needs to be high-capacity, quick and available on motorway networks. These factors limit the viability of fuels such as natural gas or hydrogen, given their low energy density and long refuelling times. Therefore, high-density, liquid diesel fuel substitutes such as advanced biodiesel are expected to play an important role in cutting truck CO₂-eq emissions.

Water-borne transport, including national and international maritime transport, also accounts for an increasing share of total emissions over time (Figure 7.10). As with heavy trucks, the options for CO₂-eq reductions in the future are limited. But many opportunities for efficiency improvements and use of biofuels could lead to potentially significant greenhouse-gas emission mitigation even in this mode.

**Figure 7.10**  
Well-to-wheel freight mobility greenhouse-gas emissions by mode

The contribution of well-to-tank (WTT) and tank-to-wheel (TTW) CO₂-eq greenhouse-gas emissions varies over time and between scenarios. Until 2050, WTT emissions account for between 7% and 20% of the total well-to-wheel (WTW) greenhouse-gas emissions in the scenarios considered. As vehicles become more efficient, the proportion of WTT emissions may increase in some cases. In particular, zero tailpipe vehicle emission technologies such as FCVs and EVs shift CO₂-eq emissions from TTW to WTT. The decarbonisation of the energy production process may in many cases be less expensive in terms of costs per tonne of CO₂-eq saved than reducing CO₂-eq emissions from vehicles themselves.
Sources of greenhouse-gas reduction

Both technology innovations and modal shifts will help to achieve the strong reductions in greenhouse gases projected in the BLUE scenarios. The reductions achieved by different approaches will depend both on relative costs and on the ability of governments to implement effective policies relating to travel, efficiency and fuel use.

Greenhouse-gas reductions for transport will come from three main sources:

- **Modal shifts** in urban short-distance travel and in long-distance travel from, for example, the greater use of high-speed trains.

- **Efficiency improvements** from new technologies that allow vehicles to reduce their energy use and from operational changes in truck transport management.

- **Alternative fuels** which allow vehicles to emit less CO₂-eq per unit of energy used, for example through the use of less carbon-intensive energy sources.

The BLUE Shifts scenario results in a saving of around 3 Gt of CO₂-eq compared to the Baseline scenario in 2050 and nearly 6 Gt of CO₂-eq compared to the High Baseline scenario in 2050. In the BLUE Map scenario, strong efficiency improvements and adoption of low-carbon fuels make similar contributions to a total CO₂-eq reduction of about 10 Gt relative to the Baseline scenario in 2050. This is more than a 60% reduction. It is also about 20% below 2007 levels.

Combining the assumptions in the BLUE Map scenario with those in the BLUE Shifts scenario into the BLUE Map/Shifts scenario results in reductions of nearly 11 Gt of CO₂-eq compared to the Baseline scenario in 2050. As shown in Figure 7.11, this comprises about 2 Gt of CO₂-eq from modal shifts, 4 Gt CO₂-eq from alternative fuels and 5 Gt CO₂-eq from vehicle efficiency improvements. In this scenario, each element contributes slightly less than in the two scenarios run separately, as the separate effects are not fully additive. Strong decarbonisation across all modes in the BLUE Map scenario reduces the differences in CO₂-eq intensity between different modes, thereby reducing the CO₂-eq benefits of shifting between modes. And with the lower levels of LDV and air travel in the BLUE Shifts scenario, the efficiency gains and lower-carbon fuels implicit in the BLUE Map scenario provide slightly smaller CO₂-eq reductions. But the combined effects are nonetheless quite large.

It is not clear that, in practice, the maximum potential impact of improved efficiency, fuel switching and modal shifts will all be achieved. But since there appear to be low-cost opportunities in all three areas, the optimum strategy is to pursue all of them vigorously. If for some reason one line of development plays a reduced role, then the others will tend to provide bigger CO₂-eq reductions than would otherwise be expected. In other words, if one “wedge” in Figure 7.11 is smaller than targeted, other wedges will likely become larger.

Each of the scenarios reaches different levels of CO₂-eq emissions and of CO₂-eq reductions for different regions over time (Figure 7.12). All regions reduce their emissions in 2050, compared to the Baseline, by more than 50% in the BLUE Map/Shifts scenario. Compared to 2007 emission levels, however, OECD regions
make far bigger reductions than non-OECD regions. Most non-OECD countries, including India and China, show significant increases.

**Figure 7.11** Sources of greenhouse-gas emissions reduction, transport sector

- Modal shifts
- Hydrogen, CNG, biogas
- Liquid biofuels
- Electricity decarbonisation
- EV
- PHEV
- Other LDV
- Trucks
- Other modes

**Key point**

Modal shift, efficiency and alternative fuels all play significant roles in cutting greenhouse-gas emissions by 2050.

**Figure 7.12** Well-to-wheel transport CO₂-equivalent emissions by region and by scenario

**Key point**

All regions achieve deep CO₂-eq reductions by 2050 in the BLUE Map scenario compared to the Baseline scenario.
In the BLUE Shifts and BLUE Map/Shifts scenarios, travel levels per capita begin to converge across all regions by 2050, especially for urban travel. Even so, non-urban travel levels in OECD countries remain far higher than those in non-OECD countries. The use of alternative fuels and advanced technology vehicles also begins to even out across regions after an assumed five- to ten-year head start in OECD regions in most cases. Accordingly, the CO$_2$-eq emissions in the BLUE Map/Shifts scenario in 2050 reflect both much more sustainable travel in all regions and more uniform travel patterns across regions than they are either today or in the Baseline scenario in 2050.

Investment requirements and fuel cost savings

The Baseline and BLUE Map scenarios require different levels of investment in specific vehicle types and in the fuels they use (Figure 7.13). Taking into account the value of fuel savings, BLUE Map does not appear to be more expensive than the Baseline scenario, and may be significantly cheaper.

Today the world spends several trillion US dollars each year on vehicles and fuels. In the Baseline scenario, the total undiscounted cost of vehicles and fuel from 2010 to 2050 is about USD 374 trillion, comprising USD 231 trillion on vehicles and USD 144 trillion on fuels. This is equivalent to nearly USD 10 trillion per year on average, although it starts well below this level and rises over time. In the BLUE Map scenario, vehicle investment needs increase by about 10% to USD 253 trillion, about USD 22 trillion over the Baseline scenario in 2050. For fuel, the BLUE Map scenario costs about USD 96 trillion, USD 48 trillion less than in the Baseline scenario in the period 2010-2050. The investment needed in vehicles and fuel together is, therefore, around USD 25 trillion lower in the BLUE Map scenario than in the Baseline scenario. This reflects an assumed reduction in oil prices from USD 120/bbl in the Baseline to USD 70/bbl in the BLUE Map scenario in 2050. If fuel prices do not change, the fuel cost reduction is only USD 19 trillion and the net (vehicle plus fuel) cost difference in BLUE Map is about USD 2 trillion. If fuel prices do not change and if a 10% discount rate is assumed across the 40-year time period for all vehicle and fuel purchases (not shown in Figure 7.13), this results in vehicle and fuel costs dropping by more than half in both the Baseline and BLUE Map. In the Baseline these costs drop to USD 95 trillion over the time period. In BLUE Map they become about USD 96 trillion, for a net cost increase of about USD 1 trillion over the Baseline. Discounting slightly reduces the net cost difference.

All of these calculations only include costs through 2050, whereas the energy savings from vehicles bought through 2050 actually would extend well after. Including the fuel savings after 2050 would tend to increase the net savings in BLUE Map, which uses less fuel. It would also increase the difference between the undiscounted and 10% discount cases, since the fuel savings after 2050 would be heavily discounted to present value.

Although the analysis projects net vehicle and fuel costs in BLUE Map between 2010 and 2050 that are similar to or even lower than in the Baseline scenario, the range of results shows that the outcome is subject to quite significant uncertainties, such as future oil prices, and the extent of cost reductions that occur over time for advanced-
technology vehicles. Even so, the analysis suggests that achieving the transport outcomes envisaged in the BLUE Map scenario may be of very low or negative net cost, particularly when considering societal cost (with low discount rates).

**Figure 7.13** Transport vehicle investment costs and fuel costs, 2010-50

Vehicle cost increases in BLUE Map are mostly offset by oil savings if oil prices remain at USD 120/bbl, and more than fully offset if oil prices drop to USD 70/bbl.

**Travel activity**

The overall picture that emerges from the ETP transport projections is that as of 2010, OECD countries are nearing or have reached saturation levels in many aspects of travel. Non-OECD countries, especially rapidly developing countries such as China and India, are likely to continue to experience strong growth rates into the future through at least 2050. In OECD countries, the biggest increases in travel appear likely to come from long-distance travel, mainly by air. In non-OECD countries, passenger LDV ownership and motorised two-wheeler travel are likely to grow rapidly, although growth in two-wheeler travel may eventually give way to passenger LDV travel as countries become richer. Freight movement, especially trucking, is also likely to grow rapidly in non-OECD regions. In all regions of the world, international shipping and aviation are likely to increase rapidly.
In the Baseline scenario, travel growth will be triggered by strong growth in the number of households that gain access to individual motorised transport modes such as cars and motorcycles. This will in turn lead to a rise in average travel speeds and increased travel distances, and reinforce land-use changes such as suburbanisation. Increasing wealth will also trigger more frequent and longer-distance leisure-related trips, in particular through increased tourism that generates considerable amounts of long-distance travel. Estimated motorised passenger travel worldwide was about 40 trillion kilometres in 2007. This is projected to more than double by 2050 in the Baseline scenario and to increase by 150% in the High Baseline scenario (Figure 7.14).

The BLUE Shifts scenario projects a different future for travel. Although it only reduces overall passenger travel slightly on a worldwide basis compared to the Baseline scenario, the composition of that travel changes significantly, with much greater travel shares being undertaken by buses and rail, the most efficient travel modes. For freight movement, the strong link between GDP and freight continues in the future in the Baseline scenario. As a result, non-OECD countries are expected to show the biggest growth in freight transport.

**Figure 7.14** - Passenger and freight mobility by mode, year and scenario

Key point

The BLUE Shifts scenario explores a future with significantly different modal shares than the Baseline scenario, resulting in 25% less air and car travel and 20% less energy use in 2050.

The Baseline, High Baseline and BLUE Shifts scenarios result in different travel patterns by mode. In OECD countries:

- urban rail travel in 2050 is nearly 100% higher in the BLUE Shifts scenario than in 2005; urban bus travel in 2050 is 50% higher in the BLUE Shifts scenario than in the Baseline scenario;
the higher use of LDVs in urban travel from 2007 to 2050 in both the Baseline and High Baseline scenarios is reversed in the BLUE Shifts scenario, with light truck travel slightly lower than in 2007 and car travel far lower than in 2007;

for non-urban travel, in the BLUE Map/Shifts scenario in 2050 the growth in air travel is cut by half with the result that it doubles in the BLUE Shifts scenario rather than tripling in the Baseline scenario. Intercity rail travel triples compared to 2007 and doubles compared to the Baseline scenario in 2050.

In non-OECD countries:

the very rapid growth in urban car use in the BLUE Map scenario is curtailed in the BLUE Shifts scenario. Instead, urban bus use and rail use increase by over 50%;

for non-urban travel, rail travel increases to a share similar to that of air travel and LDVs in the BLUE Shifts scenario, as a result of rapid expansion of rail systems such as high-speed rail and regional rail; air travel growth is cut from about 600% in the Baseline scenario from 2007 to 2050 to about 400% in the BLUE Shifts scenario in 2050.

The BLUE Shifts scenario represents a significant departure from the Baseline scenario. At minimum it would require a major change in patterns of development and investment, away from road systems and private vehicles and towards collective modes of transport, particularly rail systems. This must be coupled with spatial development that helps make these collective modes of transport efficient and attractive to users. Intelligent transport systems such as real-time schedule information and traffic routing systems will also support a modal shift. In some countries, it may also require disincentives for car use, such as higher fuel taxes or the widespread implementation of road pricing. The changes in investment costs implicit in the BLUE Shifts scenario have not yet been evaluated. Such an analysis would help in the better understanding of the relative costs and benefits of the BLUE Shifts scenario.

### Passenger LDV ownership

Passenger LDV ownership rates are likely to have a particularly significant impact on future travel patterns and energy use. Historically, there has been a strong correlation between income levels and the rate of passenger LDV ownership. This typically follows an S-shaped curve that becomes steep when per-capita income reaches about USD 5 000. LDV ownership rises rapidly with income above this level until income reaches a level at which LDV ownership saturates. Experts have used such a curve to model rates of LDV ownership against per-capita GDP, reflecting such factors as income distribution, road infrastructure development, the urbanisation of the population and the cost of LDV ownership relative to income (Dargay and Gately, 1999; IEEJ, 2010).

The Baseline and High Baseline scenarios reflect different assumptions as to the way in which the income/LDV ownership relationship may evolve. In the High Baseline scenario, growth in LDV ownership in non-OECD countries is assumed broadly to follow the pattern in which passenger LDV ownership has grown historically in OECD countries. In the Baseline scenario, LDV ownership in non-OECD countries
is lower than it has historically been in the OECD for the same level of income, and levels of ownership saturate at a lower level.

There are a number of reasons why this might be the case. Income growth in some non-OECD countries such as China may reflect much greater income disparities than in most OECD countries in the past. Some regions are likely to reach higher levels of urbanisation with more wealth concentration in urban areas and hence less need for personalised travel. In South and East Asia, ownership of motorised two-wheelers is already very high. This may dampen growth in the ownership of LDVs. And a relatively slower rate of road infrastructure development could also inhibit the rate of increase in LDV ownership, for example if severe traffic congestion develops.

The impact of the different ownership assumptions in the two scenarios by region, together with the corresponding assumptions used for the BLUE Shifts scenario, is shown in Figure 7.15. By 2050, passenger LDV ownership levels in the Baseline scenario reach about 350 LDVs per 1 000 people in Korea, Russia, Eastern Europe, Latin America and South Africa, and about 250 LDVs per 1 000 people in China, India and South–East Asia. The overall difference in the total number of LDVs in the three scenarios is very significant: in the Baseline scenario, world LDV stock reaches about 2.2 billion vehicles in 2050, whereas in the High Baseline scenario it reaches 2.6 billion, and only 1.7 billion in the BLUE Shifts scenario.

Figure 7.15  Passenger LDV ownership rates versus GDP per capita in three scenarios

The Baseline, High Baseline and BLUE Shifts scenarios assume significantly different futures for car ownership.
The sales of different vehicle technologies varies considerably between the Baseline and BLUE Map scenarios (with BLUE Shifts the same as the Baseline). In the Baseline scenario, conventional gasoline and diesel vehicles continue to dominate to 2050 (Figure 7.16), with just a small increase in the sale of hybrid vehicles over time. Gaseous-fuelled vehicles (mainly running on CNG) hold a small share of the global market, though in a few countries with abundant natural gas, they achieve a significant share.

In the BLUE Map scenario, changes over time are based on the projected evolution of technologies and costs described later in this chapter, and assume that strong policies are enacted to encourage a shift away from conventional vehicles. After 2010, the rate of growth in conventional gasoline and diesel LDV sales begins to be trimmed by the sale of hybrids, with PHEV and EV sales increasing quickly after 2015 (Figure 7.16). By 2020, PHEV sales reach 5 million and EV sales 2 million worldwide. Around 2020, commercial hydrogen (H₂) FCVs sales begin. From 2030, EV and FCV sales increase significantly, taking a progressively higher proportion of the overall growth in LDV sales. From 2030 onwards, demand for non-PHEV ICEs declines rapidly in absolute terms. By 2040, more EVs and FCVs are sold than any ICE vehicles. By 2050, LDV sales are equally split between FCVs, EVs and PHEVs. As described below, strong policies will be needed to make these changes happen.

**Figure 7.16** Evolution of passenger LDV sales by technology type in the Baseline and BLUE Map scenarios

*Key point*

In the BLUE Map scenario, advanced technology vehicles such as PHEVs, EVs and FCVs dominate sales after 2030.
Advanced technology vehicles in the BLUE Map scenario

There are currently only four main LDV engine types: gasoline, diesel, gasoline hybrid and gaseous fuel (CNG/LPG). By 2050 in the BLUE Map scenario, many new types of LDV are being sold (Figure 7.16).

Diesel hybrids, plug-in gasoline hybrids, plug-in diesel hybrids and pure electric vehicles seem likely to start to enter the market in material numbers within the next few years. Hydrogen vehicles are likely to take longer to achieve a material market share. In the near term, current and alternative technologies may all play a part in the worldwide market for LDVs, although different types may dominate in different countries, just as diesel and gasoline vehicles currently dominate in different countries. The extent to which diesel hybrids and plug-ins sell will mainly depend on their cost and fuel savings relative to their gasoline counterparts. In the BLUE Map scenario, they are assumed to be important, especially in Europe.

In the longer term, if PHEVs and EVs successfully secure a significant market share, the question is likely to be the extent to which FCVs can penetrate the market. In the BLUE Map scenario, it is assumed that FCV costs are low enough by 2025 that they can compete in some market segments, given some policy support e.g. to develop the necessary refuelling infrastructure. The BLUE Map scenario assumes that the potential of FCVs to provide long-range, zero-emission driving creates a niche for these vehicles, such that they take some market share from PHEVs and EVs, especially in Japan and the United States. In addition, fuel-cell vehicles provide a “portfolio” benefit. Given the uncertainty regarding whether EVs (and especially batteries) will achieve the improvements and cost-reductions assumed in BLUE Map, having both electric and fuel-cell vehicles in the mix acknowledges that broad mix of options should be pursued, given the underlying technology uncertainties.

Energy and greenhouse-gas intensity

In both the Baseline and BLUE Map scenarios, the energy intensity and associated greenhouse-gas intensity of all major passenger transport modes improves between 2007 and 2050 (Figure 7.17). In the Baseline scenario, higher oil prices and existing policies such as the fuel economy standards in many OECD countries result in a 30% reduction in the greenhouse-gas intensity of LDVs between 2007 and 2050. The greenhouse-gas intensity of all other modes except motorised two-wheelers also decreases, by about 15%. In the BLUE Map scenario, all modes reduce their greenhouse-gas intensity by at least 50% by 2050. The widespread availability of very low-carbon hydrogen and/or electricity by 2050 enables FCVs, EVs, two-wheelers and rail transport to cut their CO₂-eq emissions to very low levels by 2050.

In the BLUE Shifts scenario, some future travel growth shifts towards more efficient modes such as bus and rail for passenger transport and rail for freight transport help to reduce average energy and CO₂-eq intensities compared to the Baseline scenario. But as all modes become much less energy-intensive in the BLUE Map scenario, modal shift offers smaller emissions reductions in the BLUE Map/Shifts scenario than it does in the BLUE Shifts scenario. The BLUE Map/Shifts scenario achieves lower levels of CO₂-eq intensity than the BLUE Map scenario, but not
significantly so, since in the BLUE Map scenario by 2050 LDVs have achieved almost the same average CO₂-eq intensity as mass transit modes. Shifting from air to rail travel still provides a strong efficiency and CO₂-eq intensity benefit.

**Figure 7.17** Evolution of the greenhouse-gas intensity of passenger transport modes

![Graph showing the evolution of greenhouse-gas intensity for different modes of transport.](image)

**Note:** Covers the range of values for vehicle stocks by region. The clear line indicates world's average, the bar representing regional differences.

**Key point**

The CO₂-eq intensity of all modes improves significantly by 2050 in the BLUE Map scenario, with all but air travel emitting less than 50 g of CO₂-eq per passenger-kilometre.

**Transport technologies and policies**

**Fuels**

Petroleum fuels offer a number of benefits such as high energy density. These make it likely that, in the Baseline scenario, they will continue to dominate the overall fuel mix. But petroleum fuels also have at least two major drawbacks: potential supply limitations, including for many countries significant geopolitical risks, and high CO₂-eq emissions. For both of these reasons, there are strong incentives to develop and secure acceptable substitutes. A range of feedstocks and fuels is included in the ETP fuels analysis (Table 7.2). These fuels are described in IEA (2009a), where the IEA’s recent cost analysis of these fuels is also available.

The cost of reducing greenhouse-gas emissions through the use of different fuels can be estimated by combining fuel costs with life-cycle greenhouse-gas emissions, compared to a common gasoline baseline. The same set of information can be used to evaluate the effect of carbon prices on the relative costs of different fuels.
The incremental cost of a range of alternative fuels as a function of their CO₂-eq saving potentials varies widely (Figure 7.18). The rectangles in Figure 7.18 indicate typical ranges of variation for both CO₂-eq savings and cost.

### Table 7.2  Fuels and their production process

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Feedstock</th>
<th>Process/notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid petroleum fuels: gasoline, diesel, kerosene, jet fuel</td>
<td>Oil from both conventional and non-conventional sources such as heavy crudes and tar sands</td>
<td>Refining</td>
</tr>
<tr>
<td>Liquid synthetic fuels</td>
<td>Natural gas, coal</td>
<td>Gasification/Fischer-Tropsch (FT) process (with or without CCS): GTL or CTL</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>Oil-seed crops</td>
<td>Esterification, hydrogenation (resulting in fatty acid methyl esters [FAME]) or H₂-treated oils</td>
</tr>
<tr>
<td>Ethanol</td>
<td>Grains</td>
<td>Saccharification and distillation</td>
</tr>
<tr>
<td>Ethanol (and other distillate fuels)</td>
<td>Sugar crops (cane)</td>
<td>Distillation</td>
</tr>
<tr>
<td>Compressed natural gas</td>
<td>Natural gas, Biomass</td>
<td>Compression to store on vehicle</td>
</tr>
<tr>
<td>Electricity</td>
<td>Coal, gas, oil, nuclear, renewables</td>
<td>Different mixes in different regions, including with or without CCS</td>
</tr>
<tr>
<td>H₂</td>
<td>Natural gas</td>
<td>Reforming, compression, centralised with or without CCS, or at point of use</td>
</tr>
<tr>
<td>Electricity</td>
<td>Direct production using e.g. solar, nuclear energy, biomass</td>
<td>Electrolysis at point of use</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High-temperature process or biomass gasification</td>
</tr>
</tbody>
</table>

Biofuels for LDVs as well as for other vehicle types and modes will play an increasing role over time. The use of ethanol and biodiesel is likely to require only minor modifications to new vehicles. But a transition is needed to achieve much more sustainable approaches to the production of feedstocks and fuels. As sustainability criteria and rating systems emerge, policies will need to shift towards promoting the most sustainable, lowest-CO₂-eq, and most cost-efficient biofuels while minimising impacts from land-use change. A transition to second-generation fuels from non-food feedstocks will play a key role. This is particularly true in OECD countries, since their current biofuels production is dominated by ethanol from grain crops and biodiesel from oil-seed crops. These compete with food/feed supplies and do not perform well in terms of costs per tonne of CO₂-eq saved or land-use efficiency. The long-run supply potential of sustainable biomass feedstocks is uncertain, but with careful management it should be large enough to support the levels of bioenergy and transport biofuels envisaged in the BLUE Map scenario. Agriculture and forestry residues alone could be sufficient to supply most of the feedstocks in this scenario, at least until 2030 (IEA, 2010).
Figure 7.18 Incremental cost of alternative fuels as a function of their CO₂-equivalent saving potentials (at USD 120/bbl)

Note 1: Negative CO₂-eq savings means the use of the fuel results in higher WTW CO₂-eq emissions than using gasoline
Note 2: Assumes oil priced at USD 120/bbl. Costs reflect a bottom-up technology cost analysis of making each fuel, including feedstock production, transport, conversion to fuel, fuel transport, storage and retail supply to vehicles.
Note 3: Natural gas and bio-SG are assumed to be widely used in different end uses, sharing the costs of the transmission and distribution infrastructure required.

Key point
At USD 120/bbl, first- and second-generation biofuels become a cost-effective solution in certain regions.

Box 7.2 Natural gas for transport: the role of biogas and bio-synthetic gas²

The transport scenarios include a significant uptake of CNG as a transport fuel in some regions. Some countries, such as India, have already taken steps in this direction. The inclusion of CNG recognises the energy security and air quality benefits that are associated with the use of natural gas as a transport fuel, as well as CNG’s lower cost than oil for vehicle owners, notwithstanding the incremental costs associated with the need for refuelling infrastructure.

Natural gas emits typically about 25% less CO₂-eq per kilometre than gasoline in spark-ignition vehicles on a WTW basis. Emissions are similar to those of diesel vehicles. The use of CNG in diesel engines can bring greater emissions reductions.

2. Bio-synthetic gas (bio-SG) is sometimes termed bio-synthetic natural gas (bio-SNG). The word “natural” has been dropped here since the gas is synthetic, not natural.
If CNG vehicles are to play a more significant role in the long-term decarbonisation of transport, a substitute for fossil natural gas will need to be found. There are two main renewable alternatives for natural gas: biogas and bio-SG.

- **Biogas** is obtained by the anaerobic digestion of biomass, and contains mainly methane and CO₂. Digestion requires specific wet feedstocks which are available in only limited amounts.

- **Bio-SG** is a methane-rich gas produced by the thermo-chemical conversion of biomass first into a combination of synthetic gas (H₂ and CO), methane and other gases and, later, by the cleaning and the transformation of the synthetic gas component (as well as other gases) into methane through a catalytic process. The bio-SG product also needs to be further upgraded to pipeline specification by removal of CO₂ and water. Nearly all biomass materials are suitable as feedstocks for the production of bio-SG.

Both fuels can be produced with zero or possibly negative (if methane emissions are avoided) greenhouse-gas emissions. The energy efficiency of SG production from biomass typically is close to 65% and can exceed 70% in large-scale plants (Åhman, 2010). The heat generated during gas production can also serve as a useful energy source.

Since bio-SG can be derived from a wide range of biomass products, its potential availability is comparable with that of other biofuels. Its large-scale implementation would require an adequate transport and logistics system for biomass, as well as guaranteed supplies of sustainable biomass.

The production costs of bio-SG are estimated to be comparable to the cost of production of sugar-cane ethanol, at around USD 0.40/litre of gasoline-equivalent (lge) to USD 0.50/lge for large-scale plants after a wide technology deployment. This is at the low end of the cost range for advanced low greenhouse-gas biofuels.

More work is needed to better understand the regions and countries with the potential to produce sufficiently large quantities of biogas or bio-SG to support a significant transition to these fuels. The extent to which it would be advantageous to use biogas or bio-SG for transport rather than as a substitute for fossil natural gas in other sectors also needs to be assessed.

**Light-duty vehicles**

Passenger LDV ownership around the world is expected to rise broadly in parallel with incomes. In the Baseline scenario, the total stock increases from about 750 million in 2007 to more than 2.2 billion by 2050. In the High Baseline scenario, car ownership rates rise even faster, with ownership more closely tracking the historical rates observed in OECD Europe and Japan for a given income level, and reach 2.7 billion in 2050. This growth results in a less-than-proportionate increase in the rate of fuel use, given about a 25% improvement in vehicle fuel economy in the Baseline scenario over time. This improvement reaches 50% in the BLUE Map scenario, which along with a strong uptake of electric and fuel-cell vehicles, results in 2050 LDV fuel use about half that in the Baseline scenario. In the BLUE Shifts scenario, LDV fuel economy and technology shares closely mirror those...
in the Baseline scenario. But stocks grow more slowly, to about 1.8 billion by 2050, with less driving per vehicle. This results in nearly 25% less LDV energy use than in the Baseline scenario in 2050. In the BLUE Map/Shifts scenario, a combination of technology improvements and modal shifts results in a 60% reduction in 2050 LDV fuel use compared to the Baseline.

Improvements to ICE vehicles, including full hybridisation, can provide a 50% reduction in fuel use per kilometre for average new LDVs around the world by 2030 if average vehicle size and power do not significantly increase. These improvements are likely to be cost-effective at oil prices of USD 120/bbl or even well below this, using a societal discount rate. Many of these changes could be achieved at net negative CO₂-eq reduction costs, i.e. reducing emissions and saving costs at the same time. Policies will be needed both to ensure the maximum uptake of efficiency technologies and to ensure that their benefits are fully translated into fuel economy improvement. Fuel economy standards already play an important role in a number of OECD countries. If complemented by CO₂-based vehicle registration fees, these standards can help achieve the 50% target. It is important that non-OECD countries adopt similar policies, and that all countries continue to update these policies in the future, rather than letting policies expire or stagnate. The Global Fuel Economy Initiative, in which the IEA is a partner, is focused on helping achieve such outcomes (GFEI, 2010).

**Advanced technology vehicles**

Beyond incremental improvements to today’s ICE vehicles, rapid growth in the number of advanced technology vehicles will also play an important role, especially after 2020. Initiatives to promote EVs and PHEVs, and the continuing development of FCVs, will be extremely important in order to achieve a very low-CO₂ stock of LDVs around the world by 2050. Achieving the co-development of vehicle and battery production, a recharging infrastructure, and incentives to ensure sufficient consumer demand to support market growth will be a significant near-term challenge for governments. Working initially with regions and metropolitan areas which are keen to be early adopters, and achieving early market success in these areas, may be an effective approach. As described in IEA (2009d), lessons learned and information sharing over the next three to five years will be critical in moving towards a global mass market for EVs between 2015 and 2020.

**Plug-in hybrid electric vehicles (PHEVs)**

PHEVs are essentially similar to conventional ICE-electric hybrids except that they also have the capacity to draw electricity from the grid to charge their batteries. They require electric motors with sufficient power to drive the vehicle on their own in a wide range of driving conditions. They also require more battery capacity than conventional hybrids to increase the vehicle range on battery power and to provide more motive power, since the vehicle is designed to run on its electric motor a significant percentage of the time.

PHEVs would rely mostly on their batteries in what is known as charge-depleting mode, e.g. for shopping trips or commuting between home and work after the
batteries have been recharged at night or during working hours. PHEVs, however, can also function in the same way as conventional hybrids. When the battery charge is relatively low, for example on longer trips, the ICE can work with the electric motor in a charge-sustaining mode to make the most of the available battery power. This characteristic adds a significant degree of flexibility in the design of PHEVs, allowing manufacturers to choose among plug-in versions that have different degrees of reliance on the electric components for the delivery of power and energy. Different configurations can have very different electricity and system costs, especially for batteries.

The battery power in ICE-electric PHEVs may also be used when these are stationary either to offset electricity grid demands, for example in households, or to help stabilise the electricity grid. Such uses would need to be supported by appropriate battery management systems to avoid over-depletion of batteries or excessive cycling that could reduce battery life. Appropriate metering and billing systems will also be needed.

**Electric vehicles**

Electric vehicles are entirely powered by batteries and use a motor without the need for an ICE. They are charged solely by electricity from external sources (e.g. the grid). This is stored in batteries or other storage devices on board the vehicle. They offer the prospect of zero vehicle emissions, as well as very low noise. An important advantage of EVs is the very high efficiency and relatively low cost of the electric motor. The main drawback is the need to rely exclusively on batteries which are a costly, heavy and cumbersome means of storing energy.

Given the high cost of batteries, their high weight and limited storage capacity, if EVs are to be cost-competitive, they need to compromise on their range. They may be particularly useful in towns and cities, where ranges are inherently shorter and where it may be easier and more cost-effective to set up recharging infrastructures. Viewing urban mobility as a service would enable conventional charging, fast charging and battery replacement to be integrated in such as way that EVs might be sold at prices that would exclude the relatively high capital cost of the battery, that cost being recovered during the battery’s life in the cost of the electricity needed to run the vehicle.

Electric vehicles are well suited to urban driving, given the short distances and the high value of eliminating vehicle pollutant emissions in the urban context. For EVs to play a bigger role, it will be necessary to develop a public-access recharging infrastructure and eventually either fast-charge facilities or battery-swap centres where drivers can quickly get a fresh set of batteries. Such infrastructure is likely to be expensive and finding a cost-effective balance between consumer demands and recharging options will be critical.

**Batteries for PHEVs and EVs**

A number of technical issues, especially related to batteries, still need to be resolved. Unless batteries continue to improve and become cheaper, they may form a major barrier to the rapid and widespread introduction of EVs. Achieving a
target of USD 300/kWh for EV battery costs by 2015 would help ensure that EVs become affordable in the mass market.

Batteries for PHEVs and EVs need to be designed to optimise their energy storage capacity. The need for higher specific energy and energy densities, as well as to contain costs, will require a strong commitment to ongoing RD&D programmes. Although rapid improvements in the lithium-ion family of batteries have improved the near-term potential for EVs and PHEVs, specific energy and energy density must continue to improve if these vehicles are ever to fully replace ICE LDVs in all applications. Batteries for PHEVs and EVs also need to be able to cope with a range of different discharging cycles. They will be subjected both to deep discharging cycles, for example on commuting trips, and to more frequent shallower cycles such as those from regenerative braking while driving.

It seems likely that the first ICE-electric PHEVs will need to offer a range of 30 to 50 km of pure electric range. For this, they would need batteries with a storage capacity of roughly 6 to 10 kilowatt-hours (kWh) capable of delivering 50 kW of power, or more if the vehicle is to run on battery-only power for some of the time. PHEVs with a lower battery-based driving range, e.g. 10 to 20 km, would allow for much cheaper battery systems, and may still provide a significant share of daily driving on electricity. But whether this is sufficient battery range to be interesting to consumers is uncertain.

**Fuel-cell vehicles**

Fuel-cell vehicles use fuel cells to convert the chemical energy contained in hydrogen into electricity, which is then used to power an electric motor that propels the vehicle.

Although several types of fuel cells have been developed, the most suitable for vehicle applications is the proton exchange membrane (PEM) fuel cell. Proton exchange membrane are relatively efficient, especially under partial load, and operate best at temperatures of around 80°C. PEM FCVs can start quickly, but they need to warm up to optimal operating temperatures and then need to be cooled to avoid overheating. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes with a platinum catalyst. The use of platinum makes PEM cells highly sensitive to carbon monoxide and sulphur pollutants. As a result, they need to be fuelled by very pure hydrogen. Hydrogen produced from natural gas, for instance, is likely to require purification before being used by PEM fuel cells.

Fuel-cell vehicles are well suited to recover the energy dissipated in braking, since their motors can be reversed to act as generators. This, together with the fact that fuel cells achieve their maximum efficiency at partial loads, suggests that they are particularly well adapted to use in hybridised EVs in which the batteries can be used both to store recovered braking energy and to help provide peak power. Hybridisation in this way can also help reduce costs if the battery has higher specific power and lower cost than the fuel-cell stack, as seems likely to be the

3. Fuel cells are significantly more efficient than ICEs when operated at partial load, in which circumstances they can achieve efficiencies of 50% to 60%. At high loads, the efficiency of the two systems is similar at around 35% to 40%.
case when comparing Li-ion battery costs to fuel-cell system costs. Given these considerations, it seems likely that most FCVs will be FCV-EV hybrids⁴ (Ahluwalia et al., 2005).

The refuelling of FCVs raises difficult issues. They either need on-board hydrogen reforming, which is expensive, or they need on-board hydrogen storage, which raises issues of cost, safety, driving range, and the need for an extensive hydrogen production and distribution infrastructure. As fuel-cell systems improve and FCVs are proven technically, the refuelling and fuel infrastructure issues are likely to become the main barriers to commercialisation. Vehicle fuel-cell stack and system costs have declined in recent years but are still very expensive compared to conventional ICE vehicles.

Carbon dioxide reduction and cost comparison

Different vehicle and fuel combinations result in different lifetime incremental costs and CO₂-eq savings (Figure 7.19). These variables also affect the resulting cost per tonne of CO₂-eq saved corresponding to different vehicle and fuel options (Figure 7.20).

At USD 120/bbl of oil, some of the options are cost-competitive in the near term and virtually all are characterised by low incremental costs or negative costs in the longer term. In contrast, at oil prices around USD 70/bbl (not shown), none of the vehicle options considered achieves CO₂-eq savings at a net negative cost per tonne saved in the near term though several do in the longer term (IEA, 2009a).

The CO₂-eq reduction potential of EVs and FCVs is heavily dependent on the electricity generation mix. Depending on the mix, the use of PHEVs, EVs and FCVs can result in large CO₂-eq reductions or substantial CO₂-eq emission increases compared to a 2050 gasoline vehicle. The mix also has a significant impact on costs per tonne of CO₂-eq saved, with the least CO₂-intensive options also being among the most expensive. The generation mix also affects the emissions associated with hydrogen produced by electrolysis. FCVs using hydrogen from electrolysis in carbon-intensive power generation regions may increase CO₂-eq emissions compared to gasoline vehicles.

The net CO₂-eq mitigation costs for advanced ICEs and ICE-hybrids is very close to zero USD/tCO₂-eq in the near term, and negative in the case of spark-ignition ICE hybrids and advanced spark-ignition ICEs in the long term. PHEVs deliver CO₂-eq savings at a cost between USD 140/tCO₂-eq and USD 210 /tCO₂-eq in the short term, reducing to USD 20/tCO₂-eq in the best case (electricity from hydro), and up to USD 50/tCO₂-eq using more expensive electricity (e.g. from biomass) in the long term. This reflects a significant reduction in battery and other technology costs.

---

⁴. FCVs could even be conceived as plug-ins, if they have sufficient storage capacity and their batteries are optimised for such a configuration.
Figure 7.19  ▶ Lifetime incremental cost of vehicle and fuel pathways as a function of CO₂-equivalent savings

**Near term**

- GHG emissions savings (t CO₂-eq/vehicle)
- Lifetime incremental cost (USD/vehicle)

**Long term**

- GHG emissions savings (t CO₂-eq/vehicle)
- Lifetime incremental cost (USD/vehicle)

**Key point**

Most technologies and fuels lead to net greenhouse-gas savings over the vehicle lifetime, but at a wide range of costs.

Notes: The points along the dotted lines represent typical electricity mixes, which determine the net CO₂-eq emissions for electricity. From the left, the first symbol is electricity from coal, then from natural gas and, clustered on the right side, a range of renewables. For visualisation purposes, the vertical axes in the near and long term do not have the same range. Costs and CO₂-eq savings based on 7.5 lge/100km for baseline vehicle, 200 000 km, 3% discount rate, 15 years, US 90 cents/lge for oil-based fuels (USD 120/bbl), US 13 to 26 cents/kWh for electricity, US 70 cents to USD 1.10/lge for biofuels.
In regions with low CO₂-eq power generation, in the long run EVs with 150 km range reach roughly USD 80/tCO₂-eq, rising to USD 120/tCO₂-eq for renewable electricity produced from biomass. In the same timeframe, FCV hybrids achieve values close to USD 100/tCO₂-eq if they use hydrogen produced from low-cost, low-carbon electricity, with a high cost of USD 190/tCO₂-eq for more expensive generation. Across the range of electricity generation mixes by region in the BLUE Map scenario, the marginal cost of EVs and FCVs does not exceed USD 175/tCO₂-eq in the long run. These values compare with near-term cost estimates of as much as USD 500/tCO₂-eq for both vehicle technologies. The difference reflects the expected cost reductions in advanced technologies over the coming 10-20 years.

**Figure 7.20** Cost per tonne of CO₂-equivalent saved over the vehicle’s life, oil price at USD 120/bbl

With oil at USD 120/bbl, long-term CO₂-eq mitigation costs range from negative to about USD 175 per tonne for FCVs using hydrogen from biomass (this excludes options that use H₂ or electricity from fossil sources, not included in BLUE Map).
Trucking and rail freight

Trucking has been one of the fastest growing modes in most countries over the past ten to twenty years. This growth is likely to continue in the future, although possibly with some decoupling from GDP growth as an increasing share of economic growth comes from information and other non-material sectors. Trucks have also become more efficient over time. But there remain major opportunities to improve efficiency further, through technical measures, operational measures such as driver training and logistical systems to improve the efficiency in the handling and routing of goods. Rail remains, on average, far more energy-efficient than trucking and shifting more future freight movement to rail systems, where possible and cost-effective, remains an important option.

Through better technologies such as improved engines, light-weighting, better aerodynamics and better tyres, new trucks can probably be made 30% to 40% more efficient by 2030. More information is needed on technology costs. But many of the improvements appear likely to be quite cost-effective. This suggests that truck operators are less responsive to market signals on the cost-effectiveness of truck technologies than is often believed. Logistic systems to ensure better use of trucks, and shifts to larger trucks in some cases, can provide additional system efficiency gains, and may also be cost-effective. But to maximise the gains, governments will need to work with trucking companies, for example through supporting driver training programmes, and to create incentives or requirements for improved efficiency. Japan’s Top-Runner efficiency requirements for trucks are the first of their kind in the world.

Diesel-powered trucks can use biodiesel fuel very easily, especially the very high-quality biodiesel that comes from biomass gasification and Fischer-Tropsch liquefaction. Electricity will not be appropriate in most trucking contexts, given range requirements and energy storage limitations. Hydrogen may be a good long-term option for certain types of trucks, depending in part on the evolution of hydrogen storage technologies. Other gaseous fuels, such as CNG and liquefied natural gas (LNG), and eventually bio-SG, may also play a key role for trucks, especially if high-quality biodiesel does not become affordable over time.

Modal shift to rail continues to be an attractive option to save energy and cut CO₂-equivalent emissions, given the inherently efficient nature of rail freight transport. Many countries move only a small share of goods by rail. But to achieve shifts, very large investments in rail and intermodal systems will be necessary in most countries.

As for passenger travel, the BLUE Map scenario takes into account the contributions of freight transport technology improvements, whereas BLUE Shifts focuses on opportunities to shift some of the road freight transport towards more efficient modes (Figure 7.21). The BLUE Map/Shifts scenario combines technology improvement and modal shifts. For trucks, both the BLUE Shifts and BLUE Map scenarios result in about a 20% reduction in fuel use in 2050 compared to the Baseline scenario. This increases to over a 30% reduction in the BLUE Map/Shifts scenario, somewhat less than the sum of the two individual cases since, as trucks improve their efficiency, the benefits of shifting to rail are reduced. The outcomes envisaged in the BLUE Map scenario are achieved by strong efficiency improvements reaching nearly 40%
by 2050 compared to 2007, against about a 20% improvement in the Baseline. Trucks also increase their use of alternative fuels, in particular of advanced biofuels. Second-generation biofuels are used as a blend in diesel fuel, reaching 30% by 2050. Some hydrogen fuel-cell trucks, plug-in hybrid trucks and pure electric trucks are also assumed in this scenario, mostly for light commercial and medium-duty freight movement.

The shift from road to rail freight in the BLUE Shifts scenario results in rail freight using more energy than in the Baseline scenario (Figure 7.21). In the BLUE Map/Shifts scenario, a 25% improvement in rail efficiency led by a strong shift towards more efficient rail electrification results in rail energy use in 2050 being kept at the level of the Baseline scenario, while providing the higher level of transport activity in BLUE Shifts.

**Figure 7.21** Road and rail freight energy use by fuel, by scenario and by year

![Graph showing energy use by fuel for road and rail freight](image)

**Key point**

Trucks increase fuel use in the Baseline and High Baseline scenarios far more than rail, owing to faster activity growth. Both shift away from conventional diesel in BLUE Map. Rail energy use increases in BLUE Shifts as freight is shifted over from trucking.

The available information permits only a very broad categorisation of fuel-savings potentials and costs across a range of fuel-saving policies and measures for freight transport (Table 7.3). The measures in blue text are those requiring direct public regulatory intervention, although most of the others can also be encouraged by government fiscal policy and advisory programmes.
### Table 7.3  A rough guide to energy-saving measures for truck and rail freight transport

<table>
<thead>
<tr>
<th>Energy/CO₂-eq savings</th>
<th>Lower</th>
<th>Higher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower</td>
<td>• Idling control devices</td>
<td>• Improved diesel powertrains</td>
</tr>
<tr>
<td></td>
<td>• Lower rolling resistance tyres</td>
<td>• Retrofit package including aerodynamics</td>
</tr>
<tr>
<td></td>
<td>• Improved intermodal logistics through information and communication</td>
<td>• Vehicle routing and scheduling systems</td>
</tr>
<tr>
<td></td>
<td>technology</td>
<td>• Lower speed limits</td>
</tr>
<tr>
<td></td>
<td>• Night-time delivery</td>
<td>• Increase truck size/weight limits</td>
</tr>
<tr>
<td></td>
<td>• Rail locomotive efficiency</td>
<td>• Driver training</td>
</tr>
<tr>
<td>Higher</td>
<td>• Hybridisation of long-haul trucks</td>
<td>• Hybridisation of local delivery vehicles</td>
</tr>
<tr>
<td></td>
<td>• Reduce vehicle tare weight (truck or rail)</td>
<td>• Advanced powertrains (e.g. fuel cell)</td>
</tr>
<tr>
<td></td>
<td>• Scrappage incentives for older trucks</td>
<td>• Decentralisation of production/warehousing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Relax just-in-time regimes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• More localised sourcing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Improved rail infrastructure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Fiscal incentives for use of rail</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Road user charging</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Biofuels, LPG, CNG</td>
</tr>
</tbody>
</table>

Colour code: grey = technical efficiency measures, orange = system efficiency measures, green = measures directed towards rail, blue= fiscal incentive measures, magenta = alternative fuels.

Measures that appear to offer the greatest potential for fuel savings at minimal cost include improved diesel powertrains, retrofit truck efficiency packages, better routing systems, lower speed limits, increased truck size/weight limits and driver training programmes. A package of measures might be able to improve overall trucking efficiency by around 20% to 30%, at low or possibly even negative costs per tonne of CO₂-eq saved. Although uncertain, this is likely to be consistent with an estimate of a 33% efficiency improvement in the BLUE Map scenario at a marginal cost below USD 175 per tonne of CO₂-eq saved, possibly well below. Additional cost-effective CO₂-eq reductions can come from fuel switching, especially to advanced biofuels, and from modal shift.

### Aviation

Air travel is expected to be the fastest growing transport mode in the future as it has tended to grow even faster than incomes during normal economic cycles. Air passenger-kilometres increase by a factor of four between 2005 and 2050 in the Baseline scenario, and by a factor of five in the High Baseline scenario. In the same period, aviation benefits from steady efficiency improvements in successive generations of aircraft.

The technical potential to reduce the energy intensity of new aircraft has been estimated to lie between 25% and 50% by 2050 (Lee et al., 2001). This is equivalent to an improvement of about 0.5% to 1% a year on average.

Given the length of time it takes for new aircraft fully to replace the existing stock, the average efficiency of the current stock may lag behind new aircraft efficiency by
up to 20 years. But since new aircraft are more efficient than average aircraft, the overall stock of aircraft can also be expected to improve at a steady rate, with an average annual rate that is similar to or slightly faster than the improvement rate of new aircraft.

Steps to increase operational efficiencies and load factors on the existing stock of aircraft continue to offer an important opportunity for efficiency improvement. If the annual historical rate of improvement in load factors of around 0.2% a year continues, the worldwide average load factor could reach nearly 0.8 (i.e. 80% of available seats filled with passengers) by 2025. This may be close to an upper bound.

Improving logistical operations and air-traffic controls can also improve aircraft efficiency, for example by reducing delays in landing and by allowing aircraft to fly on more optimal routes. Such measures may also reduce environmental impacts by around 10% (Penner et al., 1999). New practices such as continuous-descent landing patterns can lead to additional savings. Most of these changes will require regulations to be amended and air-traffic control technologies and procedures to be increasingly harmonised (RCEP, 2007).

As a result of some of these measures, aircraft efficiency is projected to improve by 30% between 2010 and 2050 in the Baseline scenario, an improvement of about 0.6% a year (Figure 7.22). Much higher efficiency improvements, of nearly 1% a year, are achieved in the BLUE Map scenario where an overall improvement of 43% is achieved by 2050.

**Figure 7.22** Average energy intensity of aircraft by region

![Energy Intensity Graph](image)

- **Key point**

  An efficiency gap between OECD and non-OECD countries is expected to remain as second-hand planes are sold mainly in non-OECD countries.

More work is needed better to understand the cost-effectiveness of different options for aviation. Recent estimates suggest that some available options may be quite cost-effective (IEA, 2009a). One significant factor in assessing technology costs and
benefits for aircraft is that aircraft burn large quantities of fuel over their lifetimes. A very large aircraft may use up to a billion litres of jet fuel in a 30-year lifetime. So cutting fuel use can provide enormous long-run fuel cost savings. This suggests that even major investments to improve aircraft efficiency may be cost-effective, at least using a long-term, societal cost perspective.

Aircraft have very few alternatives to today’s kerosene jet fuels. The energy density of jet fuel is critical for providing adequate aircraft flying range, so shifting to gaseous fuels or electricity appears impractical. Liquid hydrogen would require major compromises in other airplane design features, while other gaseous options are limited by the large storage volume they would require. This would be incompatible with the aerodynamic shape of airplanes. So high-quality, high energy-density biodiesel fuels are of great interest to airlines and aircraft manufacturers, as these may hold the best hope of providing low-CO₂-eq aircraft fuels in the future. But the concerns expressed above regarding biofuels and sustainable feedstock supplies apply to aircraft as they do for other modes. In the BLUE Map scenario, by 2050 30% of aircraft fuel is second-generation biofuel such as BTL fuel or other aircraft-compatible advanced biofuel.

Figure 7.23 > Aircraft greenhouse-gas emission projections by scenario

Modal shift and a general reduction in aviation travel growth can also help. In the BLUE Shifts scenario, air travel growth is cut by 25%, resulting in its tripling by 2050 rather than quadrupling. This will to some extent occur naturally if alternatives such as high-speed rail systems are available, but it must also be encouraged by policies that, for example, help ensure the availability and cost-competitiveness of rail travel. Substituting telematics such as teleconferencing for some long-distance trips could
also play an important role, and could also be encouraged by governments as well as by businesses. Since the BLUE Shifts scenario focuses on travel shifting rather than efficiency gains, it makes the same assumptions about efficiency improvements as the Baseline scenario.

The different scenarios, taking into account efficiency improvements, modal shifts and biofuels, result in different net impacts on energy use and CO₂-eq emissions (Figure 7.23). The growth in CO₂-eq emissions in the Baseline scenario is very large, increasing nearly threefold between 2005 and 2050, even after efficiency improvements are taken into account. In the High Baseline scenario, the increase is almost fourfold. In the BLUE Map scenario, CO₂-eq emissions in 2050 are cut by 43% relative to the Baseline scenario. In the BLUE Map/Shifts scenario, the reduction reaches 55%, although emissions still remain above 2007 levels.

Shipping

International maritime activity has grown significantly in recent years, doubling between 1985 and 2007 (Figure 7.24). This growth has been driven in particular by the growth in Asian manufacturing and exports to other countries. International maritime activity now represents about 90% of all shipping energy use, the remainder being used in-country by river and coastal shipping. Container-shipping fuel use has risen the fastest, and may rise much more in the future; projections of up to an eightfold increase for container shipping to 2050 have been made (Buhaug et al, 2008). Shipping has become steadily more efficient per tonne-kilometre moved as the average size of ships has risen, although practical limits to ship size may be close to being reached.

Figure 7.24  Trends in maritime transport volumes and related CO₂-equivalent emissions

Key point

Transport volumes of major categories of shipped goods have doubled in the past 20 years, but CO₂-eq intensity has improved by only 15%. 
Steady increases in average ship size in recent years have helped improve fuel efficiency. Apart from this, however, ship efficiency has not changed significantly in recent years. The fragmented structure of the shipping industry, with different systems of ownership, operation and registration, often all happening in different countries for a given ship, may serve to limit the market incentives to optimise ship efficiency.

The ETP Baseline projections of energy use and CO₂-eq emissions by international shipping are based on the growth projections of the International Maritime Organization (Buhaug et al., 2008). The energy use projections reflect past relationships between GDP growth, shipping activity and fuel use (Figure 7.25). In the Baseline scenario, activity roughly doubles by 2050, energy intensity improves by 25% and, as a result, energy use increases by about 50%. In the High Baseline scenario, activity growth nearly triples. Therefore, with the same energy intensity improvement as in the Baseline scenario, energy use more than doubles. In the BLUE Map scenario, activity growth matches that in the Baseline scenario but energy intensity is cut by half, resulting in essentially unchanged energy use over time. Achieving a reduction in energy intensity that matches the rate of activity growth in the Baseline scenario will be very challenging. If activity growth is closer to that in the High Baseline scenario, it will be virtually impossible to achieve sufficient improvements in energy intensity to offset the volume growth.

**Figure 7.25**  International shipping activity, energy intensity and energy use by scenario

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2007</td>
<td>2030</td>
<td>2050</td>
</tr>
<tr>
<td>Baseline tkm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Baseline tkm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BLUE Map tkm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline Energy intensity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Baseline Energy intensity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BLUE Map Energy intensity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline Energy use</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Baseline Energy use</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BLUE Map Energy use</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: IEA projections based in part on Buhaug et al. (2008).

**Key point**

In the BLUE Map scenario, energy intensity is cut by half and energy use remains nearly flat through 2050.

The improvement in energy intensity assumed in the BLUE Map scenario is justified by the large number of efficiency improvement measures that have been identified for the shipping sector. About 50 energy efficiency options for shipping are outlined
in IEA (2009a). If most of these options were adopted, it is estimated that a 50% or
greater reduction in energy use per tonne-kilometre could be achieved, even taking
into account various interactions between options. Recent research also suggests
that many options for retrofitting existing ships could achieve substantial energy and
CO₂-eq savings at very low or net negative cost.

The more conservative estimates on energy intensity used in the Baseline and
High Baseline scenarios account on the one hand for the significant opportunities
identified, and on the other for the relatively negative performance of the sector in
achieving efficiency improvements to date.

The resulting demand for different fuels, using IEA data, for both national and
international shipping is shown in Figure 7.26. In the Baseline scenario, fuel
use grows from about 210 Mtoe in 2007 to about 306 Mtoe by 2030 and to
381 Mtoe by 2050, reflecting a decoupling of shipping growth from GDP growth
as economies grow more in information sectors than material sectors. In the High
Baseline scenario, past growth rates are assumed to decouple far less than in
the Baseline scenario. Shipping energy use reaches 400 Mtoe by 2050. In both
cases, most of the fuel used is HFO, although the share of diesel-type fuel (middle
distillate) is assumed to increase.

**Figure 7.26 Shipping energy use by scenario**

![Graph showing shipping energy use by scenario](image)

Note: Figure based on IEA data for 2007.

**Key point**

*With efficiency improvements and advanced biofuels, petroleum fuel use in BLUE Map in 2050 is slightly lower than
in 2007.*

Biofuels and some gaseous fuels may also have the potential to help decarbonise
shipping. Ship engines are capable of using a wide range of fuels, and may be
able to use relatively low-cost types of biofuels such as biodiesel or even “bio-
crude” oils from pyrolysis or other processes. LNG already plays a role, particularly for powering LNG tankers; this fuel could be used more widely and eventually produced from biomass, such as bio-SG (see Box 7.2). In the BLUE Map scenario, 30% of ship fuel by 2050 is low greenhouse-gas biofuel.

Fuel use by shipping within national borders is much less than that used for international shipping, reaching about 70 Mtoe in 2050 in the Baseline scenario and about 90 Mtoe in the High Baseline scenario.

Growth in CO₂-eq emissions generally closely follows fuel use except in the BLUE Map scenario where the increased use of second-generation biofuels reduces the CO₂-eq emissions attributable to the petroleum fuels they displace by 80% to 90%. This is dependent on successful development of such fuels and on the production of enough sustainably produced feedstocks to meet the demand from a number of competing sectors. If achievable, a 30% biofuels share would provide about a 25% reduction in CO₂-eq emissions in the BLUE Map scenario on top of that already resulting from reductions in energy use.
Key findings

In the Baseline scenario, OECD Europe’s primary energy demand grows by 5% between 2007 and 2050. The increased use of renewable energy and natural gas results in CO₂ emissions decreasing by 8% in the same period.

Countries in OECD Europe need to cut their carbon dioxide (CO₂) emissions by about three-quarters of their 2007 levels by 2050 if they are to make their full contribution to the halving of global CO₂ emissions envisaged in the BLUE Map scenario. These developments also bring considerable energy security benefits. The share of fossil fuels in the primary energy mix in 2050 is halved compared to 2007 levels.

To achieve the BLUE Map scenario, OECD Europe will need to invest an additional USD 7.1 trillion between 2010 and 2050 compared to the Baseline scenario. However, this will bring substantial fuel savings that will more than offset these investments on an undiscounted basis.

End-use sectors contribute two-thirds of the CO₂ savings required from OECD Europe in the BLUE Map scenario. The transport sector, including fuel transformation, provides 50% of these end-use reductions. Buildings provide 35% and industry 15%. In industry, energy efficiency and the use of carbon capture and storage (CCS) offer the largest least-cost emissions reductions.

Despite a large proportion of older housing in Europe and the expected growth in the number of households and in floor area in the service sector, buildings’ energy consumption falls by 14% between 2007 and 2050 in the BLUE Map scenario. Efficiency improvements and better building insulation in space and water heating provide almost 40% of the emissions reduction in the buildings sector. Solar thermal heating, heat pumps, combined heat and power (CHP) and more efficient appliances also contribute.

Transport volumes in OECD Europe are expected to remain relatively constant. Deep emissions reductions can be realised by more efficient vehicles as well as a shift to electricity and biofuels. The greater use of natural gas, followed by a transition to biogas and bio-synthetic gas, offers a further option for reducing emissions in the transport sector.

Nuclear, CCS and renewable energy sources contribute with broadly equal shares to the CO₂ savings from the power sector in the BLUE Map scenario. Given very different local conditions, the energy mix varies widely between different countries in OECD Europe.

Europe has a comprehensive and ambitious energy and climate change programme. Further actions are recommended to rapidly decarbonise power generation, improve the electricity infrastructure, strengthen energy efficiency targets and encourage modal shifts to public transport.

Particular emphasis should be put on improving the efficiency of Europe’s existing housing stock. Policies are needed to encourage improvements in building shells
and the installation of energy-efficient heating and lighting. Gradual improvements in the building standards for residential and service sector buildings will also be important, coupled with improved compliance with these standards.

More funding will be required for energy technology research, development and demonstration (RD&D) if Europe is to maintain its strong position in renewable and other low-carbon technologies. Further co-ordination of European Union (EU) and member state level RD&D activities and additional funding is needed to deliver the priority actions identified in the EU Strategic Energy Technologies plan.

Regional description

In 2007, the 23 European member countries of the OECD represented a population of 543 million people or 8% of the global population. Geographically, OECD Europe stretches from Norway to Spain and from Portugal to Turkey. With the exception of Iceland, Norway, Switzerland and Turkey, all other countries within OECD Europe are also member states of the European Union. The energy and climate policies of the 19 EU states in OECD Europe are heavily influenced by decisions taken at EU level. Of the non-EU members, Iceland, Norway and Switzerland are members of the European Free Trade Association (EFTA). Norway and Iceland are part of the European Economic Area (EEA) which allows them to participate in the single European market with free movement of goods, capital, services and people.

OECD Europe’s GDP in 2007 was USD 10 532 billion, roughly one-fifth of global GDP in that year. OECD Europe was responsible for 15% of global primary energy consumption in 2007, but accounted for only 9% of global primary energy production. OECD Europe’s 4 gigatonnes (Gt) of energy-related CO₂ emissions in 2007 represented 14% of global CO₂ emissions.

Recent trends in energy and CO₂ emissions

OECD Europe was responsible for nearly one-sixth of global primary energy consumption in 2007. Of these energy needs, 58% were met by indigenous energy sources.

OECD Europe’s hard coal deposits represent 3% of global hard coal reserves (Table 8.1). They are mainly located in Poland, the United Kingdom and Germany. Indigenous hard coal production has been declining since the beginning of the 1990s, mainly for economic reasons. OECD Europe has 20% of global lignite reserves, mainly in Germany, Greece and Poland. Nearly all lignite is used for power generation in plants located near mines, given the very large volumes of lignite that are needed per unit of electricity generated.

1. OECD Europe comprises Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey and the United Kingdom.
There are still significant oil and gas reserves in the North Sea, although these amount to only 1.3% of global oil reserves and 2.7% of global gas reserves. Oil production in the North Sea, mainly by the United Kingdom and Norway, has been in decline since 2000. Natural gas production from the United Kingdom’s continental shelf is in decline, to the extent that the United Kingdom has become a net importer of natural gas in recent years. But Norway’s production has almost doubled since 2000.

### Table 8.1 Proven energy reserves in OECD Europe and the world

<table>
<thead>
<tr>
<th></th>
<th>Hard coal (billion tonnes)</th>
<th>Lignite (billion tonnes)</th>
<th>Crude oil (million toe)</th>
<th>Natural gas (billion cubic metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proven reserves: OECD Europe</td>
<td>18.5</td>
<td>52.5</td>
<td>2,219</td>
<td>5,044</td>
</tr>
<tr>
<td>Proven reserves: World</td>
<td>558</td>
<td>268</td>
<td>170,800</td>
<td>185,020</td>
</tr>
<tr>
<td>Production in 2007: OECD Europe</td>
<td>0.16</td>
<td>0.45</td>
<td>230</td>
<td>290</td>
</tr>
<tr>
<td>Reserve-to-production ratio: OECD Europe</td>
<td>116</td>
<td>117</td>
<td>10</td>
<td>17</td>
</tr>
</tbody>
</table>

*Note: Reserve-to-production ratio indicates the length of time that the proven reserves would last if production were to continue at current rates and if no additional reserves could be recovered.*

*Sources: BGR (2009); BP (2009); IEA (2009a).*

### Energy production and supply

Total primary energy supply (TPES) in OECD Europe has increased only slightly since 2000 (Figure 8.1). Oil accounts for more than one-third of primary energy needs. Although the primary energy supply of coal, oil, hydro and nuclear levelled off or slightly declined between 2000 and 2007, natural gas and renewables grew at a rate of 2% a year and 4% a year respectively. Including hydro, renewable energy sources accounted for 9% of TPES in 2007.

Renewables have grown, albeit from a low base. But OECD Europe remains strongly dependent on the import of fossil fuels (Figure 8.2). OECD Europe imports 45% of its coal supplies, mainly from Russia, South Africa, Colombia and Australia. The increasing use of gas for power generation and increased gas use in industry and the residential sector have led to growth of almost three-quarters in natural gas consumption in OECD Europe between 1990 and 2007. The United Kingdom, Germany and Italy are the largest gas consumers, representing 51% of OECD Europe’s consumption in 2007. Indigenous gas supplies met roughly half of all demand in 2007. Imports from Russia and Algeria accounted for more than 70% of OECD Europe’s gas imports.

OECD Europe accounted for 17% of global oil demand in 2007. Nearly two-thirds of its petroleum demand was satisfied by imports, mainly from Russia, the Middle East and Africa.
**Figure 8.1**  Total primary energy supply in OECD Europe

Note: Other includes renewables and heat.

**Key point**

Total primary energy supply has grown only slightly since 2000, with the growth coming mainly from increases in natural gas and renewables.

**Figure 8.2**  Energy production, imports and exports by fuel for OECD Europe

Note: Nuclear production refers to the heat produced in nuclear reactors, irrespectively of whether the nuclear fuel used is from domestic sources or imported.

**Key point**

More than half of OECD Europe's fossil fuel consumption relies on energy imports, with two-thirds of oil imported.
Energy consumption

Final energy consumption in OECD Europe grew on average by less than 1% a year between 1990 and 2007, with wide differences in the levels of growth in different countries. Annual growth rates in final energy consumption in Ireland, Portugal, Spain and Greece were between 2% and 3%, but have slowed to 1% to 2% in recent years. The former Eastern Bloc countries of the Czech Republic, the Slovak Republic, Hungary and Poland experienced a decline in final energy demand by between 1% and 3% a year between 1990 and 2000, increasing modestly since then. From 1990 to 2007, Turkey has shown the highest rate of growth in final energy demand of between 3% and 4% a year, nearly doubling total demand from 40 million tonnes of oil equivalent (Mtoe) to 76 Mtoe.

The changes in the final energy mix between 1990 and 2007 in OECD Europe are characterised by a drop in coal consumption of 46% due to reduced demand in industry and the residential sector in the formerly centrally planned countries. In the same period, electricity demand and gas consumption grew by 38% each (Figure 8.3).

Overall, petroleum demand grew only slightly between 1990 and 2007 with an average annual growth of 0.8%, declining oil consumption in the buildings sectors being more than offset by growth of 1.8% a year for transportation. Nearly 70% of final petroleum consumption was used in the transport sector in 2007. Biomass and waste, mainly used in the residential and industry sectors, reached a share of 5% in total final energy consumption in 2007. Biofuels accounted for 8 Mtoe in 2007, only 2% of the transport sector’s final energy consumption.

Figure 8.3 Final energy consumption by fuel and by sector in OECD Europe

Notes: Final transport consumption includes international aviation and marine bunkers; industry includes coke ovens, blast furnaces and petrochemical feedstocks; other sectors comprise agriculture, forestry and fishing.

Key point

Between 1990 and 2007 final consumption rose mainly for electricity and natural gas, but stagnated for other fuels. Growth in total final consumption is mainly caused by transport and to a lesser extent by the buildings sector.
End-use efficiency improvement

Final energy intensity in OECD Europe is currently 0.122 tonnes of oil equivalent (toe) per USD 1 000. Final energy intensity improved on average by 1.3% a year between 1990 and 2007, largely thanks to energy efficiency improvements in most countries (IEA, 2009f).

Analysis based on end-use data shows that the overall improvement in energy efficiency in the 12 European countries for which data are available was 0.6% per year between 1990 and 2006. Without the energy savings resulting from these improvements, total final energy consumption would have been 11% higher in 2006.

Carbon dioxide emissions

Energy-related CO₂ emissions in OECD Europe were 4 374 million tonnes (Mt) in 2007. Emissions increased by 7% between 1990 and 2007 while primary energy supply increased by about 16% over the same period. This difference was due to fuel switching from coal to natural gas and an increase in the share of renewables.

Overall energy policy framework

European Union policy, which directly affects 19 of the 23 countries that constitute OECD Europe, plays a major part in determining the broad thrust of policy within the OECD European countries. Current EU energy policy focuses on “creating a competitive internal energy market offering quality service at low prices, developing renewable energy sources, reducing dependence on imported fuels, and doing more with a lower consumption of energy”. These priorities are reflected in the integrated energy and climate package adopted by the EU member states in 2008 (EC, 2008a). This package commits the European Union to achieve so-called “20/20/20 targets” of:

- reducing greenhouse-gas emissions by at least 20% compared to 1990 by 2020, or by 30% if a satisfactory international agreement is reached which commits other countries to higher than 20% cuts;
- meeting at least 20% of total EU gross final energy consumption, including electricity, heat and transport, from renewable sources by 2020;
- reducing total primary energy consumption by 20% by 2020 compared to a business-as-usual baseline.

2. The 12 countries are Austria, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom.
Most EU energy policies are enacted through EU legislation in the form of EU directives. These directives are proposed by the European Commission (EC) following a period of stakeholder consultation, and then approved by the European Parliament and the European Council. In some areas in the energy field, EU member states have gone further than the requirements of EU directives or have adopted innovative national policies to achieve their contributions towards EU targets. Some of those OECD Europe countries that are outside the European Union have also implemented policies specifically designed to tackle climate change-related energy issues.

**Current status of energy policies and climate change initiatives**

**Energy markets and security of supply**

The process of liberalising the market for natural gas and electricity in the European Union started in the late 1990s with the first directives for electricity and gas (EU, 1996; EU, 1998). These directives required member states to allow large consumers to choose their supplier, to give third parties access to the grid, and to unbundled transmission system operations from vertically integrated utilities and gas companies. Different degrees of market opening among the member states and recognition that effective markets depended on non-discriminatory access to the electricity and gas networks led to a second set of directives for gas and electricity, which were adopted in 2003. These opened the market for small customers and required that transmission networks be operated independently of generation and supply (EU, 2003a; EU 2003b). A third package of directives was adopted in June 2009. This requires the full unbundling of transmission from generation and supply, strengthens the role of national regulators, foresees the creation of a new European agency with some regulatory power for cross-border trade and investment in interconnections, and requires the establishment of a European Network of Transmission System Operators to harmonise standards in pipeline and grid access and to co-ordinate investments in cross-border transmission capacities (EU, 2009a).

**Security of supply**

Traditionally the European Union has regarded a well-functioning internal market for energy as the best guarantee of security of supply. External aspects of energy policy have largely been left to member states. But electricity blackouts and disruptions in gas supply from Russia in recent years have led to greater focus on energy security at the EU level. The European Union’s 2nd Strategic Energy Review proposed by the EC in November 2008 includes recommendations to strengthen infrastructure, to diversify energy supplies, more proactively to engage in external energy relations, to manage and report on oil and gas stocks, to improve energy efficiency and to make best use of the EU’s indigenous energy resources (EC, 2008b). The EC’s January 2009 proposal for a European Economic Recovery Plan includes approximately a EUR 4.85 billion component focused on investments...
in interconnections and infrastructures aimed at enhancing the EU’s energy security (HSBC, 2010).

The European Union Emissions Trading Scheme (EU ETS)

The EU ETS is the European Union’s main policy instrument for improving efficiency and reducing CO₂ emissions in the power and industry sectors. It is the world’s largest greenhouse-gas emissions trading scheme. It covers around 12,000 installations and nearly 50% of all European Union CO₂ emissions. These installations include combustion plants, oil refineries, coke ovens, iron and steel plants, and factories making cement, glass, lime, brick, ceramics, pulp and paper. The EU ETS is currently in its second phase, which will limit emissions from these sectors to 2,080 Mt CO₂-equivalent for the period 2008-12, corresponding to a greenhouse-gas emissions reduction of 1.9% compared to 2005 levels. Currently, national allocation plans drawn up by member states create the basis for national emission caps. For the third phase of the EU ETS from 2013 to 2020, the European Union agreed on a system-wide cap in contrast to national ones in the first two phases. The gap corresponds to an emissions reduction of 21% by 2020 compared to 2005 levels for the sectors included in the ETS. The third phase will also introduce new sectors including aviation, will include provisions to increase the proportion of allowances that are auctioned and will take steps to support those EU industry sectors that are assessed to be most at threat from the potential movement of business to countries that are not subject to the ETS, an undesirable consequence of the application of a price to carbon emissions known as carbon leakage (EU, 2009b). Iceland, Liechtenstein and Norway joined the EU ETS in 2008. Switzerland has a national ETS and plans to link it to the EU system in due course (EC, 2009a).

Renewable energy

The Renewable Energy Directive of April 2009 sets out the EU’s target to have renewable energies constitute 20% of gross final energy consumption by 2020 (EU, 2009c). This includes an obligation for at least 10% of transport fuel to be from renewable sources by 2020, provided that production is sustainable and that second-generation biofuels become commercially available. The directive sets mandatory national targets for member states that take account of their different starting points and potentials, including existing levels of energy from renewable sources and energy mixes. This has led to a wide range of targets, from 10% in Malta to 49% in Sweden.

Feed-in tariffs to support renewable energy are in place in many European countries, including Denmark, France, Germany, Spain and Switzerland. Under these policies, generators can sell renewable electricity at a fixed tariff, often significantly higher than market rates, for a specified time period under specific conditions depending on location and technology. The price remains constant for a defined period but may be reduced for new connections in subsequent years. National feed-in tariffs are often combined with priority grid access. The tariff costs are usually passed on to electricity consumers.
Italy, Belgium, the Netherlands and the United Kingdom have adopted forms of green certificate trading in which electricity generators are required to ensure that a certain quantity of electricity is based on renewables. Generators can buy renewable generation from other suppliers if they have a shortfall against their obligation, or sell it if they produce more than they are obliged to produce. Setting the obligation at a level higher than the expected total level of renewables creates a market advantage for renewable generation. The United Kingdom and Italy have recently revised their schemes to differentiate between different renewable technologies. Less mature technologies such as wave power and offshore wind now receive more support than established technologies such as onshore wind and biogas. Both countries are also introducing feed-in tariffs for smaller installations.

### Carbon capture and storage

An EU directive on the geological storage of CO₂ entered into force on 25 June 2009 (EU, 2009d). The CCS Directive sets out a comprehensive regime to regulate exploration and storage, and applies to all projects which intend to store more than 100 kilotonnes (kt) of CO₂. It covers aspects such as the criteria for selection of storage sites, procedures for exploration and storage permits, operation, closure and post-closure obligations, and national reporting requirements. EU member states have until June 2011 to transpose the CCS directive into their respective national laws.

Allowances have been set aside within the EU ETS to support up to twelve CCS demonstration projects and a range of innovative renewable projects. At a carbon price of USD 30/tCO₂, these allowances would be worth up to some USD 8.8 billion. Further funding has since been pledged from the EU’s Economic Recovery Plan for six CCS demonstration projects in Germany, Spain, the Netherlands, the United Kingdom, Poland and Italy. The European Union is also working with China on CCS, through the Near Zero Emissions Coal (NZEC) initiative (EC, 2009b).

Outside the European Union, Norway is developing a CCS policy framework and a series of projects focused on CCS from gas-fired power plant, drawing on its extensive experience of geological storage. Over one million tonnes of CO₂ a year have been separated from gas production in the Sleipner field and stored under the North Sea since 1996 (Ministry of Petroleum and Energy of Norway, 2010).

### Energy efficiency

The European Union has initiated a range of policies and measures to improve energy efficiency in the industry, services and residential sectors. An overarching Directive on Energy End-Use Efficiency and Energy Services (ESD; EU, 2006b) covers all sectors except those included in the EU ETS. The ESD requires member states to put in place National Energy Efficiency Action Plans which set out policies that will contribute to the achievement of an energy saving of at least 9% from energy efficiency measures between 2008 and 2016.

and the Energy Performance of Buildings Directive (EPBD; EU, 2002). Many of these directives are currently being revised and strengthened in light of the targets in the energy and climate package. For example, proposed revisions to the EPBD would expand the scope of the existing directive to more buildings, require new houses being built after 2020 to be nearly zero-carbon buildings and make the installation of smart meters mandatory in new or renovated buildings.

The EUP Directive establishes a framework for setting eco-design requirements, including energy efficiency requirements, for all energy-using products in the residential, services and industrial sectors. It will be followed by implementing measures which will establish specific eco-design requirements for products such as household appliances, electric motors, air-conditioning units and refrigeration systems.

A number of countries in Europe have agreements with industry sectors or organisations to improve energy efficiency and reduce CO₂ emissions. Most of these agreements are voluntary, although they often include incentives for participation such as tax reductions. A scheme of negotiated voluntary agreements in the Netherlands has been running since 1999 and currently involves about 900 companies (Janssen, 2009). These agreements are supplemented by sector roadmaps to encourage innovation and are expected to lead to a 30% energy efficiency improvement between 2005 and 2020. Turkey has recently set up similar voluntary agreements with industrial organisations that pledge to reduce their energy intensity by 10% on average over a three-year period in return for financial support equivalent to up to 20% of their energy costs in the first year (IEA, 2010).

In the residential sector, the United Kingdom, France and Italy have established innovative white certificate schemes that encourage energy suppliers to install insulation and more energy-efficient appliances including boilers in the homes of their customers. Latvia, Finland and Denmark have had long-standing and successful schemes to promote CHP in the residential and commercial sectors.

**Energy use in transport**

In December 2009, the European Union adopted a new regulation which sets emissions performance standards for new passenger cars. These require that by 2015 all car manufacturers achieve a maximum fleet average level of emissions of 130 grammes (g) of CO₂/kilometre (km) for all their cars that are registered in the European Union, with a phased introduction from 2012 (EC, 2009c). A so-called limit-value curve has also been set which allows heavier cars to have higher emissions than lighter cars while preserving the overall fleet average. A longer-term target of 95 gCO₂/km by 2020 has been set. This regulatory approach replaces previous voluntary agreements with the European, Japanese and Korean automotive trade associations. A similar regulation is currently being prepared on CO₂ emissions from vans.

Other relevant EU transport policies include a requirement for the fuel economy labelling of all new cars, although the impact of this is reduced by the lack of any standardised labelling scale across European countries. The provision of data on
CO$_2$ emissions is also mandatory on new passenger cars. The requirement that 10% of transport fuel must be renewable by 2020 and the introduction of high-speed rail networks and the proposed inclusion of aviation within the EU ETS by 2012 will also all contribute to reductions in greenhouse-gas emissions.

Individual OECD European countries also have a wide range of national policies in place to reduce CO$_2$ emissions. These include regulations on the adoption of alternative fuels, incentives for motorists to purchase more fuel-efficient vehicles, measures to increase vehicle occupancy through car sharing and policies to encourage modal shifts to public or non-motorised transport. Alternative fuels policies are generally tailored to local circumstances and fuels. For example, Germany has a major programme to support the use of biodiesel, Sweden’s policies promote the use of bioethanol, and Iceland is seeking to promote the use of hydrogen. Many countries have introduced incentives to purchase more efficient cars through differential purchase taxes or graduated annual registration taxes. For example, United Kingdom motorists currently pay an annual car tax ranging from about USD 20 for the lowest emitting to USD 220 for the highest emitting cars. Cars that emit less than 100 gCO$_2$/km pay no annual road tax (Directgov, 2010).

**Energy research and development**

The multi-annual Framework Programmes for Research and Technology Development (FP) are the main instrument for the implementation of European energy research policy, and for the provision of EU R&D funding. The Seventh FP, which runs from 2007 to 2013, allocates 7% of its overall budget to energy-related R&D. To amplify this, the Commission has recently implemented a Strategic Energy Technology Plan that aims to accelerate the development and implementation of low-carbon technologies in the priority areas of wind, solar, bioenergy, CCS, the European electricity grid and sustainable nuclear fission (EC, 2009d).

**Overview of scenarios and CO$_2$ abatement options**

A number of significant energy indicators for OECD Europe in the Baseline and BLUE Map scenarios are set out in Table 8.2. Population and GDP growth assumptions are the same in both scenarios.

In the Baseline scenario, TPES grows only slightly between 2007 and 2050 at an annual rate of 0.1%. Historic rates of decoupling between GDP and energy use are assumed to continue, with the result that 35% less energy is needed per unit of GDP in 2050 than in 2007. In the BLUE Map scenario, per-capita CO$_2$ emissions are reduced from 8.0 t in 2007 to 1.9 t in 2050, 72% lower than in the Baseline scenario. Total primary energy supply in 2050 is 20% lower than in the Baseline scenario, with the result that primary energy consumption per unit of GDP in the BLUE Map scenario is almost halved in 2050 relative to 2007.
Table 8.2 High-level indicators for OECD Europe

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>BLUE Map</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000</td>
<td>2007</td>
</tr>
<tr>
<td>TPES (Mtoe)</td>
<td>1 818</td>
<td>1 926</td>
</tr>
<tr>
<td>Electricity consumption (TWh)</td>
<td>3 000</td>
<td>3 387</td>
</tr>
<tr>
<td>CO₂ emissions (Gt)</td>
<td>4.22</td>
<td>4.37</td>
</tr>
<tr>
<td>GDP (billion USD using exch. rates)</td>
<td>9 066</td>
<td>10 532</td>
</tr>
<tr>
<td>GDP (billion USD using PPP)</td>
<td>11 258</td>
<td>13 223</td>
</tr>
<tr>
<td>Population (millions)</td>
<td>522</td>
<td>543</td>
</tr>
<tr>
<td>TPES/GDP (toe per thousand USD 2 000 PPP)</td>
<td>0.161</td>
<td>0.146</td>
</tr>
<tr>
<td>TPES/population (toe per capita)</td>
<td>3.48</td>
<td>3.55</td>
</tr>
<tr>
<td>Electricity consumption /population (kWh per capita)</td>
<td>5 753</td>
<td>6 239</td>
</tr>
</tbody>
</table>

Note: International aviation and shipping are included in TPES and CO₂ emissions; GDP is expressed in 2000 USD.
Sources: IEA (2009a); IEA analysis.

Energy and CO₂ emission scenarios

In the Baseline scenario for OECD Europe, fossil fuels account for 75% of TPES in 2050, lower than the 79% they accounted for in 2007 (Figure 8.4). Oil consumption decreases by 19%. Natural gas use increases by 38%, mainly driven by power generation. The share of renewables more than doubles, from 9% in 2007 to 18% in 2050, with increased wind and solar generation.

Figure 8.4 Total primary energy supply by fuel for OECD Europe, Baseline and BLUE Map scenarios

Note: International aviation and shipping are included in TPES.
Sources: IEA (2009a); IEA analysis.

Key point

The share of fossil fuels in TPES is halved in BLUE Map in 2050 compared to 2007, while the share of renewable energy grows more than fourfold.
In the BLUE Map scenario, TPES in 2050 is 16% lower than in 2007 and 20% lower than in the Baseline scenario in 2050. Fossil fuels account for 40% of TPES in the BLUE Map scenario in 2050, while renewables and nuclear cover 40% and 21%, respectively.

OECD Europe emissions reductions by sector in the BLUE Map scenario are shown in Table 8.3. Absolute CO₂ emissions of OECD Europe fall in this scenario from 4 374 Mt CO₂ in 2007 to 1 122 Mt CO₂ in 2050, i.e. by 3 252 Mt CO₂ or 74%. To achieve a 50% reduction in global emissions by 2050, the BLUE Map scenario projects that OECD Europe has to cut its emissions by almost three-quarters. To realise this ambitious reduction, electricity generation is nearly decarbonised by cutting its CO₂ emissions by 95%. Other sectors show a reduction of between 66% for buildings and 42% for transformation other than power generation compared to 2007. Transport becomes the largest emitting sector in 2050, accounting for 46% of CO₂ emissions, despite achieving the second-largest absolute reductions. After 2050, it is likely that the transport sector will need to make the largest contribution to any further efforts to reduce CO₂ emissions.

### Table 8.3 OECD Europe’s absolute and relative CO₂ emissions reductions by sector in the BLUE Map scenario

<table>
<thead>
<tr>
<th>Reference</th>
<th>Absolute reductions in the BLUE Map scenario 2050 (Mt CO₂) relative to 2007</th>
<th>Relative reductions in the BLUE Map scenario 2050 (%) relative to Baseline 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power sector</td>
<td>1 409 1 160</td>
<td>-95% -94%</td>
</tr>
<tr>
<td>Other transformation</td>
<td>31 225</td>
<td>-35% -80%</td>
</tr>
<tr>
<td>Industry</td>
<td>545 277</td>
<td>-70% -54%</td>
</tr>
<tr>
<td>Transport</td>
<td>798 694</td>
<td>-61% -57%</td>
</tr>
<tr>
<td>Buildings</td>
<td>469 533</td>
<td>-66% -68%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3 252 2 889</strong></td>
<td><strong>-74% -72%</strong></td>
</tr>
</tbody>
</table>

*Notes: Industry includes blast furnaces, coke ovens and emissions from non-energy use of feedstocks; industrial process emissions are excluded.*

## Carbon dioxide abatement options

OECD Europe’s CO₂ emissions to 2050 in the Baseline and BLUE Map scenarios are shown in Figure 8.5. CO₂ emissions reduce by 2.9 Gt or 72% in 2050 in the BLUE Map scenario as compared with the Baseline scenario. Measures in the end-use sectors contribute 66% of the CO₂ savings. On the end-use side, efficiency improvements deliver 33% of the overall CO₂ savings followed by fuel switching to electricity and natural gas (12%), CCS in industry and fuel transformation (12%) and the increased use of biofuels (9%). The power sector contributes 34% of the overall emissions reduction between the Baseline and BLUE Map scenarios in 2050, with around 12% each from renewables and CCS and a further 7% from nuclear.
Figure 8.5 Contributions to emissions reductions in OECD Europe

![Graph showing contributions to emissions reductions.]

Note: Unlike otherwise indicated, all material derives from IEA data and analysis.

Key point

End-use sector measures contribute nearly two-thirds of the emissions reductions between the Baseline and BLUE scenarios in 2050.

Sectoral results

Power sector

Europe’s electricity system today

In 2007, OECD Europe had a total installed generating capacity of 847 gigawatts (GW), of which 196 GW were based on coal, 185 GW on hydro (including 40 GW of pumped storage), 184 GW on gas, 130 GW on nuclear, 68 GW on oil, 57 GW on wind, 20 GW on biomass and 7 GW on other renewable sources (Figure 8.6). Utilities owned 93% of the total capacity, with the remainder being owned by industrial producers. Germany, France, Italy, Spain and the United Kingdom have the largest installed capacities, together accounting for 62% of the capacity in OECD Europe in 2007. The capacity of CHP stood at 89 GW in 2007 (Eurostat, 2009; Eurelectric, 2009). This was 11% of the total installed capacity in OECD Europe in that year.

OECD Europe generated 3 575 terawatt-hours (TWh) of electricity in 2007. Of this, 54% was based on fossil fuels, 26% on nuclear and 20% on renewables.

Generation from coal and oil declined between 1990 and 2007 while generation from hydro and nuclear grew modestly by 12% and 18%, respectively. Gas-fired power generation grew almost fivefold between 1990 and 2007, accounting for 800 TWh in 2007. The growth in gas-fired generation was driven by the favourable economics of new highly efficient natural gas combined-cycle (NGCC) power plants which have lower emissions than coal and oil plants and higher operational flexibilities.
Figure 8.6  Electricity generating capacity and generation for OECD Europe, 2007

Installed capacity 847 GW

Electricity generation 3 575 TWh

Nuclear 15.3%
Hydro 21.8%
Wind 6.7%
Natural gas 21.7%
Coal 23.2%
Oil 8.0%
Solar PV 0.6%
Geothermal 0.3%
Biomass and waste 2.4%

Oil 3.1%
Hydro 13.9%
Wind 2.9%
Natural gas 22.4%
Coal 28.4%
Biomass and waste 3.0%
Nuclear 25.9%

Sources: Platts (2010); IEA (2009a).

Key point

More than half of all power generation in 2007 was based on fossil fuels, with the remainder split between nuclear and renewable energies.

Developments in renewable power generation

Renewable electricity generation has grown rapidly over the last 20 years as a result of government support in many OECD European countries. In 1990, renewables excluding hydro generated 20 TWh. This grew by a factor of 10, to 209 TWh in 2007, mainly owing to support policies such as renewable feed-in tariffs or green certificate schemes in many European countries. Most of the growth is from wind (+104 TWh) and biomass (+75 TWh). Germany and Spain are responsible for much of the wind deployment, while the uptake of biomass focused on Germany, Finland, Sweden and the United Kingdom. Including hydro, which grew by only 12% between 1990 and 2007, renewable power generation comprised 707 TWh, one-fifth of total generation, in 2007.

The share of renewable power generation varies among OECD member states. Abundant hydro and geothermal resources allow Norway and Iceland to cover nearly their entire electricity generation from renewable sources. Low renewable shares of 4% to 5% are found in many of the new EU member states such as Poland, Hungary and the Czech Republic, but also in the United Kingdom with a share of just 6%.

Regional electricity supply in 2007

The generation mix varies widely between countries in OECD Europe (Figure 8.7). Germany and Poland rely predominantly on coal-fired generation which accounts for 49% and 96% of their total generation respectively. Italy (55%) and the Netherlands (57%) rely to a high degree on natural gas. France generates a high
proportion of its electricity from nuclear power stations. Norway, Iceland and Switzerland also have very high percentages of non-fossil power, mostly from hydro.

**Figure 8.7** Electricity generation mix, OECD Europe, 2007

*Key point*

Fuel mix in the power sector varies widely between countries in OECD Europe.

**Electricity transmission and distribution**

The trading of electricity between countries in Europe has increased steadily, from 171 TWh in 1990 to 309 TWh in 2007. Investment in transmission capacities has not kept pace with this growth. As a result, cross-border capacities at a number of places within the European electricity system have become increasingly congested.

Price differences between countries are helping to drive increased trading. This has led to congestion from Northern and Central Europe to Germany and, to a lesser extent, for electricity imports to Italy. The interconnection between the United Kingdom and France is always at its capacity limit.
The integration of larger amounts of wind energy in Northern Europe and Germany has also required a reinforcement of the North-South grid. Other interconnection capacity shortfalls are a result of geographical constraints, for example across the Pyrenees and the Alps.

The EC has developed a set of energy priority projects within its Trans-European Networks programme to address bottlenecks in the European gas and electricity transmission infrastructure. These projects seek to increase competition in the internal energy markets, to strengthen security of supply, and to support the increased use of renewables. In 2002, the EC set a goal to increase the interconnection capacity between member states to a minimum of 10% of their electricity demand. In 2006, in a new regulation for guidelines to list and rank electricity and gas infrastructure projects, nine priority axes for electricity have been identified (EU, 2006a). Within the European Energy Programme for Recovery the EC has granted EUR 910 million to 12 electricity interconnection projects (EC, 2010).

Electricity demand projections

Total final electricity demand in OECD Europe increases by 19% between 2007 and 2050 in the BLUE Map scenario (Table 8.4). At the same time, overall final energy demand decreases owing to reduced demand for fossil fuels by 13%, so that the share of electricity in final energy consumption grows from 19% in 2007 to 27% in 2050. The main drivers for the growth in electricity demand are the buildings and transport sectors, in which the increased use of electricity, for example by heat pumps or electric vehicles (EVs), is essential to the overall BLUE Map reduction in CO₂ emissions.

<table>
<thead>
<tr>
<th>End-use sector</th>
<th>Baseline</th>
<th>BLUE Map</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2007</td>
<td>2030</td>
</tr>
<tr>
<td>Industry</td>
<td>1 250</td>
<td>1 414</td>
</tr>
<tr>
<td>Transport</td>
<td>76</td>
<td>109</td>
</tr>
<tr>
<td>Residential</td>
<td>853</td>
<td>1 084</td>
</tr>
<tr>
<td>Commercial</td>
<td>756</td>
<td>1 142</td>
</tr>
<tr>
<td>Other</td>
<td>127</td>
<td>107</td>
</tr>
<tr>
<td>Total</td>
<td>3 062</td>
<td>3 856</td>
</tr>
</tbody>
</table>

Sources: IEA (2009a); IEA analysis.

Power capacity and generation projections

In the Baseline scenario, power capacity in OECD Europe grows by 77% between 2007 and 2050 to 1 495 GW. The share of fossil fuels in power generation declines between 2007 and 2050 from 54% to 44% (Table 8.5). Compared to other countries and regions, where the share of fossil fuels increases in the Baseline scenario, in OECD Europe the continuation of the EU ETS beyond 2012 is assumed
to continue to constrain fossil fuel use. The Baseline scenario assumes that carbon prices in the ETS sectors increase from USD 43/tCO₂ in 2020 to USD 83/tCO₂ in 2050.⁴ Nuclear power’s generation share falls in the Baseline scenario from 26% in 2007 to 17% in 2050 as a result of policies in several European countries to phase out nuclear power and of the retirement of old reactors. Renewables constitute 40% of electricity generation in 2050 compared to 20% in 2007.

In the BLUE Map scenario, the power sector is nearly decarbonised in OECD Europe, emitting 15 gCO₂/kWh in 2050. The power generation mix changes significantly compared to the Baseline scenario. Power plants with carbon capture from coal, gas or biomass comprise 19% of the power generating capacity in 2050. Generation from fossil fuel plants without CCS is nearly completely abandoned by 2050. Coal capacity of 25 GW is scrapped before the end of its technical lifetime. The remaining 211 GW of gas capacity without CCS runs partly as reserve capacity and partly to support 50 GW of pumped storage, to balance the fluctuating generation from wind and photovoltaics (PV). Renewables further increase their share in power generation compared to the Baseline scenario, reaching 55% in 2050. Combined heat and power generation increases from 10% in 2007 to nearly 20% by 2050, mainly with biomass-fired CHP plants. Increases in nuclear power in the BLUE Map scenario result in nuclear generating 29% of electricity in 2050.

### Table 8.5 OECD Europe’s power generation mix and capacity, Baseline and BLUE Map scenarios, 2050

<table>
<thead>
<tr>
<th>Power generation share</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
</tr>
<tr>
<td>Coal</td>
<td>13.3</td>
</tr>
<tr>
<td>Coal + CCS</td>
<td>0.0</td>
</tr>
<tr>
<td>Gas</td>
<td>30.4</td>
</tr>
<tr>
<td>Gas + CCS</td>
<td>0.0</td>
</tr>
<tr>
<td>Biomass</td>
<td>5.6</td>
</tr>
<tr>
<td>Biomass + CCS</td>
<td>0.0</td>
</tr>
<tr>
<td>Oil</td>
<td>0.1</td>
</tr>
<tr>
<td>Nuclear</td>
<td>16.7</td>
</tr>
<tr>
<td>Hydro</td>
<td>13.9</td>
</tr>
<tr>
<td>Tidal</td>
<td>0.2</td>
</tr>
<tr>
<td>Geothermal</td>
<td>0.5</td>
</tr>
<tr>
<td>Solar PV</td>
<td>2.5</td>
</tr>
<tr>
<td>Solar CSP</td>
<td>1.2</td>
</tr>
<tr>
<td>Wind onshore</td>
<td>11.8</td>
</tr>
<tr>
<td>Wind offshore</td>
<td>3.9</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>

- This assumption is consistent with the World Energy Outlook 2009 (IEA, 2009e). There, a carbon price of USD 43/tCO₂ is reached for the EU ETS sectors (industry and power generation) in 2020, increasing by 2.2% until 2030. In the ETP baseline scenario, this trend is assumed to continue resulting in a price of USD 83/tCO₂ by 2050.
The power generation fuel mix of the largest electricity producing countries in OECD Europe in 2050 varies widely in the BLUE Map scenario (Figure 8.8). Unlike in 2007, power generation is dominated in all countries by low-carbon technologies. France relies on nuclear power and increases its nuclear share from 77% in 2007 to 83% in 2050 in the BLUE Map scenario.

Figure 8.8  Power generation mix in major European electricity producing countries in BLUE Map scenario, 2050

Key point

Technology choices to decarbonise the power sector in BLUE Map differ largely between countries in OECD Europe depending on national conditions.

Countries such as Italy and Spain generate 60% and 73% of their total electricity needs from renewable sources, primarily through the increased utilisation of solar, biomass and wind. Wind power generation, especially offshore wind, is
also expanded in countries in Northern Europe, such as the United Kingdom and Germany. The countries bordering the North Sea also have access to offshore CO₂ storage sites at comparably low costs. This makes power generation at coal plants equipped with carbon capture a further important option for cutting emissions in the power sector in the BLUE Map scenario.

**Decarbonising the power sector**

In OECD Europe, electricity demand only grows moderately in the BLUE Map scenario between 2007 and 2050 at an average annual rate of 0.6%. As a result, unlike many non-OECD countries, total installed capacity in OECD Europe increases at moderate rates in this timeframe (1.1% per year in BLUE Map). But OECD Europe will need to reduce its CO₂ emissions by nearly 75% if it is to play its full part in achieving the overall 50% reduction in emissions needed by 2050.

A large proportion of the existing capacity is expected to reach the end of its lifetime over the next 20 years. Decisions on the replacement of this capacity, given the long life of a power plant, will have a major impact on Europe’s ability to decarbonise the power sector and the speed at which it can do so. Renewables, CCS and nuclear offer the principal options for reducing CO₂ emissions in the power sector. Different European countries are likely to adopt each in different measures. In the BLUE Map scenario, nuclear contributes 20% of the reductions needed to decarbonise power generation from an additional capacity of 55 GW in 2050. CCS enables 36% of the total reduction achieved in power generation, saving a further 34½ Mt CO₂ in 2050. Fuel switching from coal to gas and efficiency improvements in fossil power generation are responsible for 8% of the reductions in the power sector. The balance comes from the wider deployment of renewable energy sources, particularly biomass, wind and solar energy, which deliver 36% of the reduction needed in the power sector.

The import of low-carbon electricity from outside Europe is also an option. Plans to import electricity produced from solar thermal plants in Northern Africa are being pursued within the DESERTEC project (DESERTEC, 2009). In the BLUE Map high renewable scenario described in Chapter 3, these imports of solar electricity meet around 550 TWh of OECD Europe’s electricity needs in 2050.

**Industry sector**

In OECD Europe, industry used 438 Mtoe in 2007. This accounted for a third of total energy used. Europe’s industries account for 15% of global industrial energy use. The final energy mix of industry is dominated by oil and natural gas (Figure 8.9). Industry accounts for 41% of all electricity consumption in OECD Europe.

The chemicals and iron and steel sectors in OECD Europe account for almost half of all industrial energy use and CO₂ emissions (Table 8.6). Measures taken to improve energy use and reduce emissions in these two sectors will have an important impact on the overall energy use and emissions of European industry.
**Figure 8.9**  Industrial final energy mix in OECD Europe and the world, 2007

OECD Europe 438 Mtoe

World 3,019 Mtoe

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>OECD Europe (Mtoe)</th>
<th>World (Mtoe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>26%</td>
<td>20%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>24%</td>
<td>20%</td>
</tr>
<tr>
<td>Electricity</td>
<td>24%</td>
<td>20%</td>
</tr>
<tr>
<td>Coal</td>
<td>17%</td>
<td>6%</td>
</tr>
<tr>
<td>Biomass and waste</td>
<td>5%</td>
<td>6%</td>
</tr>
<tr>
<td>Other</td>
<td>4%</td>
<td>4%</td>
</tr>
</tbody>
</table>

Note: Includes coke ovens, blast furnaces and petrochemical feedstocks.
Sources: IEA (2009a and 2009b).

**Key point**

Oil and gas represent half of all energy use by industry in OECD Europe.

---

**Table 8.6**  Industrial production, energy use and CO₂ emissions in OECD Europe, 2007

<table>
<thead>
<tr>
<th>Industry sector</th>
<th>Production (Mt)</th>
<th>Reported energy use (Mtoe)</th>
<th>CO₂ emissions (Mt CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry sector</td>
<td>438</td>
<td>932</td>
<td></td>
</tr>
<tr>
<td>Iron and steel</td>
<td>228</td>
<td>71</td>
<td>258</td>
</tr>
<tr>
<td>Chemicals and petrochemicals</td>
<td>84</td>
<td>137</td>
<td>187</td>
</tr>
<tr>
<td>Aluminium</td>
<td>14</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Cement</td>
<td>307</td>
<td>24</td>
<td>200</td>
</tr>
<tr>
<td>Paper and paperboard</td>
<td>105</td>
<td>40</td>
<td>34</td>
</tr>
<tr>
<td>Pulp</td>
<td>43</td>
<td>43</td>
<td>43</td>
</tr>
<tr>
<td>Recovered paper</td>
<td>58</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td>Other</td>
<td>155</td>
<td>241</td>
<td>241</td>
</tr>
</tbody>
</table>

Note: Iron and steel includes energy use for coke-making and the energy data for chemicals and petrochemicals include feedstocks. The table has been compiled from a mixture of top-down and bottom-up sources and so the totals may not match.
Sources: IEA (2009a and 2009c); IEA analysis.

---

**Energy and CO₂ savings potential with best available technologies**

Significant energy and CO₂ savings in European industry are possible through the implementation of currently available best available technologies (BATs). It is
estimated that the application of BATs could reduce final energy use by between 9% and 28% in the five most energy-intensive sectors. Total estimated savings for the five sectors is 45 Mtoe per year, equivalent to 10% of energy use in industry and 3% of total energy consumption in OECD Europe in 2007.

OECD Europe has on average one of the most energy-efficient industry sectors. The energy savings potential from the implementation of BATs is, therefore, below global levels at around 10% to 20%. Some of this will be realised as old capacity is scrapped and replaced by BATs.

Scenarios for industrial energy use and CO₂ emissions

Two variants of the Baseline and BLUE scenarios are considered for the industry sector: a low-demand variant assuming a modest decline in material production in OECD Europe, and a high-demand variant stipulating a moderate demand growth in materials (Figure 8.10). Industrial energy use in OECD Europe in 2050 in the Baseline scenarios is lower than 2007 levels, thanks to increased energy efficiency measures and some reduction in cement and crude steel industrial production. Higher levels of energy efficiency in the BLUE scenarios lead to significant reductions in industrial energy use in 2050, 32% lower than in 2007 and about 25% lower than in the Baseline scenarios in 2050 for both the low- and high-demand cases. The largest reductions are achieved in the iron and steel sector (66%) as well as in the chemical industry (41% to 53%).

![Figure 8.10: Materials production in OECD Europe in the low-demand and high-demand scenarios](image-url)

**Note:** Production of materials is the same for both the Baseline and BLUE scenarios.

**Source:** IEA data and estimates.

**Key point**

The production of materials in OECD Europe declines or grows only moderately between 2007 and 2050.
In the Baseline scenarios, industry emissions in OECD Europe decline by about 30% between 2007 and 2050. In the BLUE low- and high-demand scenarios, direct industrial CO$_2$ emissions fall by 66% and 71% compared to 2007 levels (Table 8.7).

**Table 8.7**  
Direct energy and process CO$_2$ emissions by industry sector in OECD Europe

<table>
<thead>
<tr>
<th>Industry Sector</th>
<th>Mt CO$_2$ 2007</th>
<th>Baseline low 2050</th>
<th>Baseline high 2050</th>
<th>BLUE low 2050</th>
<th>BLUE high 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>12</td>
<td>21</td>
<td>27</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Iron and steel</td>
<td>258</td>
<td>157</td>
<td>152</td>
<td>53</td>
<td>51</td>
</tr>
<tr>
<td>Chemicals</td>
<td>187</td>
<td>177</td>
<td>176</td>
<td>83</td>
<td>68</td>
</tr>
<tr>
<td>Cement</td>
<td>200</td>
<td>167</td>
<td>190</td>
<td>108</td>
<td>77</td>
</tr>
<tr>
<td>Pulp and paper</td>
<td>34</td>
<td>30</td>
<td>33</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Other</td>
<td>241</td>
<td>95</td>
<td>95</td>
<td>44</td>
<td>46</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>932</strong></td>
<td><strong>648</strong></td>
<td><strong>673</strong></td>
<td><strong>316</strong></td>
<td><strong>267</strong></td>
</tr>
</tbody>
</table>

Note: Emissions from blast furnaces, coke ovens and feedstock are included.  
Sources: IEA (2009a and 2009c); IEA analysis.

Carbon capture and storage offers the largest potential to reduce industrial CO$_2$ emissions in OECD Europe, representing 40% of all industry emissions reductions in the BLUE scenarios (Figure 8.11). Energy efficiency represents another third and the remaining 28% is attributed to fuel and feedstock switching and higher recycling and energy recovery.

**Figure 8.11**  
Options for reducing direct CO$_2$ emissions from European industry

Source: IEA (2009c).

**Key point**

Energy efficiency and CCS offer the best important opportunities to decrease OECD Europe’s industrial CO$_2$ emissions.
Buildings sector

The buildings sector (including the residential, commercial and public service sectors) accounts for about 26% of TPES in OECD Europe. Although energy consumption by the sector has grown by 11% since 1990, the consumption of coal and oil has declined by 7.3% and 1.9% a year respectively. Energy consumption in the commercial and public service sectors grew by 1.3% a year between 1990 and 2007, and by 0.4% in the residential sector (Figure 8.12).

Figure 8.12  Residential and service sectors' energy consumption by fuel in OECD Europe

Sources: IEA (2009a).

Key point

Energy demand in the service sector has grown faster than in the residential sector since 1990.

Part of the reason for stronger growth in the commercial and service sectors has been the faster growth in service sector activity compared to the growth in the number of households. Between 1990 and 2006, value added in the service sector
grew by an estimated 2.8% a year (Figure 8.13) while household numbers grew by an estimated 1.2% per year in the same period.\textsuperscript{5}

**Figure 8.13** Commercial and services value added for OECD Europe

![Graph showing commercial and services value added for OECD Europe](image)

Sources: IEA indicators database (IEA, 2009f); IEA estimates.

**Key point**

Significant growth of the commercial and service sector in many countries is one of the main drivers for the sector’s energy demand.

**Energy consumption by end use**

Europe covers a number of very diverse climate regions. The Scandinavian countries have very significant heating loads for most of the year. Countries in Central Europe have cold winters and warm summers. In Southern Europe, heating needs are much lower, but cooling needs can be significant. This diversity has a significant impact on individual countries’ energy consumption levels and patterns.

The estimated breakdown of energy consumption by end use is shown in Figure 8.14.\textsuperscript{6} In the residential sector, space and water heating dominates. In the service sector electrical end uses are much more important, although space heating still has the largest share. The rapid growth in electrical end uses in the residential and service sectors means that electricity consumption and the electrical end uses share of the total are both growing quickly.

---

\textsuperscript{5} Data for service sector value added and household numbers come from the IEA’s Energy Indicators database. Household numbers for Turkey were estimated from population data.

\textsuperscript{6} The estimate for the residential sector is based on 18 European countries that have data from which estimates can be derived. The service sector end-use shares are based on IEA energy consumption statistics, with an allocation to end-uses made using data available for four OECD countries. In the service sector, energy consumption for space cooling and ventilation is likely to be underestimated.
Figure 8.14 Residential and service sectors’ energy consumption by end use in OECD Europe, 2006/07

**Residential**
- Space heating: 66%
- Water heating: 13%
- Cooling: 0.3%
- Lighting: 3%
- Cooking: 6%
- Other: 12%

**Services**
- Space heating: 45%
- Water heating: 13%
- Cooling: 4%
- Lighting: 9%
- Other: 29%

Sources: IEA indicators database; IEA estimates.

**Key point**
Energy demand for space and water heating currently represents the majority of energy consumption in the buildings sector.

**Scenarios for buildings energy use and CO₂ emissions**

The population of OECD Europe is projected to grow by 0.1% a year between 2007 and 2050, to reach around 577 million in 2050. The growth in households will be much higher than this as the trend towards fewer persons per household continues. Total households will grow from an estimated 209 million in 2005 to 287 million in 2050, growing by 0.7% a year. In the service sector, floor area is projected to grow to more than twice the 2007 level by 2050.

**The Baseline scenario**

In Europe, the vast bulk of the building stock was built before the first oil crisis (Figure 8.15). The biggest challenge for the buildings sector in Europe, if CO₂ emissions are to be significantly reduced, is to address the existing building stock.

Energy efficiency policies have been successful in restricting the growth in energy consumption, particularly in the residential sector for space heating. Building codes for new construction have been progressively tightened in many countries, and significant programmes to improve the thermal envelope of existing buildings have also helped reduce energy consumption growth.

The average consumption of large appliances has declined steadily over time as a result of energy efficiency labelling and minimum energy performance standards. But the growing use of an ever increasing range of smaller electrical appliances has...
seen the overall energy consumption of appliances grow strongly and the share of small appliances increase significantly.

![Figure 8.15 Residential building stock in selected countries by vintage](image)


**Key point**

The vast majority of Europe’s building stock was built before 1970.

Energy consumption increases by 0.9% a year between 2007 and 2050 in the Baseline scenario, from around 463 Mtoe to 668 Mtoe in 2050, an increase of 44%. The consumption of gas grows at 0.7% a year, electricity at 1.4% a year, solar at 3.9% a year, and purchased heat at 0.9% a year. The consumption of coal declines by 3.5% a year and that of oil by 0.5% a year (Figure 8.16). The continued rapid growth of the service sector sees its share of energy consumption in the buildings sector increase from 36% in 2007 to 42% in 2050. Energy consumption in the service sector grows at 1.2% a year between 2007 and 2050, while the residential sector sees growth of 0.6% a year.

**The BLUE Map scenario**

In the BLUE Map scenario, energy consumption in the residential and service sectors reduces by 40% below the Baseline level in 2050, equivalent to a saving of 265 Mtoe (Figure 8.16). This represents a decline in energy consumption in 2050 of 14% compared to 2007 levels in the BLUE Map scenario, despite the 0.7% a year growth in household numbers and the doubling of service sector floor area. Gas consumption is reduced by the most in percentage (77%) and absolute terms (173 Mtoe) as heat demand is reduced both by tighter building codes for new buildings and by the refurbishment in cold climates of around three-quarters of the existing building stock to low-energy standards. The increased use of CO₂-free fuel sources, such as solar thermal and decarbonised electricity for space and water heating, also reduces emissions.
In the BLUE Map scenario, energy consumption in buildings is 9% lower than today’s level in 2050.

In the BLUE Map scenario, electricity demand is reduced by 91 Mtoe, being equivalent to 35% of the Baseline scenario level in 2050. Oil consumption is also significantly reduced. Solar thermal space and water heating increases significantly and solar use increases to 62 Mtoe in 2050, a level almost four times larger than in the Baseline scenario in 2050 and 20 times larger than in 2007. Heat consumption increases slightly over the Baseline scenario level in 2050, despite the decline in underlying demand for space heating, as building-scale CHP using hydrogen starts to penetrate from 2030.

Energy consumption in the BLUE Map scenario is 150 Mtoe (39%) lower in the residential sector in 2050 than the Baseline scenario level, and 98 Mtoe (35%) lower in the service sector. In the residential sector, around four-fifths of the savings come from space heating, as a very large-scale refurbishment programme on the existing building stock halves space heating demand by 2050 compared to the Baseline level. Important contributions come from electrical end uses, notably lighting and appliances.

In the service sector, water and space heating accounts for around half of the savings. Very significant savings from the electricity-intensive end uses of cooling, lighting and other miscellaneous loads make a significant contribution to the CO₂ savings in the BLUE Map scenario.

CO₂ emissions attributable to the residential and service sector in the BLUE Map scenario are 42% or 785 Mt CO₂ lower than in the Baseline scenario in 2050. Taking into account that the residential and service sectors, because of their electricity and district heat demand, cause indirect CO₂ emissions in the power sector, the buildings sector is responsible for 1.9 Gt of CO₂ emissions in 2050 in the
Baseline scenario. Thanks to the decarbonisation of power generation in the BLUE Map scenario by 2050, these indirect emissions are reduced by 1.1 Gt in the BLUE Map scenario compared to the Baseline development.

The savings attributed to electricity production are offset to some extent by the switching from fossil fuels to electricity for space and water heating and for cooking. In the BLUE Map scenario, the substantial decarbonisation of the electricity sector allows electrification to be an attractive abatement option. Space and water heating account as well as improvements in the building shell for 72% of the reduction in direct CO₂ emissions below the Baseline scenario in 2050 (Figure 8.17). The assumed continuous tightening of building codes and standards results in accelerated savings after 2030. Important contributions are also made by solar thermal, heat pumps and CHP/district heating. Fuel switching to biofuels and energy efficiency improvements in cooling, lighting appliances and miscellaneous end uses account for 28% of the reduction below the Baseline level.

**Figure 8.17** Contribution to reductions in CO₂ emissions in the buildings sector in OECD Europe under the BLUE Map scenario

![Graph showing contributions to CO₂ emissions reductions in the buildings sector](image)

**Key point**

A wide range of options are needed to limit growth in CO₂ emissions in the buildings sector.

The CO₂ emissions reductions from cooling are achieved predominantly by cooling system improvements but also by improvements in building shells through, for example, the increased use of shading and active shutters, reflective coatings and insulation. Lighting systems become significantly more efficient in the Baseline scenario. Extensive further improvements are still possible, particularly in the service sector, and the emergence of solid state lighting will help expand the savings potential.
Transport sector

The transport sector in OECD Europe, including international aviation and shipping, used 447 Mtoe in 2007. This accounted for 31% of total final energy use in OECD Europe and about 20% of worldwide transport energy use. OECD Europe’s energy shares are similar to world averages, but with a higher share of energy-intensive modes, such as light-duty vehicles (LDVs) and aviation (Figure 8.18).

Figure 8.18  Transport sector final energy use by mode in OECD Europe and the world, 2007

OECD Europe 447 Mtoe

- LDV 44%
- Road freight 23%
- Buses 4%
- Rail 1%
- Air 14%
- 2-3-wheelers 1%
- Shipping 13%

World 2 220 Mtoe

- LDV 44%
- Road freight 23%
- Buses 6%
- Rail 3%
- Air 11%
- 2-3-wheelers 3%
- Shipping 10%

Sources: IEA (2009a and 2009b).
Notes: Air and shipping include an estimate of international trips starting from OECD Europe; energy use for pipeline transportation are excluded.

Key point

The energy mix in the transport sector in OECD Europe is similar to the global mix.

A range of transport indicators by mode, including activity, intensity and fuel use variables, is outlined in Table 8.8. The energy use data reported in the IEA statistics do not specify road fuel use in terms of vehicle type. This is estimated by the IEA using data and assumptions on vehicle stocks, efficiency, and average travel. Both the energy use as reported in IEA statistics as well as estimates for energy use that have been used in the present analysis are shown in Table 8.8. These estimates are based on current production levels and energy intensities from a range of sources. These data need further validation.
Europe has an extensive public transit infrastructure. Even though, cars and other passenger LDVs carry nearly two-thirds of total passenger-kilometres of travel. Rail accounts for about 5%, although perhaps twice as large a share in urban areas. Buses account for about three times as much passenger travel as rail.

Trucks carry about five times as much freight (in tonne-kilometres) as rail. Buses carry passengers at about half the energy intensity per passenger-kilometre of cars, and rail at less than a quarter. Rail is less than one-tenth as energy-intensive as trucking, on average. The net effect of these factors in OECD Europe is that LDVs dominate fuel use, followed by trucks and air travel. In terms of CO₂ emissions (Table 8.9), a similar pattern emerges.

### Table 8.8 Transport energy indicators in OECD Europe, 2007

<table>
<thead>
<tr>
<th></th>
<th>Passenger travel</th>
<th>Freight travel</th>
<th>Stock average energy intensity</th>
<th>Fuel use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(bn pkkm)</td>
<td>(bn tkm)</td>
<td>(MJ/pkm)</td>
<td>(MJ/tkm)</td>
</tr>
<tr>
<td>LDVs</td>
<td>4 366</td>
<td>1.9</td>
<td></td>
<td>193</td>
</tr>
<tr>
<td>2-3-wheelers</td>
<td>205</td>
<td>1.1</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Buses</td>
<td>917</td>
<td>0.8</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Freight trucks</td>
<td>1 682</td>
<td>2.6</td>
<td></td>
<td>105</td>
</tr>
<tr>
<td>Rail</td>
<td>334</td>
<td>0.3</td>
<td>0.4</td>
<td>5</td>
</tr>
<tr>
<td>Air</td>
<td>1 089</td>
<td>0.3</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>60</td>
</tr>
<tr>
<td>Total/Average</td>
<td>6 911</td>
<td>1 948</td>
<td>1.7</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Notes: In totals row, averages are provided for intensity figures and are weighted across modes. bn pkkm = billion passenger-kilometres, bn tkm = billion tonne-kilometres.
Sources: IEA (2009d); IEA analysis.

### Table 8.9 Transport CO₂ indicators in OECD Europe, 2007

<table>
<thead>
<tr>
<th></th>
<th>Passenger (Mt CO₂-eq)</th>
<th>Passenger (kg CO₂-eq/pkm)</th>
<th>Freight (Mt CO₂-eq)</th>
<th>Freight (kg CO₂-eq/tkm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDVs</td>
<td>665</td>
<td>0.15</td>
<td>1.692</td>
<td>0.03</td>
</tr>
<tr>
<td>2-3-wheelers</td>
<td>18</td>
<td>0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buses</td>
<td>60</td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freight trucks</td>
<td>11</td>
<td>0.03</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>Rail</td>
<td>218</td>
<td>0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>219</td>
<td>n.a.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total/average</td>
<td>967</td>
<td>0.14</td>
<td>610</td>
<td>0.31</td>
</tr>
</tbody>
</table>

Note: In totals row, averages are provided for intensity figures and are weighted across modes.
Sources: IEA (2009d); IEA analysis.

Scenarios for transport energy use and CO₂ emissions

OECD Europe has a high average travel per capita. With little expected population growth over the next 40 years, total transport activity is unlikely to grow significantly in Europe. It is also unlikely that energy use per passenger-kilometre and per tonne-kilometre for freight will improve significantly without strong policy interventions.
In the Baseline scenario, transport energy use in OECD Europe remains fairly flat, reflecting the impact of a wide range of initiatives around Europe which are expected to help cut energy intensity over the next 5 to 10 years. Without further significant expansion of these initiatives, energy intensity is projected to improve little if at all after 2020, especially in LDVs.

Energy efficiency gains affect the consumption of different fuels in different ways (Figure 8.19). Gasoline demand is likely to decrease, thanks to improvements in the fuel efficiency of passenger LDVs and the partial or total electrification of smaller vehicles. Larger diesel vehicles, including trucks, are much less likely to be shifted to electricity, so the consumption of diesel fuel becomes relatively more significant. The refining implications of this scenario have not been explored in detail. Growing demand for aviation is likely to overshadow efficiency gains in planes, creating a need for more jet fuel in Europe. Synfuels also rapidly increase their share after 2030, as conventional oil supplies decline.

In 2007, the transport sector in OECD Europe used about 447 Mtoe, or around 20% of global transport energy use. By 2050 this share is likely to drop to about 10%, as the transport sector energy use of developing economies grows very quickly over the next 40 years (IEA, 2009d).

**Figure 8.19** Transport energy use by fuel in the Baseline and BLUE scenarios* in OECD Europe

* The Baseline and BLUE Map variant scenarios for transport are described in detail in Chapter 7.
Sources: IEA (2009a); IEA analysis.

**Key point**

Energy use in 2050 is very similar to today in the Baseline scenario but there are major changes in the fuel mix in the BLUE scenarios.
The BLUE Map scenarios: technological pathways for transport in OECD Europe

Different European countries, with cultural differences, transport system differences, climate differences and a range of different commitments on CO₂, will adopt different approaches to ensuring that their transport sectors make the contributions they need to make to attain the outcomes implicit in the BLUE Map scenario. Some countries will rely heavily on biofuels, others more on electrification. Some countries may have particular opportunities to deploy EVs, for example because they have a proportion of LDVs used exclusively within large cities. Cold and biomass-rich Scandinavian countries may be more likely to go towards compressed (and eventually bio-synthetic) natural gas or biomass-to-liquids fuel options. In most of the big passenger LDV markets such as the United Kingdom, France, Germany, Spain and Italy, the electrification of vehicles is now high on the agenda.

The projected OECD Europe greenhouse-gas emissions in each of the transport scenarios explored in Chapter 7 are set out in Figure 8.20. The emissions for individual modes depend on a combination of efficiency improvements and the use of low-carbon fuels. Modal shifts to the most efficient modes account for the remaining reductions.

In particular, reductions depend on:

- Achieving a 50% improvement in new LDV fuel efficiency by 2030 compared to 2005.

- Achieving efficiency improvements in the stock of trucks, ships, trains and aircraft of the order of 40% to 50% by 2050.

- Reaching substantial sales of EVs and plug-in hybrid electric vehicles (PHEVs) by 2030 (9 million) and 2050 (12 million).

- Biofuel being about 12% of transport fuel by 2030 and 25% by 2050. This assumes that most of the biofuel is imported into OECD Europe.

In the BLUE Shifts scenario, travel by rail and bus in 2050 increases by 50% to 100% compared to the Baseline scenario in that year. This, together with other changes such as improvements in land-use planning and investment in non-motorised transport infrastructure, results in a 25% cut in the growth of car and air travel in OECD Europe.

Decarbonisation of power generation will also play an important part in reducing greenhouse-gas emissions in the transport sector as EVs start to play a larger role. Europe starts from a relatively good position, producing on average 345 gCO₂/kWh of generation in 2007. This is expected to reduce to 208 gCO₂/kWh in 2050 in the Baseline scenario and to 15 gCO₂/kWh in the BLUE Map scenario. In the BLUE Map scenario, CO₂ emissions reductions benefit not only from there being many more EVs than in the Baseline scenario, but also from the much lower carbon footprint of the electricity that runs them.

In the BLUE Map scenario, transport greenhouse-gas emissions are reduced by around 60% in OECD Europe, with the aggressive promotion of low-greenhouse-gas technologies into the market. The cost of such greenhouse-gas emissions
reductions over the lifetime of a vehicle depends on energy prices. But it will often be negative as energy savings exceed the extra investment cost in new technologies.

Figure 8.20  OECD Europe’s greenhouse-gas emissions evolution by transport mode

In the BLUE Map scenario, PHEV and EV technologies dominate new LDV sales after 2030 (Figure 8.21). Sales of EVs and PHEVs begin in earnest in 2015; by 2030 they reach more than 50% of sales; and by 2050 70% of all new vehicles are electric.

Transport volumes in OECD Europe are relatively stable. They may also decline during periods of slow economic growth or when energy prices increase, as in 2008. Deep cuts in greenhouse-gas emissions can be achieved by adopting an aggressive strategy towards efficiency. This has already begun for passenger LDVs. Further big reductions will come from shifting towards electricity and advanced biofuels. Natural gas can also play a significant role in European transport for cars and perhaps especially for trucks. Over time there must be a transition to biogas and bio-synthesised gas in order to reach very low CO₂ intensities by 2050. Pursuing a growth strategy for the most efficient transit and non-motorised modes, and dampening demand growth for the least efficient single-occupant passenger LDVs can also contribute to substantial energy savings and greenhouse-gas reductions by 2050 or even earlier.
**Figure 8.21** Passenger light-duty vehicles sales by technology in OECD Europe in the Baseline and BLUE Map scenarios

Sources: IEA (2009a); IEA analysis.

**Key point**

A wide range of new LDV technologies contribute to emissions reductions under the BLUE scenario.

**Investment needs in the BLUE Map scenario**

To achieve an almost 75% reduction in CO₂ emissions between 2007 and 2050 in OECD Europe will require investment of around USD 7.1 trillion. Most of this (52%) will need to be made in the transport sector, with less in power generation (11%) and the buildings sector (35%) (Figure 8.22). Investment needs increase over time, as the least-cost emissions reduction options are taken first. Achieving around 50% reductions in CO₂ emissions in OECD Europe by 2030 requires the investment of USD 2.6 trillion. Moving from a 50% reduction in 2030 to a 75% reduction by 2050 in OECD Europe requires approximately twice as much investment, of the order of USD 4.5 trillion.

Almost all of this additional investment should be offset by fuel savings due to the more efficient use of energy, especially in the transport sector. Additional vehicle costs are estimated to be offset by undiscounted fuel savings of around USD 5.0 trillion. So, changes in the BLUE Map scenario may result in net savings of USD 1.3 trillion in the OECD Europe an transport sector. Similarly, in the buildings sector fuel cost savings result in net savings of USD 0.8 trillion. Overall, the additional investment needs of USD 7.1 trillion are more than compensated by total fuel savings of USD 13.1 trillion. Although these estimates are inevitably uncertain, it seems at least possible that the additional investment needed in vehicles and the fuel infrastructure in OECD Europe will be largely compensated for by reduced fuel costs.
Figure 8.22 Additional investment needs and fuel cost savings for OECD Europe

![Graph showing additional investments and fuel savings over time](image)

**Note:** Fuel savings are calculated on the basis of BLUE Map fuel prices. They refer to final energy use for the transport and industry sectors and to primary energy consumption for the power and transport sectors. Savings drop significantly, if Baseline energy prices are assumed, as fossil fuel prices in BLUE Map are significantly lower than in the Baseline scenario, reflecting the impact of lower fossil energy use on prices.

**Key point**

Large investment needs in transport and the building sectors may be compensated by fuel savings.

**Transition to a low-carbon energy future**

In the BLUE Map scenario, OECD Europe’s CO₂ emissions in 2050 are cut by roughly three-quarters compared to 2007 levels. Achieving the deep emission cuts required in the BLUE Map scenario will require a significant intensification of current efforts to develop and deploy low-carbon technologies through the expansion and further radical development of existing policy measures in OECD Europe.

**Future technology priorities**

Different sectors and technology options make different levels of contribution to the achievement of the reduction of CO₂ emissions in the BLUE Map scenario in 2050 compared to the Baseline scenario (Figure 8.23). End-use sectors contribute 66% of the reduction; the transport sector is responsible for 23%, buildings for 25% and industry together with CCS in fuel transformation for 18%. The power sector contributes the remaining 34% of the total emissions reductions.
Decarbonising power generation is crucial to the achievement of deep CO₂ emission cuts, since it reduces emissions not only in power generation, but also in those end-use sectors which have the potential for greater electrification.

A large proportion of the existing generating capacity in OECD Europe will reach the end of its planned lifetime over the next 20 years. This presents an opportunity to invest in low-carbon generation technologies. To prepare for this, RD&D efforts in power generation should focus on:

- Improving efficiency in conventional fossil power generation, which will subsequently also improve the overall performance of CCS.
- The implementation of CCS demonstration projects which can prove the viability of the capture, transport and storage technologies that are needed.
- Continuing R&D on immature or not yet cost-competitive renewable energy technologies.
Continuing research on the impacts of the increased penetration of variable renewables such as wind and solar on system stability and the grid and storage options for ensuring stable operation of the electricity system.

More R&D on the components needed for smart grids and their operation.

The import of solar electricity produced in the Middle East and North Africa may also help to decarbonise the power sector in Europe. High-voltage direct current (HVDC) transmission technology will be fundamental to the success of this strategy. Bi-directional HVDC lines are already operating today, but further developments are needed in the operation of meshed HVDC network structures.

In the transport sector, a transition to biofuels, biogas and EVs may offer a route to significantly reduce CO$_2$ emissions from Europe’s transport sector. Further research and deployment in the production of second-generation biofuels is needed. Strategies for the provision of industrial-scale plants with biomass resources have to be developed. This is being analysed in an EU-funded OPTFUEL project (OPTFUEL, 2009). Further research in the areas of battery technology, biogas combustion technologies and the impacts of transport electricity demand on the electricity infrastructure is also needed. These are being addressed in the European Green Car Initiative project (EC, n.d.) which is part of the European recovery package.

In the industry sector, major reductions are expected in the BLUE Map scenario through efficiency improvements and the use of CCS in the cement, chemicals and iron and steel sectors. To fully exploit efficiency improvement potentials, all industry sectors have to be brought up to BAT standards. For example, older cement kilns should be replaced with six-stage pre-heating and pre-calciners. The benefits of using the coke dry quenching process in iron and steel production should also be investigated. Areas for further RD&D include the use of carbon-free energy and alternative feedstocks such as hydrogen in the iron and steel sector, bio-based feedstocks in the chemicals industry, and the demonstration of CCS.

In the buildings sector, new and improved technologies will be required to achieve deep greenhouse-gas reductions in the second quarter of this century. For example, more efficient and lower-cost heat pumps will make a major contribution. R&D efforts are also required on fuel cells and advanced lighting technologies.

**Future policy priorities**

To achieve these technology changes, OECD Europe should also:

- Continue to develop ambitious climate change policies at EU level and through national programmes both within and outside the EU.

- Strengthen the EU ETS such that it sets a carbon price over the next decade that is high enough to drive the necessary investment in energy efficiency in the traded sector. Allocation rules should be designed to prevent carbon leakage.

- Consider developing a harmonised trading system for renewables in the EU that is consistent with the internal energy market and the EU ETS.
- Clarify national policies on new nuclear power plants.
- Develop a roadmap for improving gas and electricity interconnections in Europe consistent with the requirements of a low-carbon economy. This will require closer transnational co-operation within OECD Europe and with neighbouring countries.
- Consider the introduction of mandatory national energy efficiency targets for EU member states to replace the indicative targets in the Energy Services Directive.
- Introduce additional national policies on white certificates, efficiency obligations and whole-building retrofits to ensure many more residential buildings are retrofitted to low-energy standards.
- Strive to achieve agreed vehicle standards for new passenger cars of 130 gCO₂/km in 2015 and 95 gCO₂/km in 2020. Tighten fuel efficiency standards for vans and trucks.
- Consider further policies to reduce greenhouse-gas emissions from ships, trains and aircraft.
- Fully implement the Strategic Energy Technology (SET) plan and associated roadmaps. This will require additional funding of about USD 5 billion per year, better alignment of this funding with the priorities in the SET plan and more co-ordination of RD&D activities between the EU and its member states.
Key findings

In the Baseline scenario, primary energy supply in the United States (US) increases by more than 5% between 2007 and 2050. Carbon dioxide (CO₂) emissions increase by only 1%. In the BLUE Map scenario, primary energy supply decreases by 17% and CO₂ emissions by 81% by 2050 from 2007 levels.

The BLUE Map scenario brings energy security benefits as well as climate benefits. Oil and gas demand in 2050 is reduced to around 40% of 2007 levels. As a result, the United States is much less dependent on imported oil and gas in the BLUE Map scenario than in the Baseline scenario.

The investments between 2010 and 2050 needed to achieve the BLUE Map scenario are USD 5.8 trillion higher than for the Baseline scenario. However, fuel savings from these investments are projected to be even higher on an undiscounted basis.

The US outcomes in the BLUE Map scenario are largely achieved through increased energy efficiency in all end-use sectors and by essentially decarbonising the power and transport sectors. Measures to improve energy efficiency and fuel switching in the end-use sectors together provide more than half of all emissions reductions. Other major contributors include carbon capture and storage (CCS), biofuels and other renewables.

Energy efficiency measures should be given high priority. Efficiency improvements represent some of the lowest-cost means of achieving a low-carbon energy future. While the United States has made important progress in this area, all levels of government (federal, state and local) need to accelerate their efforts.

In the BLUE Map scenario, the generation mix in 2050 is dominated by low-carbon technologies such as wind, solar, biomass, nuclear and fossil fuels with CCS. The installed capacity of nuclear generation doubles and there is a 24-fold increase in wind power generation. Gas- and coal-fired generation with CCS accounts for about 16% of generation in 2050.

To realise a more diversified and low-carbon power sector, policy actions are required to reduce subsidies for fossil fuels, harmonise national policies on renewables and remove uncertainties affecting the development of new capacity. Measures are also required to increase the efficiency of power generation through regulation, incentives and cost-reflective prices.

Improvements in energy efficiency and the transition to decarbonised power and transport sectors will require major investment in the electricity transmission grid, including the strengthening of interstate connections and the development of smart grid technologies.
Regional description

The United States covers a land area of 9 570 million square kilometres (km²). It had a population of 302 million in 2007. It is the largest economy in the world. The major population centres are New York City and northern New Jersey with 20 million inhabitants on the east coast; Los Angeles, Long Beach and Santa Ana with 15 million on the west coast; and the Chicago area with 10 million in the eastern-central part of the country. The civilian labour force stood at 154 million in 2008. The population density of the United States is relatively low, with 30.4 inhabitants per km². The country is a union of 50 states and the District of Columbia.

The US gross domestic product (GDP) per capita was USD 46 673 in 2007. From 2000 to 2007, GDP per capita grew by an average of approximately 3.2% a year (World Bank, 2009). Like all major economies, the economic performance of the United States has weakened since the start of the financial crisis at the end of 2008.

Recent trends in energy and CO₂ emissions

Today, most of the energy consumed in the United States comes from fossil fuels, particularly oil. The United States is self-sufficient in coal. It is largely self-sufficient in natural gas, with about 16% of gas supplied by imports from North American neighbours. Renewable energy resources supply 7% of the country’s energy needs. In the late 1950s, nuclear power generation began to be used to generate electricity. It currently supplies 20% of electricity output and 9% of all energy used in the United States (EIA, 2008).

The United States has substantial proven reserves of fossil fuels (Table 9.1). About 29% of the world’s proven coal reserves are located in the United States and about 4% of the natural gas reserves.
Table 9.1  Proven energy reserves in the United States and in the world, 2008

<table>
<thead>
<tr>
<th></th>
<th>Coal (Mt)</th>
<th>Crude oil (Mt)</th>
<th>Natural gas (bcm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proven reserves: US</td>
<td>238 308</td>
<td>3 700</td>
<td>6 730</td>
</tr>
<tr>
<td>Proven reserves: World</td>
<td>826 000</td>
<td>170 800</td>
<td>185 020</td>
</tr>
<tr>
<td>Production in 2008: US</td>
<td>1 063</td>
<td>305.1</td>
<td>582.2</td>
</tr>
<tr>
<td>Reserve-to-production ratio: US</td>
<td>224</td>
<td>12.4</td>
<td>11.6</td>
</tr>
</tbody>
</table>

Note: Reserve-to-production ratio indicates the length of time that recoverable reserves would last if production were to continue at current rates and if no additional reserves could be recovered.


Energy production and supply

Total primary energy supply (TPES) in the United States has steadily increased since 1971 across all energy sources (Figure 9.1). Between 1971 and 2007, energy supplied from coal almost doubled to 554 million tonnes of oil equivalent (Mtoe); oil rose by 30% to 957 Mtoe; natural gas rose by 4% to 538 Mtoe; nuclear increased from 11 Mtoe to 218 Mtoe; and renewables increased by almost 150% to 85 Mtoe. Energy supplied from hydropower declined by around 7% to 22 Mtoe in 2007.

Figure 9.1  Total primary energy supply in the United States


Key point

The United States continues to rely heavily on fossil fuels.
In 2007, the United States imported 840 Mtoe of energy and exported 127 Mtoe. It was self-sufficient in energy until the late 1950s when energy consumption began to outpace domestic production. In 2007, net energy imports accounted for 25% of all energy consumed (Figure 9.2). Historically, most of the exported energy from the United States was in the form of coal although in recent years oil exports have exceeded coal exports. In 2007 most (84%) of the imported energy was in the form of oil. In the last 20 years, natural gas imports, particularly from Canada, have grown rapidly, rising from 35 Mtoe in 1990 to 107 Mtoe in 2007. The United States now imports more oil and natural gas than any other country.

**Figure 9.2**  United States energy production, imports and exports

![Graph showing United States energy production, imports, and exports from 1990 to 2007.](image)

**Note:** Nuclear production refers to the heat produced in nuclear reactors, irrespective of whether the nuclear fuel used is from domestic sources or imported.

**Source:** IEA (2009a).

**Key point**

The United States is a significant net importer of energy, primarily oil.

**Energy consumption**

In 2007, oil consumption was 52% of total energy consumption, natural gas 20%, renewables 5% and electricity 21%. The pattern of energy use varies by sector. For example, oil provides 96% of the energy used for transportation but only 1% of the energy used to generate electric power (Figure 9.3). The transport sector was the largest consumer of energy (43%), followed by buildings (31%) and industry (25%) in 2007.
**Figure 9.3** Final energy consumption by fuel and by sector in the United States

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>400</td>
<td>500</td>
<td>600</td>
</tr>
<tr>
<td>Transport</td>
<td>300</td>
<td>400</td>
<td>500</td>
</tr>
<tr>
<td>Buildings</td>
<td>100</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>Other</td>
<td>100</td>
<td>200</td>
<td>300</td>
</tr>
</tbody>
</table>

Notes: Industry includes coke ovens, blast furnaces and feedstocks. Transport includes international aviation and marine bunkers. Other sectors include agriculture, fishing and forestry as well as energy use for pipeline transport.


**Key point**

The transport sector continues to be the largest consumer of oil.

### End-use efficiency improvement

The final energy intensity of the United States is currently 0.20 tonnes of oil equivalent (toe)/USD 1 000. The final energy intensity in 2000 was 0.23 toe/USD 1 000. This improvement can partly be explained by strong efficiency improvements resulting from the introduction of modern technologies and processes.

Analysis based on end-use data shows that the overall improvement in energy efficiency in the United States was 1.5% per year between 1990 and 2006. Without the energy savings resulting from these improvements, total final energy consumption would have been 25% higher in 2006.

### Carbon dioxide emissions

Energy-related CO₂ emissions in the United States were 5 915 Mt in 2007. Emissions increased by 18% between 1990 and 2007 while primary energy supply increased by about 22% over the same period. This difference was due to some fuel switching from coal in the industry sector and increases in the share of nuclear power and renewables.

### Overall energy policy framework

Energy policy in the United States is developed through a series of co-ordinated efforts by several agencies and among the executive and legislative branches of government. Primary responsibility for federal energy policies and programmes
is vested in the United States Department of Energy (DOE). Data collection and analysis is headed by the Energy Information Agency (EIA), an independent administration within DOE.

The DOE’s mission is to advance the national, economic and energy security of the United States; to promote scientific and technological innovation in support of that mission; and to ensure the environmental clean-up of the national nuclear weapons complex.

The federal government has a strong preference for market-based policies and regulations in the energy and environment policy area. Consistent with this, the current Administration has established a set of principles to guide its energy policy. These principles include:

- **Investing in the clean energy jobs of the future** by creating new clean energy jobs, and investing USD 150 billion over ten years in energy R&D in next-generation clean energy technologies.

- **Securing the nation’s energy future** through investments in clean energy sources to curb dependence on fossil fuels and make the country energy-independent. Efforts will focus on:
  - promoting the next generation of cars and trucks and the fuels they run on,
  - enhancing US energy supplies through the responsible development of domestic renewable energy, fossil fuels, advanced biofuels and nuclear energy, and
  - promoting investments in the transport, electricity, industrial, building and agricultural sectors that reduce energy bills.

- **Creating a fair but effective market framework to drive down emissions** by applying a market-based cap on emissions, eliminating carbon leakage,¹ and ensuring a level playing field for domestic manufacturing by securing significant actions to combat climate change on the part of the United States’ trading partners.

In addition to the DOE, a number of other federal agencies and executive branch offices are actively engaged in energy policy. These include the Federal Energy Regulatory Commission (FERC), the North American Electric Reliability Corporation (NERC), the Department of Transportation (DOT), the Department of the Interior (DOI), the Environmental Protection Agency (EPA), the Council on Environmental Quality (CEQ) and the Office of Science and Technology Policy (OSTP).

The 50 federal states, the District of Columbia and US Territories are responsible for many environmental and energy-related issues within their borders. They have regulatory commissions, usually elected or appointed by state governors or state legislatures, which are responsible for regulating energy undertakings with the state. States regulate all retail electricity rates and services as well as the siting and construction of electricity generation and transmission infrastructures.

---

¹ Carbon leakage refers to the movement of economic capacity from areas that are subject to emission controls to areas that are not, simply to avoid the cost of reducing emissions.
Current status of energy policies and climate change initiatives

Since January 2009, the United States government has taken a number of initiatives on energy and climate change. These include:

Domestic actions

- Through the 2009 American Recovery and Reinvestment Act (the Recovery Act), more than USD 90 billion will be invested in clean energy, including programmes intended to double the generation of clean renewable energies such as wind and solar in three years. Specific funding includes commitments for smarter grids and for 40 million smart meters to be deployed in American homes, home weatherisation projects, the greening of federal buildings, and a range of state and local renewable energy and energy efficiency efforts. The package also includes USD 600 million for green job training programmes.

- USD 2.0 billion in competitive grants to develop the next generation of batteries.

- A new Efficiency Standard for Automobiles. This sets for the first time joint fuel economy and greenhouse-gas emission standards for 2011 model cars and trucks to increase fuel economy to 6.7 litres per 100 kilometres or 35 miles per gallon by 2020.

- Steps to advance far-reaching energy and climate change legislation. The United States House of Representatives passed the American Clean Energy and Security Act in June 2009. This aims to promote clean energy investments and to lower US greenhouse-gas emissions by more than 80% by 2050. This legislation is currently held up in the US Senate.

- Implementing more aggressive efficiency standards for residential appliances, including microwaves, cookers, dishwashers, light bulbs and other common appliances.

- A new regulatory framework has been established to facilitate the development of alternative energy projects. This will enable the United States to tap into the vast energy potential of its Outer Continental Shelf.

- Steps to catalogue greenhouse-gas emissions from large emission sources. This will for the first time enable transparent measurement, on the basis of which greenhouse-gas emissions reductions can be quantified.

International actions

- Initiating the Major Economies Forum on Energy and Climate (MEF) to create a new dialogue among developed and emerging economies to combat climate change and promote clean energy. This group has 17 member countries. In December 2009, it published a suite of ten Technology Action Plans based on an IEA analysis of global gaps in research, development and demonstration (RD&D) funding.

2. www.majoreconomiesforum.org
Leading an initiative for all G20 nations to phase out their fossil fuel subsidies over the medium term and to work with other countries to do the same. Asia-Pacific Economic Co-operation (APEC) nations have since adopted a similar approach, expanding the number of countries committing to abolishing these subsidies.

Plans for accelerating collaboration with China, India, Mexico, Canada and other international partners to combat climate change, co-ordinate clean energy R&D, and support the international climate talks.

Partnering with neighbours in the western hemisphere to advance energy security and combat climate change. An early product of this co-operation is Chile’s Renewable Energy Centre, which receives technical support from the US DOE.

Box 9.1  Clean energy investment under the 2009 Recovery Act

Under the 2009 Recovery Act, more than USD 90 billion was earmarked for government investment and tax incentives to lay the foundation for a clean energy economy of the future. Over USD 30 billion had been committed and over USD 5 billion had been spent by December 2009 (Table 9.2). Because most of the clean energy investments occur through grants and contracts that require that proposals be reviewed before funds can be expended, only a portion of the appropriation has been spent to date.

The largest investments are in renewable energy generation, energy efficiency, transit, and grid modernisation.

Table 9.2  United States clean energy spending by category

<table>
<thead>
<tr>
<th>(USD millions)</th>
<th>Appropriations</th>
<th>Commitments to December 2009</th>
<th>Spent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy efficiency</td>
<td>19 935</td>
<td>11 913</td>
<td>1 162</td>
</tr>
<tr>
<td>Renewable generation</td>
<td>26 598</td>
<td>1 513</td>
<td>1 479</td>
</tr>
<tr>
<td>Grid modernisation</td>
<td>10 453</td>
<td>2 666</td>
<td>72</td>
</tr>
<tr>
<td>Advanced vehicles and fuel technologies</td>
<td>6 142</td>
<td>3 149</td>
<td>450</td>
</tr>
<tr>
<td>Traditional transit and high-speed rail</td>
<td>18 113</td>
<td>8 834</td>
<td>1 805</td>
</tr>
<tr>
<td>Carbon capture and storage</td>
<td>3 400</td>
<td>425</td>
<td>4</td>
</tr>
<tr>
<td>Green innovation and job training</td>
<td>3 549</td>
<td>2 197</td>
<td>123</td>
</tr>
<tr>
<td>Clean energy equipment manufacturing</td>
<td>1 624</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Other</td>
<td>408</td>
<td>148</td>
<td>12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>90 222</strong></td>
<td><strong>30 859</strong></td>
<td><strong>5 121</strong></td>
</tr>
</tbody>
</table>

Note: Other contains programmes that do not fit in elsewhere.

In terms of jobs saved or created by clean energy investments, the US Council of Economic Advisers (US CEA) estimates that the clean energy segments of the Recovery Act saved or created about 52 000 clean energy jobs and supported another 11 000 jobs throughout the United States.
Overview of scenarios and \( \text{CO}_2 \) abatement options

Significant energy indicators for the United States in the Baseline and BLUE Map scenarios are set out in Table 9.3. In both the Baseline and the BLUE Map scenarios, GDP and population projections are the same. Carbon dioxide emissions reduction potentials are based on an assumed marginal cost of up to USD 175/tonne (t) of \( \text{CO}_2 \) in 2050.

### Table 9.3  
**High-level indicators for the United States**

<table>
<thead>
<tr>
<th></th>
<th>Baseline scenario</th>
<th>BLUE Map scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000</td>
<td>2007</td>
</tr>
<tr>
<td>TPES (Mtoe)</td>
<td>2 350</td>
<td>2 387</td>
</tr>
<tr>
<td>Electricity consumption (TWh)</td>
<td>3 857</td>
<td>4 113</td>
</tr>
<tr>
<td>( \text{CO}_2 ) emissions (Gt)</td>
<td>5.84</td>
<td>5.92</td>
</tr>
<tr>
<td>GDP (USD billion 2000)</td>
<td>9 765</td>
<td>11 468</td>
</tr>
<tr>
<td>Population (millions)</td>
<td>282</td>
<td>302</td>
</tr>
<tr>
<td>TPES/GDP (toe per thousand USD/2000)</td>
<td>0.241</td>
<td>0.208</td>
</tr>
<tr>
<td>TPES/population (toe per capita)</td>
<td>8.5</td>
<td>7.9</td>
</tr>
<tr>
<td>Electricity consumption /population (kWh per capita)</td>
<td>13 657</td>
<td>13 616</td>
</tr>
</tbody>
</table>

**Notes:** TWh = terawatt-hours; international aviation and shipping are included in TPES and \( \text{CO}_2 \) emissions. Source: IEA (2009a).

Energy and \( \text{CO}_2 \) emission scenarios

Total primary energy supply increases by more than 5% between 2007 and 2050 in the Baseline scenario (Figure 9.4). Nuclear and hydro remain fairly constant over the period. Coal use grows from 554 Mtoe to 686 Mtoe a year and biomass including waste grows from 82 Mtoe to 188 Mtoe a year. Oil use declines during the same period from 957 Mtoe to 686 Mtoe a year. The decrease in oil is driven mainly by increased fuel efficiency in the transport sector. Coal remains the primary energy supply source in the Baseline scenario.

In the BLUE Map scenario, TPES reduces by 17% from 2 387 Mtoe to 1 979 Mtoe between 2007 and 2050. The energy mix changes significantly, with nuclear, biomass and waste and renewables playing an increasing role. Coal, oil and natural gas all decline between 2007 and 2050.
Figure 9.4  ▶ Total primary energy supply by fuel for the United States, Baseline and BLUE Map scenarios

Note: Other includes non-combustible renewables and heat. Oil includes international bunkers. Source: IEA (2009a).

Key point
Fossil fuels decline in the BLUE Map scenario both in absolute terms and relative to growth in renewables, nuclear and biomass and waste.

Carbon dioxide abatement options

In the Baseline scenario, CO₂ emissions in the United States are estimated to grow from 5.9 gigatonnes (Gt) in 2007 to 6.0 Gt in 2050 (Figure 9.5).

Figure 9.5  ▶ Contribution to emissions reductions in the United States

Note: Unless otherwise indicated, all material derives from IEA data and analysis.

Key point
Efficiency improvements, fuel switching and CCS make the largest contributions to CO₂ reductions by 2050.
In the BLUE Map scenario, energy efficiency improvements, fuel switching and CCS enable the United States to reduce its CO₂ emissions from 5.9 Gt in 2007 to approximately 1.1 Gt by 2050. This is 81% lower than in the Baseline scenario in 2050. The largest savings come from end-use fuel and electricity efficiency (36%), end-use fuel switching (16%), CCS in power generation, industry and other transformation (18%), renewables (18%) and nuclear power (9%). All of these technologies would need to be implemented to achieve the contribution the United States needs to make to play its part in achieving a 50% reduction in global emissions by 2050.

**Sectoral results**

**Power sector**

**The US electricity system today**

The continental United States comprises a vast area, diverse in geography, climatic conditions and energy resources. As a consequence, the availability and price of access to energy sources vary across the country. Coal is abundant and widely available across much of the country. The most prolific mining areas are the Powder River basin in Wyoming and the Appalachian range, which stretches from Alabama to Pennsylvania. An extensive infrastructure of railways, barges and trucks transports the coal from the mines to end users, making coal available in most parts of the country. Because of the high availability and relatively low cost of coal, coal-fired thermal power plants form the backbone of the United States power system, currently supplying almost half (49%) of the nation’s electricity.

Natural gas is also widely available throughout the country. The main production areas are the Gulf Coast, the Mexico Gulf outer continental shelf, West Texas, Oklahoma, the Rocky Mountain region, the Appalachian basin, the Sacramento and Los Angeles basins in California and Alaska. A vast pipeline network covers most of the country and makes natural gas available to customers in virtually all parts of the country. The last few years have seen a marked increase in natural gas production as new drilling and fracturing techniques have made it possible economically to produce shale gas. Natural gas generation often serves as mid-merit or peaking generation and is often the marginal production technology, setting electricity prices. Natural gas generation comprises roughly 21% of total generation with annual totals being highly dependent on natural gas prices.

There are over 100 nuclear power stations in operation in the United States today, most of them located in the eastern parts of the country. They supply roughly 20% of the nation’s electricity. Although no new nuclear power project has been undertaken since the 1979 Three-Mile Island incident, there is growing interest in constructing new nuclear plants. Currently, more than 30 new nuclear units are under consideration, with licence applications having been submitted for 22 of these by the end of 2009 to the United States Nuclear Regulatory Commission.
United States electricity utilities generated 4 322 terawatt-hours (TWh) of electricity in 2007. Of this, 21.2% was from natural gas plants, 48.9% from coal, 19.4% from nuclear, 5.8% from hydro, 1.8% from oil and 3% from renewables (Figure 9.6).

**Key point**

Fossil fuels continue to be the primary source of electricity generation today.

Growth in electricity consumption has been led by the commercial and residential sectors, in which electricity consumption accounts for almost three-quarters of the energy used. The industrial sector accounted for 25% of electricity use in 2007 and the transport sector a negligible amount of less than 1%.

Strong growth in the commercial buildings sector is predicated on a continued rise in service industries. Growth in the residential sector is driven by a growing population, which needs more cooling as it continues to shift to warmer regions, and by per-capita floor space increases. The EIA estimates that approximately 300 GW of new generating capacity will be needed to service this increased demand by 2030. In addition, a large part of the current installed capacity will have to be replaced and modernised over the next ten years, at the same time as significant new investment in electricity networks will be required.

In terms of capacity utilisation, in 2007 nuclear plants operated at about 90% capacity and coal plants at around 73%, indicating high levels of baseload demand. Gas has a very low capacity factor of around 22%, indicating that the role of gas in the system is to act primarily to supply medium- and peak-power demand, especially in summer. Hydro availability has been constrained in recent years by dry conditions in several regions.
Natural gas continues to be viewed as the most promising and economically feasible energy source to meet future power demand. Natural gas prices are relatively low and capital costs are lower than for other plant types. Gas-fired power plants represent about half of new capacity currently under construction, and most capacity additions over the next decade are expected to be gas-fired.

There are 12.5 GW of coal-fired plants currently under construction for entry into service between 2009 and 2011. New coal-fired plants are expected to make up more than half of all capacity additions between 2006 and 2030. The EIA’s Annual Energy Outlook 2007 estimates that demand will grow by 400 TWh between 2006 and 2012 and that 250 TWh of this demand will be met by new combined-cycle gasification turbine (CCGT) plant.

Developments in renewable power generation

Renewable electricity generation accounted in 2008 for around 9% of total electricity production, with the bulk of this (6%) coming from hydroelectric power plants. Wind generation has expanded rapidly over the past few years and accounted in 2008 for 1.3% of total electricity generation. Biomass generation, including co-firing at coal power stations, accounts for around 1% of the total. Geothermal, municipal solid waste and solar make up the balance.

Wind power is available throughout most of the country, but suitable areas with high average wind speeds are concentrated predominantly in the northern and western parts of the United States. The Pacific north-west and mid-west in particular have considerable potential for the development of wind power. The south-eastern United States, on the other hand, has relatively poor wind resources. Offshore wind resource potential is high along the coastlines and on the Great Lakes, but some areas are protected and off-limits to developers.

Insolation is stronger in the south than in the north and also generally higher in the west than in the east. The deserts of California, Arizona, New Mexico and Nevada are prime locations for solar power. Areas suitable for concentrating solar power (CSP) are mainly found in the south-west where large undeveloped land areas are available. Investments in, and installations of, photovoltaic (PV) panels are heavily influenced by the incentives offered by state governments and a significant share of PV installations are in states that are not typically considered to be sun-rich, such as New Jersey.

Sites suited for geothermal power generation are exclusively located in the western United States. Many identified sites have not yet been developed. The resource potential could be greatly expanded through enhanced geothermal systems and engineered reservoirs if this technology proves to be viable and cost-effective.

Biomass in some form is available in most of the country, but more in the east than in the west and least in the arid south-west. The availability of woody biomass is highest in the south and south-east. The power sector is in direct competition with the forestry industries for this resource and may also see competition for biomass resources from the cellulosic biofuel industry in the future.
Regional electricity supply in 2007

Because of the vast size of the continental United States, power is delivered through a series of systems, rather than through a single unified grid. Most of these systems have strong interconnections with neighbouring systems, although some are relatively isolated. The ability to transport power between and across systems is limited by infrastructure constraints. As a result there may be instances of stranded resources where a cheap and abundant resource cannot be fully used because the local demand is not large enough and the infrastructure to transport it to other markets is not in place. Tackling such infrastructure constraints has been identified as a priority by the federal government. Federal agencies have been given the additional responsibility to increase transmission infrastructures in congested corridors. But local opposition to new transmission capacity may remain an impediment to renewable power capacity expansion.

Regional differences are not merely physical but also regulatory. Electricity utilities are regulated by state utility commissions (or by local governments in the case of municipal utilities) and regulatory and market structures differ between states. Some states have been slow to deregulate their power markets and still rely on vertically integrated monopoly utilities. Others have introduced some level of competition in generation and power marketing. Wholesale markets for electricity are regulated by the FERC.

Differences in resource availability and costs, existing infrastructures, market structures and regulation mean that climate policies will vary in their regional impact. Resource availability, existing infrastructure and regulation will influence the regional cost of the power sector mitigation options. Market structures will affect the way in which policy interventions promote greenhouse gas mitigation by power producers and the regional effectiveness of individual policy measures.

Electricity transmission and distribution

The US electricity transmission grid consists of more than 200 000 miles of high-voltage (230 kilovolt [kV] and higher) transmission lines. The national average price of electricity increased by 19.7% from US 7.6 cents per kilowatt hour (kWh) in 2004 to US 9.1 cents per kWh in 2007. Much of this increase is attributable to increases in fuel costs as well as the expiration of transitional rate caps in a number of states that had introduced retail competition into their electricity markets.

The US bulk power system is based on three major interconnected power grids within which regional transmission organisations and independent system operators operate transmission systems. Virtually all utilities are interconnected to at least one other utility by these three major grids. The exceptions are in Alaska and Hawaii. Two of these major grids are linked to Mexico and two are completely integrated with the Canadian grid or have links to the Québec Province power grid.

The bulk power system makes it possible for utilities to engage in wholesale electric power trades. These enable utilities to reduce power costs, to increase power supply options and to improve reliability. With open access and the deregulation of wholesale markets, cross-border trade has become more significant in meeting
domestic electricity requirements. United States international trades are mostly imports, predominantly from Canada.

The management of the interconnected power systems is the responsibility of the NERC. The NERC has eight regional entities which are responsible for overall co-ordination of bulk power policies that affect the reliability and adequacy of electricity service in their areas. They also regularly exchange operating and planning information among their member utilities.

In 2008, 14 states operated retail markets in which customers could choose alternative power suppliers. Eight other states have suspended deregulation or amended laws and regulations governing competition and energy procurements by regulated utilities because of the lack of competition for residential customers and the substantial rate increases that have occurred or were anticipated to occur as a result of the introduction of retail competition. Other states have retained retail competition while relaxing their controls on vertical integration between generation and supply, or created new government-owned energy suppliers.

The Energy Independence and Security Act of 2007 provided a legislative framework for transmission system modernisation, including smart grid expansion, tax incentives for investment, and federal funding for R&D.

Renewable energy sources other than conventional hydro accounted for the largest proportion of capacity additions for the first time in 2007. Wind, solar and geothermal power capacity is constrained to specific and often remote parts of the country. As a result, these capacity additions have created a need for new high-voltage transmission lines to transport their output to markets. In response, merchant transmission companies are being formed to serve renewable energy suppliers and their wholesale customers.

**Electricity demand scenarios**

Electricity consumption in the United States has increased by 7% between 2000 and 2007, driven by strong residential and commercial demand. The final electricity demand projections by end-use sectors in the Baseline and BLUE Map scenarios are shown in Table 9.4.

In both scenarios, electricity consumption is expected to continue to rise as the US economy recovers from the current recession and as consumer demand and industrial productivity recover. In the Baseline scenario in 2050, final electricity consumption is 34% higher than in 2007. In the BLUE Map scenario, it increases by 7% compared to 2007. This is 20% lower than the Baseline scenario level of consumption. The reduction is achieved by higher levels of industrial energy efficiency and more efficient lighting and air conditioners in the building sector, and by the deployment and commercialisation of electric vehicles (EVs). Electric vehicles represent a 33% share of the sale of new vehicles in 2050. As a result of the demand from EVs offsetting reductions in electricity consumption in other sectors, electricity consumption in 2050 is higher in the BLUE Map scenario than in 2007.

---

Table 9.4  Current and projected final electricity demand in the United States by end-use sector

<table>
<thead>
<tr>
<th>(TWh/yr)</th>
<th>Baseline 2007</th>
<th>Baseline 2030</th>
<th>Baseline 2050</th>
<th>BLUE Map 2030</th>
<th>BLUE Map 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>929</td>
<td>865</td>
<td>812</td>
<td>656</td>
<td>611</td>
</tr>
<tr>
<td>Transport</td>
<td>8</td>
<td>19</td>
<td>26</td>
<td>162</td>
<td>665</td>
</tr>
<tr>
<td>Residential</td>
<td>1 392</td>
<td>1 722</td>
<td>1 956</td>
<td>1 190</td>
<td>1 285</td>
</tr>
<tr>
<td>Commercial</td>
<td>1 337</td>
<td>2 047</td>
<td>2 319</td>
<td>1 559</td>
<td>1 530</td>
</tr>
<tr>
<td>Agriculture and other</td>
<td>160</td>
<td>23</td>
<td>30</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td>Total</td>
<td>3 826</td>
<td>4 676</td>
<td>5 143</td>
<td>3 584</td>
<td>4 109</td>
</tr>
</tbody>
</table>

Sources: IEA (2008a); IEA analysis.

Electricity generation scenarios

Installed capacity in the United States in 2007 amounted to 1 039 GW. Total capacity in 2050 is projected to be broadly similar in both the Baseline and BLUE Map scenarios with capacities of 1 548 GW and 1 477 GW, respectively (Table 9.5). In the Baseline scenario, fossil fuels represent 72% of total generation in 2050. In the BLUE Map scenario this is 22%. Additionally, in the BLUE Map scenario, 68 GW of coal capacity and 95 GW of gas capacity are fitted with CCS, 225 GW is from nuclear, and 409 GW is from renewables in 2050.

Table 9.5  United States power generation mix and capacity in the Baseline and BLUE Map scenarios, 2050

<table>
<thead>
<tr>
<th>Power generation share</th>
<th>Baseline (%</th>
<th>BLUE Map (%)</th>
<th>Baseline (GW)</th>
<th>BLUE Map (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>57</td>
<td>0</td>
<td>497</td>
<td>0</td>
</tr>
<tr>
<td>Coal with CCS</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>68</td>
</tr>
<tr>
<td>Gas</td>
<td>14</td>
<td>5</td>
<td>582</td>
<td>432</td>
</tr>
<tr>
<td>Gas with CCS</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>95</td>
</tr>
<tr>
<td>Biomass</td>
<td>2</td>
<td>12</td>
<td>14</td>
<td>84</td>
</tr>
<tr>
<td>Oil</td>
<td>1</td>
<td>1</td>
<td>87</td>
<td>86</td>
</tr>
<tr>
<td>Nuclear</td>
<td>12</td>
<td>35</td>
<td>93</td>
<td>225</td>
</tr>
<tr>
<td>Hydro</td>
<td>5</td>
<td>6</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td>Geothermal</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Solar</td>
<td>3</td>
<td>7</td>
<td>85</td>
<td>132</td>
</tr>
<tr>
<td>Wind</td>
<td>6</td>
<td>16</td>
<td>108</td>
<td>261</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>1 548</td>
<td>1 477</td>
</tr>
</tbody>
</table>

Decarbonising the power sector in the United States

Decarbonising the US power system will require higher levels of renewable and nuclear power generation capacity and CCS for coal, gas and bio-fired plants. It will take time to build up the country’s nuclear and renewable power capacity. As a
result, coal will likely continue to account for a large share of the US electricity mix for the next several decades.

In the BLUE Map scenario, a more radical rebuilding of the capital stock results in power sector carbon emissions declining by over 90% compared to 2010 levels. Virtually all existing generation assets are replaced by 2050. The generation mix is dominated by low-carbon technologies such as wind, solar, biomass and nuclear (Figure 9.7). By 2050, 43% of total generation is renewable and 35% nuclear. Steam coal generation is phased out by 2050. This leaves a demand for new baseload generation, which in the BLUE Map scenario is largely met by a doubling of the installed capacity of nuclear generation. Some integrated gasification combined cycle (IGCC) plants with CCS are also built. Gas- and coal-fired generation with CCS accounts for about 16% of total generation.

**Figure 9.7** Renewable power generation mix by region in the United States, 2007

Wind power capacity increases by a factor of six between 2007 and 2050 in BLUE Map scenario. Solar generation also expands rapidly from a virtually negligible contribution today to 7% in 2050. In the BLUE Map scenario, large-scale central solar plants tend to be concentrated in the south-west. Distributed rooftop PV installations are more widely dispersed across the United States, but
also particularly strongly represented in the western and south-western parts of the country (Figure 9.8).

The geothermal resource base remains relatively underdeveloped in all scenarios. Conventional resources are developed in the BLUE Map scenario, but there is little or no development of enhanced geothermal systems.

The high share of non-dispatchable renewable generation will require a significant amount of electricity storage both to cover for a shortfall in generation when variable resources are unavailable and to ensure that electricity generated during times of high production does not go to waste. In the BLUE Map scenario, 150 GW of storage is installed by 2050 in addition to the 22 GW of pumped storage plants that are currently in service.

The large increase in more dispersed renewable generation will also require significant upgrade and extension of the transmission network. As solar and wind expand, additional natural gas-fired generating capacity will be required to firm up capacity and provide enough flexibility to ensure system stability. The concentration of renewable capacity in areas which may have relatively low levels of local demand is likely to lead to additional stranded resources that will need new transmission capacity to get to market.

**Figure 9.8** Power generation mix by region in the United States in the BLUE Map scenario, 2050

![Map showing power generation mix by region in the United States in the BLUE Map scenario, 2050.]

The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

**Key point**

Different regions will produce markedly different amounts of renewable generation from very different mixes of inputs by 2050.
Industry sector

Industry accounted for the use of 400 Mtoe in 2007, 25% of total US final energy use. The United States is the third-largest industrial energy consumer, accounting for 13% of global industrial energy use. The final energy mix of industry is dominated by oil and natural gas (Figure 9.9). Industry accounts for 24% of total final electricity consumption. Electricity represents 20% of industrial final energy use.

Figure 9.9  Industrial final energy mix in the United States and in the world, 2007

Note: Includes coke ovens, blast furnaces and petrochemical feedstocks.
Sources: IEA (2009a and 2009b).

Key point

The United States continues to rely on fossil fuels in the industrial sector.

Table 9.6  Industrial production, energy use and CO₂ emissions in the United States, 2007

<table>
<thead>
<tr>
<th>Production (Mt)</th>
<th>Reported energy use (Mtoe)</th>
<th>CO₂ emissions (Mt CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry sector</td>
<td>400</td>
<td>690</td>
</tr>
<tr>
<td>Iron and steel</td>
<td>98</td>
<td>31</td>
</tr>
<tr>
<td>Chemicals and petrochemicals</td>
<td>97</td>
<td>178</td>
</tr>
<tr>
<td>Aluminium</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Cement</td>
<td>97</td>
<td>11</td>
</tr>
<tr>
<td>Pulp, paper and printing</td>
<td>57</td>
<td>62</td>
</tr>
<tr>
<td>Paper and paperboard</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>Pulp</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Recovered paper</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>117</td>
<td>197</td>
</tr>
</tbody>
</table>

Notes: Iron and steel includes energy use for coke-making. The energy data for chemicals and petrochemicals include feedstocks. The table has been compiled from a mixture of top-down and bottom-up sources and so the totals may not match.
Sources: IEA (2009a and 2009c), IEA analysis.
The United States is the largest producer of chemicals and pulp and paper in the world, and the third-largest producer of steel and cement (Table 9.6). With over half of industrial energy use and approximately 45% of industrial direct emissions attributed to the chemicals and pulp and paper sectors, reducing industrial energy use and CO₂ emissions in the United States will depend significantly on action in these sectors. Realising the potential offered from energy efficiency will require the diffusion of current best available technology (BAT) in both sectors.

**Energy and CO₂ savings potential with best available technologies**

Significant energy and CO₂ savings in US industry are possible through the implementation of currently available BATs. It is estimated that the application of BATs could reduce final energy use by between 18% and 36% in different sectors. Total estimated savings for the five sectors analysed is 92 Mtoe per year, equivalent to 23% of energy use in industry in 2007 and 6% of final energy consumption in the United States.

For chemicals, cement, and pulp and paper, the United States has a higher-than-average potential to achieve savings, while for aluminium and iron and steel the potential is less than the global average. Typically 10% to 30% efficiency gains seem feasible, on account of the gap between United States average energy use and BATs. Part of this gap will be closed by investment in new capital stock as old capacity is scrapped and replaced by current BATs.

It will not be possible to achieve these savings immediately. The rate of implementation of BATs in practice depends on a number of factors, including capital stock turnover, relative energy costs, raw material availability, rates of return on investment and regulation.

**Scenarios for industrial energy use and CO₂ emissions**

As a result of increased energy efficiency measures and some reductions in industrial production, energy use in US industry declines slightly from current levels in the Baseline scenarios. In the BLUE scenarios, even greater levels of energy efficiency are assumed. These enable a larger reduction in industrial energy use, resulting in a decrease of 30% to 33% in the BLUE low- and high-demand scenarios compared to 2007 levels and of 28% to 31% compared to the Baseline scenario (Figure 9.10).

In the Baseline low- and high-demand scenarios, US industry emissions are 5% lower in 2050 than in 2007. Total industrial CO₂ emissions fall from 690 Mt CO₂ in 2007 to approximately 658 Mt CO₂ in Baseline 2050 (Table 9.7). In the BLUE scenarios, total industrial CO₂ emissions fall even further to 242 Mt CO₂ to 283 Mt CO₂ in 2050, a reduction of 63% to 67% as against the comparable Baseline scenario levels.

Energy efficiency offers the largest potential to reduce industrial CO₂ emissions (Figure 9.11), representing almost half (48%) of all emissions reductions in the BLUE scenarios. Fuel and feedstock switching, together with higher levels of recycling and energy recovery, contribute another 23%. The remaining 28% is accounted for by CCS.
Figure 9.10  Industrial energy use in the United States, Baseline and BLUE scenarios

<table>
<thead>
<tr>
<th>Year</th>
<th>Baseline low 2050</th>
<th>Baseline high 2050</th>
<th>BLUE low 2050</th>
<th>BLUE high 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mt CO₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminium</td>
<td>3</td>
<td>6</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Iron and Steel</td>
<td>91</td>
<td>95</td>
<td>97</td>
<td>26</td>
</tr>
<tr>
<td>Chemicals</td>
<td>250</td>
<td>335</td>
<td>329</td>
<td>155</td>
</tr>
<tr>
<td>Cement</td>
<td>87</td>
<td>101</td>
<td>104</td>
<td>58</td>
</tr>
<tr>
<td>Pulp and paper</td>
<td>62</td>
<td>47</td>
<td>48</td>
<td>5</td>
</tr>
<tr>
<td>Other</td>
<td>197</td>
<td>74</td>
<td>74</td>
<td>34</td>
</tr>
<tr>
<td>Total</td>
<td>690</td>
<td>657</td>
<td>658</td>
<td>283</td>
</tr>
</tbody>
</table>

Sources: IEA (2009a and 2009c); IEA analysis.

Key point
Energy use in US industry declines significantly in the BLUE scenarios.

Table 9.7  Direct energy and process CO₂ emissions by industry in the United States

<table>
<thead>
<tr>
<th>Industry</th>
<th>2007</th>
<th>Baseline low 2050</th>
<th>Baseline high 2050</th>
<th>BLUE low 2050</th>
<th>BLUE high 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>3</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Iron and Steel</td>
<td>91</td>
<td>95</td>
<td>97</td>
<td>26</td>
<td>22</td>
</tr>
<tr>
<td>Chemicals</td>
<td>250</td>
<td>335</td>
<td>329</td>
<td>155</td>
<td>134</td>
</tr>
<tr>
<td>Cement</td>
<td>87</td>
<td>101</td>
<td>104</td>
<td>58</td>
<td>43</td>
</tr>
<tr>
<td>Pulp and paper</td>
<td>62</td>
<td>47</td>
<td>48</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>197</td>
<td>74</td>
<td>74</td>
<td>34</td>
<td>36</td>
</tr>
<tr>
<td>Total</td>
<td>690</td>
<td>657</td>
<td>658</td>
<td>283</td>
<td>242</td>
</tr>
</tbody>
</table>

Sources: IEA (2009a); IEA analysis.

Figure 9.11  Options for reducing direct CO₂ emissions from United States industry

Key point
Energy efficiency offers the most important opportunity to limit growth in industrial CO₂ emissions.
Best available technologies offer significant opportunities for improvement in industrial energy efficiency in the United States. Further reductions in greenhouse-gas emissions from industry can be realised through reductions in process-related emissions, fuel switching to lower-carbon fuels, and integrated pollution prevention and material efficiency improvements (Price and Worrell, 2004).

Many energy-intensive industries in the United States are relatively inefficient when compared to their counterparts in Europe, Japan, Canada, or to rapidly industrialising countries such as South Korea and China. The US DOE’s Industrial Technologies Program has established a goal to reduce industry energy intensity by 25% in ten years and to contribute to an 18% reduction in carbon intensity by 2012.

The DOE provides national leadership through collaborative technology R&D and the development of best energy management practices, promotes better energy management in industry, and encourages investment in energy efficiency through strategic partnerships with states, utilities, businesses and the financial community. The DOE’s Industries of the Future (IOF) programme has worked with ten industrial sectors to identify the most promising technologies and practices to receive further R&D funding. Each sector has identified around 100 to 150 technologies or processes to be funded. The DOE expects to save 50 Mtoe of energy and avoid 135 Mt CO₂-eq by 2020.

**Buildings sector**

The residential and service sectors account for about 30% of total final energy consumption in the United States, somewhat less than the global average. Including energy consumption from agriculture, fishing, forestry and other non-specified uses raises this to 32%.

Since 1995, the consumption of the residential sector has grown at 0.6% a year from 248 Mtoe to 267 Mtoe in 2007. Consumption in the service sector has grown by 1.9% a year to 218 Mtoe in 2007 (Figure 9.12). The growing importance of electrical end uses is underlined by the growth in consumption of electricity at 3.1% a year between 1995 and 2007, with electricity accounting for 49% of energy consumption in 2007, up from 41% in 1990.

The consumption of energy for space heating has remained relatively stable over time owing to increased demand being offset by improved building shells and heating system efficiencies. The share of energy consumption taken by appliances and lighting (excluding air-conditioning) has increased from 17% in 1978 to 26% in 2006 (US DOE, 2009). In the service sector, electrical end uses, excluding air-conditioning, account for around 32% of the sector’s energy use. Including air-conditioning raises this to 41%. Electrical end uses are projected to continue to grow in the future and remain the main driver of energy consumption growth in the buildings sector as a whole.

---

4. In this section, the buildings sector is defined as including the residential, service and other non-specified sectors. “Other non-specified” activities are included in the service sector, which is consistent with the treatment in the World Energy Outlook. In 2007, “other non-specified” accounted for 14 Mtoe.
Figure 9.12 Residential and service sectors energy consumption by fuel in the United States


Key point

Electricity accounts for almost half of residential and services energy consumption and is the only energy commodity to have shown significant growth since 2000.

The United States has a very diverse building stock, with a significant proportion of older homes. The number of households has grown from 94 million to 113 million between 1990 and 2006, and the average number of persons per household has declined from 2.9 to 2.7 in that time. Single-family dwellings make up 69% of households, multi-family dwellings 25% and mobile homes 6%.

Energy consumption by end use

The estimated breakdown of energy consumption by end use is presented in Figure 9.13. In the residential sector, space heating dominates, accounting for 44% of energy consumed. The high growth in electricity consumption means that the electrical end-use share of the total is growing.
In the service sector, space heating represents around one-fifth of consumption, while electrical end uses represent a higher proportion of energy consumption. Lighting is particularly important, consuming almost as much energy as space heating.

**Figure 9.13** Residential and service sectors energy consumption by end use in the United States, 2007

<table>
<thead>
<tr>
<th>End Use</th>
<th>Residential 267 Mtoe</th>
<th>Services 218 Mtoe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating</td>
<td>44%</td>
<td>21%</td>
</tr>
<tr>
<td>Water heating</td>
<td>16%</td>
<td>3%</td>
</tr>
<tr>
<td>Lighting</td>
<td>7%</td>
<td>9%</td>
</tr>
<tr>
<td>Cooking</td>
<td>4%</td>
<td>9%</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>Wet clean</td>
<td>4%</td>
<td>5%</td>
</tr>
<tr>
<td>Electronics</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>Computers</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>Other</td>
<td>7%</td>
<td>26%</td>
</tr>
</tbody>
</table>


**Key point**

Space heating and cooling consume over half of all energy consumption in the residential sector, and lighting and space cooling and heating consume nearly half the energy consumed in the service sector.

**Scenarios for buildings energy use and CO₂ emissions**

The US population is projected to grow from around 306 million in 2007 to around 404 million in 2050. The number of households will grow even faster, as the trend towards fewer persons per household continues. Total households will grow to 141 million in 2030 and to 161 million in 2050. In the service sector, floor area is assumed to grow by 1.1% a year from around 6,950 million square metres (m²) in 2006 to 11,330 million m² in 2050.

**The Baseline scenario**

The US buildings sector is one of the most energy-intensive of the 19 IEA countries for which good data are available. However, energy consumption is on a downward trend, with consumption declining from 45 gigajoules (GJ) per household in 1990 to 42 GJ per household in 2006.
The United States has a range of policies and programmes in place to address energy consumption in the residential and service sectors. These include the Energy Star labelling programme, the DOE Appliance Standards Program and the Buildings Technologies Program (IEA, 2008). The Recovery Act included USD 16.8 billion for the Office of Energy Efficiency and Renewable Energy (Pew Center, 2009). This included a USD 5 billion allocation for the DOE’s weatherisation programme over two years to help low-income households improve the energy efficiency of their homes. These programmes have been taken into account in the Baseline scenario.

Energy consumption in the residential and service sectors increases by 32% between 2007 and 2050 in the Baseline scenario (Figure 9.14). The use of solar energy grows the most rapidly at 4.4% a year, followed by electricity at 1.0% a year, heat at 0.6% a year and gas at 0.2% a year. Coal consumption declines by 2.7% per year and oil by 1.0% per year.

**Figure 9.14** Energy use in the buildings sector in the Baseline and BLUE Map scenarios in the United States

Energy efficiency and fuel switching reduce energy demand in buildings in the BLUE Map scenario.

**The BLUE Map scenario**

In the BLUE Map scenario, energy consumption in the residential and service sectors is 29% below the Baseline level in 2050. Energy consumption reduces to slightly below 2007 levels in 2015 and continues to decline slightly between 2030 and 2050. Despite growing energy service demand, energy efficiency measures and fuel switching achieve most of these savings. Gas consumption reduces by the most in percentage terms (58%) and absolute terms (115 Mtoe) as the result of improved building shell performance for new and renovated dwellings and
improved heating system efficiency, and as the use of CO₂-free fuel sources such as hydrogen combined heat and power (CHP), solar thermal and heat pumps increases for heating. Electricity demand reduces by slightly less in absolute terms (126 Mtoe), representing a 34% reduction below the Baseline scenario level in 2050. Oil consumption is also significantly reduced in percentage terms in the BLUE Map scenario. The use of solar thermal energy for space and water heating increases significantly to 47 Mtoe in 2050, a level more than three times higher than in the Baseline scenario in 2050.

Residential energy consumption accounts for slightly more than half of the total savings below the Baseline, as the larger share of space heating in the residential sector allows slightly larger cost-effective savings than in the service sector.

In the residential sector, 45% of the savings come from space and water heating. For space heating, the savings stem from improvements in the performance of the building shell, including a gradual tightening of the building codes for new buildings towards very low space heating requirements in cold climate states as well as the renovation of around 60% of the existing dwelling stock by 2050 to a low-energy standard. The use of solar water heating and heat pumps for both space and water heating also contribute significant savings. Electrical end uses account for around half of the savings. The reduction in cooling demand is achieved through a mixture of building shell improvements and cooling system improvements. The coefficient of performance (COP) of room air conditioners, for instance, approximately doubles to reach seven by 2050.5

In the service sector, water and space heating account for less than one-fifth of the savings. Very significant savings are achieved in the electricity-intensive end uses of cooling, lighting and other miscellaneous loads.

Buildings-sector CO₂ emissions are 35% lower in the BLUE Map scenario in 2050 than in the Baseline scenario. CO₂ emissions from oil are reduced by 50%, those from gas by 59% and those from electricity by 31%. Overall CO₂ emissions are reduced by 1 061 Mt CO₂ below the Baseline level in 2050, with 748 Mt CO₂ of this reduction attributable to reduced consumption of electricity. Electricity use is marginally increased from what it otherwise would be by the switching from fossil fuels to electricity for cooking and water and space heating in the BLUE Map scenario, as the substantial decarbonisation of the electricity sector allows electrification to become an increasingly effective abatement option.

Space and water heating accounts for around 24% of the reduction in CO₂ emissions below the Baseline scenario in 2050 (Figure 9.15). The assumed continuous tightening of building codes and standards results in accelerated savings after 2030. Important contributions are also achieved by solar thermal, heat pumps and CHP district heating. Energy efficiency improvements in lighting, appliances and miscellaneous end uses account for 24% of the reduction below the Baseline level.

5. The COP of a heat pump is the ratio of useful energy output (heat or cold) to energy input (typically electricity).
The CO₂ emissions reductions from cooling are around 31% of the total, with around two-thirds coming from improvements in the efficiency of heating, ventilation and air-conditioning (HVAC) systems, and the balance from improvements in building shells and design, including the increased use of shading and active shutters, reflective coatings and insulation.

**Figure 9.15** Contributions to reductions in CO₂ emissions in the buildings sector in the United States in the BLUE Map scenario

<table>
<thead>
<tr>
<th>Year</th>
<th>Cooking, lighting and appliances</th>
<th>Fuel switching to biofuels</th>
<th>Building shell</th>
<th>Cooling</th>
<th>Other efficiency</th>
<th>Solar thermal</th>
<th>CHP</th>
<th>Heat pumps</th>
<th>Electricity decarbonisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>0.0 Gt</td>
<td>0.0 Gt</td>
<td>0.0 Gt</td>
<td>0.0 Gt</td>
<td>0.0 Gt</td>
<td>0.0 Gt</td>
<td>0.0</td>
<td>0.0 Gt</td>
<td>0.0 Gt</td>
</tr>
<tr>
<td>2020</td>
<td>0.5 Gt</td>
<td>0.5 Gt</td>
<td>0.5 Gt</td>
<td>0.5 Gt</td>
<td>0.5 Gt</td>
<td>0.5 Gt</td>
<td>0.5</td>
<td>0.5 Gt</td>
<td>0.5 Gt</td>
</tr>
<tr>
<td>2030</td>
<td>1.0 Gt</td>
<td>1.0 Gt</td>
<td>1.0 Gt</td>
<td>1.0 Gt</td>
<td>1.0 Gt</td>
<td>1.0 Gt</td>
<td>1.0</td>
<td>1.0 Gt</td>
<td>1.0 Gt</td>
</tr>
<tr>
<td>2040</td>
<td>1.5 Gt</td>
<td>1.5 Gt</td>
<td>1.5 Gt</td>
<td>1.5 Gt</td>
<td>1.5 Gt</td>
<td>1.5 Gt</td>
<td>1.5</td>
<td>1.5 Gt</td>
<td>1.5 Gt</td>
</tr>
<tr>
<td>2050</td>
<td>2.0 Gt</td>
<td>2.0 Gt</td>
<td>2.0 Gt</td>
<td>2.0 Gt</td>
<td>2.0 Gt</td>
<td>2.0 Gt</td>
<td>2.0</td>
<td>2.0 Gt</td>
<td>2.0 Gt</td>
</tr>
</tbody>
</table>

**Key point**
Carbon dioxide savings accelerate from 2015 onwards.

**Transport sector**

In the United States, the transport sector used 668 Mtoe in 2007, accounting for 40% of total final energy used in the country. This share is large compared to other OECD countries. Light-duty vehicles account for nearly two-thirds of transport energy use, with freight trucks and air travel accounting for most of the rest (Figure 9.16).

A breakdown of transport indicators by mode, including activity, intensity and fuel use variables is shown in Table 9.8. The United States has a higher share of passenger travel by LDVs (82%) than any other country or region, with air travel accounting for most of the rest (14%). For freight, the United States has an almost equal split between trucks and rail in terms of tonne-kilometres (tkm). Most other countries, except Russia and China, have much greater tkm shares for trucks than rail. This suggests that rail freight has particular benefits over long distances.

---

6. Includes pipelines and international bunkers.
**Figure 9.16** Transport sector final energy use by mode in the United States and in the world, 2007

United States 668 Mtoe

World 2 220 Mtoe

**Notes:** Freight shipped by air, rail, road and water includes an estimate of international trips starting from the United States. Energy use for pipeline transport is excluded.

Sources: IEA (2009a and 2009b); IEA analysis.

**Key point**

Light-duty vehicles in the United States use a far higher share of transport energy than the world average.

The average energy intensity per passenger-kilometre (pkm) for LDVs is similar to that for air, and much larger than that for buses and rail. For freight, trucks are much more energy-intensive than rail. Although long-haul trucks are much more efficient than other types of trucks, a shift even from long-haul trucks to rail would achieve significant energy efficiencies.

**Table 9.8** Transport energy and CO₂ indicators in the United States, 2007

<table>
<thead>
<tr>
<th></th>
<th>Passenger travel</th>
<th>Freight travel</th>
<th>Stock average energy intensity</th>
<th>Fuel use</th>
<th>Passenger</th>
<th>Freight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(billion pkm)</td>
<td>(billion tkm)</td>
<td>(MJ/pkm)</td>
<td>(MJ/tkm)</td>
<td>(Mtoe)</td>
<td>(Mt CO₂)</td>
</tr>
<tr>
<td>LDVs</td>
<td>5 879</td>
<td>3.1</td>
<td>442</td>
<td>1 484</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-3-wheeler</td>
<td>19</td>
<td>1.6</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buses</td>
<td>234</td>
<td>1.2</td>
<td>7</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freight trucks</td>
<td>1 426</td>
<td>3.6</td>
<td>122</td>
<td>429</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rail</td>
<td>36</td>
<td>0.6</td>
<td>0.2</td>
<td>10</td>
<td>2</td>
<td>36</td>
</tr>
<tr>
<td>Air</td>
<td>1 001</td>
<td>2.4</td>
<td>57</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>n.a.</td>
<td>n.a.</td>
<td>29</td>
<td>108</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total/average</td>
<td>7 169</td>
<td>3 274</td>
<td>3.0</td>
<td>1.7</td>
<td>668</td>
<td>1 709</td>
</tr>
</tbody>
</table>

**Note:** In the totals row, averages are provided for intensity figures and are weighted across modes.

Sources: IEA (2009d); IEA analysis.
Scenarios for transport energy use and CO₂ emissions

**Baseline scenario**

Given current high levels of travel per capita and relatively energy-intensive vehicle stocks in the United States, there is considerable scope to save fuel in transport. In the Baseline scenario, transport energy use is roughly flat between 2010 and 2050, with a slight decrease to 2030 as a result of a planned tightening of CAFE standards and a slight increase thereafter (Figure 9.17).

By mode, the biggest growth in the Baseline scenario is in air travel. Light-duty vehicle energy use declines slightly over time. As in other regions, the availability of conventional oil declines after 2030, and increasing amounts of unconventional oil, synthetic fuels such as gas-to-liquids (GTL), coal-to-liquids (CTL) and biofuels are used.

**Figure 9.17** United States transport energy use by fuel in the Baseline and BLUE scenarios

![United States transport energy use by fuel in the Baseline and BLUE scenarios](image_url)

Source: IEA Mobility Model.

**Key point**

*United States energy use is expected to remain roughly flat in the Baseline scenario.*

**The BLUE Map scenario: technological pathways for the United States**

The BLUE Map scenario for US transport includes strong efficiency improvements for all types of internal combustion engine (ICE) vehicles and the aggressive adoption of low-CO₂ alternative fuels. The current average on-road fuel economy of US LDVs at about 11 l/100 km (or 21 mpg) is among the most energy-intensive in the world. New cars and light trucks currently average about 8.4 l/100 km (or 28 mpg).

The target improvement under the new CAFE rules is 6.6 l/100 km (35.5 mpg) by 2016 (US EPA, 2009). This is about the level achieved today in some of the most efficient countries in the world such as France and India. This improvement
is included in the Baseline scenario, with fuel economy then remaining fairly flat from 2016 onwards. The BLUE Map scenario assumes that this CAFE standard is further tightened after 2016 so that by 2030 the average efficiency of the LDV stock reaches 4.2 l/100 km (56 mpg).

Few advanced-technology vehicles penetrate the market in the Baseline scenario. In the BLUE Map scenario, EVs and plug-in hybrid electric vehicles (PHEVs) begin to be sold in the United States around 2010 and reach significant volumes by 2015. By 2020, hybrid vehicles reach a quarter of sales and PHEVs also reach sales of over one million by that year. Electric vehicles reach sales of one million a year by 2025 and are widespread among the LDV fleet by 2030. Electric vehicles penetrate the market mainly in the small- and medium-car segments and PHEVs penetrate mainly in the larger-car segments (Figure 9.18).

By 2030, significant numbers of fuel-cell vehicles (FCVs) also begin to penetrate the market, and by 2050 nearly all new LDV sales are PHEVs, EVs and FCVs. In that year, very low-CO₂ electricity and hydrogen account for over 80% of the fuel used by LDVs.

Similar patterns of development occur in trucks. Electrification is limited largely to urban delivery vehicles. Long-haul vehicles remain predominantly diesel with a small penetration of natural gas fuel in the near term and fuel cells in the longer term. Biofuels become increasingly important in achieving CO₂ reductions for diesel trucks. Advanced, low-greenhouse gas biodiesel accounts for about 30% of truck fuel by 2050. By 2050, similar middle-distillate advanced biofuels also account for around 30% of fuel for rail, ships and aircraft, as in other countries and regions. These shares could be higher worldwide if sustainable biomass was available.

Figure 9.18  Passenger light-duty vehicles sales by technology in the United States in the Baseline and BLUE Map scenarios

Source: IEA Mobility Model database.

Key point

In the BLUE Map scenario, US LDV sales become dominated by EVs, PHEVs and FCVs by 2050.
The BLUE Shifts scenario

The transport scenarios include a variant, called the BLUE Shifts scenario, which is focused on the potential to save energy and CO₂ through different patterns of travel. Since the vast majority of trips in the United States are taken by private car, there appear to be good opportunities to shift some of this travel to more efficient modes such as bus and rail. But US transport infrastructure and land-use patterns are fully developed and it will take considerable time and effort to change the underlying spatial structure to encourage more travel by transit and non-motorised modes.

In much of the United States, buses are currently more energy-intensive than cars on a pkm basis. To obtain the potential benefits of bus travel, efficiency first needs to improve by achieving higher passenger occupancies. This, in turn, will probably require significant changes in land use and policies to encourage higher levels of ridership on existing systems.

The US government has initiated a high-speed rail (HSR) development programme which would add ten new rail corridors around the country to the existing north-east corridor. Conventional rail systems would also be expanded and enhanced to carry passengers at higher speeds in areas without HSR. High-speed rail would be targeted principally for trips of distances of 160 to 1 000 km (100 to 600 miles) between and across areas with moderate to high population densities. This initiative may initially only shift a few per cent of intercity trips from air and car to rail, but it will also encourage other areas to work towards being linked into an expanding network. This will provide a basis for the network to attract an increasing share of intercity travel over time, especially if supported by policies that ensure that rail travel is competitively priced.

**Figure 9.19**

United States greenhouse-gas emissions evolution by mode for passenger travel in the Baseline and BLUE scenarios

Source: IEA Mobility Model database.

**Key point**

In the BLUE Map scenario, greenhouse-gas emissions (on a well-to-wheel basis) are cut by over half in 2050 compared to the Baseline scenario in that year.
The BLUE Shifts scenario for the United States assumes a 17% reduction in car and air travel by 2050 relative to the Baseline scenario, with about 10% coming from shifts to bus and rail travel, and 7% coming from land-use practices that result in fewer and shorter trips and travel avoidance, e.g. through substituting telecommunications for travel. These steps reduce energy use and CO₂ emissions by about 18%.

Projected US greenhouse-gas emissions in the Baseline and BLUE Map scenarios are shown in Figure 9.19. Light-duty vehicles account for the biggest increase in CO₂ emissions in the Baseline scenario, reaching more than 1 Gt CO₂ in 2050. But aviation emissions also increase significantly as US air travel grows rapidly.

The difference between the Baseline and BLUE scenarios is very significant for the United States. This highlights the enormous potential for cutting CO₂ by introducing new technologies and fuels into US transport. A 1.4 Gt reduction in CO₂ emissions is achieved by 2050 in the BLUE Map scenario.

### Investment needs in the BLUE Map scenario

US GDP is assumed to increase by 1.7% a year over the 2007 to 2050 period. This growth will be driven by increasing demand for goods, services and leisure activities that use energy. Given this expected growth in energy demand, reducing CO₂ emissions in the United States will continue to be a challenge, although the rapid deployment of low-carbon technologies will help limit the growth in emissions.

For the United States to make its contribution to the global 50% emissions reduction envisaged in the BLUE Map scenario in 2050 compared to 2007, significant investments will need to be made in energy-efficient equipment, appliances, vehicles and buildings. The power sector will need to be significantly decarbonised, requiring large investments in nuclear, renewables and CCS. In the medium and long term, additional technologies will also be needed to reduce the CO₂ intensity of transport and industry. Taken together, these changes will require additional investments of USD 5.8 trillion over Baseline scenario levels between 2010 and 2050.

Of this total, USD 3.3 trillion will be required in the transport sector, almost all of it after 2030 for low-carbon vehicles (Figure 9.20). From 2010 to 2030, energy efficiency improvements in the BLUE Map scenario reduce the need for investment in both power plants and the distribution network. But the next step, the decarbonisation of the power sector, will require an additional USD 0.7 trillion in investment, all of which will be required between 2030 and 2050. Additional investment needs between 2010 and 2050 in the buildings sector are estimated at USD 1.6 trillion. Industry represents the smallest share of additional investment needs at USD 0.2 trillion.

Additional investment in efficient and low-carbon technologies will also enable a reduction in fuel requirements. Fuel savings are projected to outweigh investment costs across all end-use sectors, with the transport sector estimated to have the largest share.
Figure 9.20 Additional investment needs and fuel cost savings for the United States

![Graph showing investment needs and fuel cost savings](image)

**Note:** Fuel savings are calculated on the basis of BLUE Map fuel prices. Savings drop if Baseline energy prices are used as the fuel price assumptions in the BLUE scenario are lower than in the Baseline scenario, reflecting the impact of lower energy use on fuel prices.

**Key point**

Most additional investments will be needed in the transport and buildings sectors.

### Transition to a low-carbon energy future

#### Future technology priorities

Deep reductions in US greenhouse-gas emissions are achievable through the application of a mix of energy technologies which are already available today and the introduction of new technologies currently being developed. Contributions will be needed from a range of technologies to achieve a 4.9 Gt CO₂ reduction in energy-related emissions by 2050 compared to 2007 levels (Figure 9.21). Compared to the Baseline scenario in 2050, this represents a reduction of 81%. Measures to improve end-use energy efficiency and fuel switching together provide about one-third of all emissions reductions. Other major contributors include CCS (18%), renewables (15%), nuclear power (9%) and FCV and PHEVs/EVs (11%).

There is still considerable scope for improving the efficiency of industry, buildings and transport. In industry, particular priority should be given to the chemicals and pulp and paper sectors, which together account for 50% of industrial energy. Improvements in building shells can reduce heating and cooling loads in both residential and commercial buildings. Energy use for cooling could then be further reduced by improving the efficiency of room air-conditioning. Research and development is also necessary to increase the efficiencies and reduce the costs of advanced space-heating technologies for buildings such as fuel cells and heat pumps. In transport, it will be important to continue to improve the efficiency of LDV
technologies beyond 2015. There is also a need to demonstrate and eventually deploy advanced EVs and to develop second-generation biofuels suitable for heavy-duty vehicles.

**Figure 9.21** CO$_2$ emissions reductions by technology area in the BLUE Map scenario in the United States, 2050

- CCS power generation: 10%
- Nuclear: 9%
- Wind: 6%
- Solar: 3%
- Other power generation: 5%
- CCS industry and transformation: 8%
- Industrial efficiency and recycling: 8%
- Industry fuel switching: 2%
- Transportation efficiency: 12%
- PHEV and EV: 8%
- FCV: 3%
- Building efficiency: 15%
- Other building reductions: 5%
- Second generation biofuels: 6%

**Key point**

A wide range of technologies will be needed to achieve a low-carbon energy future for the United States.

In the power sector, the introduction of advanced, more efficient coal-fired power generation could help reduce CO$_2$ emissions from fossil fuel use in the short-term. These plants should also incorporate CCS or at least be suitable for later retrofitting with CCS (e.g. IGCC) so that emissions can be reduced further in the longer term. This will require additional funding to ensure that CCS is technically and economically proven in a selection of applications by 2020. Equally important, a range of renewable technologies and nuclear power can also play an important role in decarbonising the power sector. The United States has significant potential for solar power. A priority should be to demonstrate large-scale centralised solar plants, particularly in the south-west. There also needs to be increased investment in the electricity transmission grid, particularly in interstate connections, and to demonstrate smart grid applications.

**Future policy priorities**

These technology changes will require particular attention in the following policy areas:
Establish a cap-and-trade scheme that promotes domestic reductions and allows the purchase of credits to support emissions reductions in other countries and sectors.

Continue to liberalise electricity markets by:

- pursuing the effective separation of network management and power marketing to ensure non-discriminatory network access;
- ensuring that independent regulation focuses on the creation of low-carbon incentives and cost-reflective prices;
- increasing the capacity for interconnection between states to enable competitive wholesale markets to work effectively.

Stimulate a diverse and adequate generation mix by removing subsidies for fossil fuels, reducing uncertainty on national climate change policy, harmonising national renewable energy policies and removing uncertainties affecting the development of new capacity.

Take measures to increase the efficiency of power generation through regulation, incentives and cost-reflective prices.

Further strengthen policies and standards for new and refurbished buildings.

Consider additional measures to improve energy efficiency in industry, such as minimum energy performance standards or incentives to accelerate the capital stock turnover and the penetration of best-in-class technologies.

Further strengthen the CAFE standards for LDVs beyond 2016.

Promote modal shift from LDVs through land-use changes and the expansion of high-speed and conventional rail.

Continue to expand the Emissions Inventory Rule initiative to catalogue greenhouse-gas emissions from large emission sources.

Strengthen commitment to invest in energy technology RD&D and increase public funding levels in line with the 2009 American Recovery and Reinvestment Act.

Set priorities within a coherent long-term strategy for public investment in RD&D based on a process involving academia, national laboratories and industry.

Continue to support basic energy science research and strengthen current efforts to improve linkages between the basic science and the applied energy technology components of the DOE.
Key findings

Since 1990, China’s economy has grown fourfold, resulting in more than a doubling of energy use. Strong energy efficiency improvements have helped to limit growth in energy use. But the rising dominance of coal in the country’s energy mix has meant that energy-related carbon dioxide (CO₂) emissions have grown faster than energy consumption.

In the Baseline scenario, CO₂ emissions rise to 15.9 Gt by 2050, a 158% increase compared to 2007 levels. In the BLUE Map scenario, the widespread deployment of low-carbon energy technologies results in emissions of 4.3 Gt, 30% less than in 2007.

The deployment of low-carbon energy technologies will help to improve China’s energy security as it reduces the need for imported fossil fuels. Oil demand in 2050 in the BLUE scenario is less than half the level in the Baseline scenario. Coal demand drops by 70%.

Achieving the BLUE Map scenario results will require additional investments of USD 10.2 trillion between 2010 and 2050. Many of the investments made will yield reductions in fuel consumption and total fuel savings are estimated at USD 19 trillion.

Measures to increase energy efficiency further could save an additional 3.9 Gt CO₂ in 2050 compared to the Baseline scenario. Stronger policy incentives and regulation will be needed to realise this savings potential.

China’s transition to a low-carbon energy system will require significant decarbonisation of the power sector. A mix of nuclear, more efficient coal technologies, carbon capture and storage (CCS), wind, solar and other renewable generation technologies will be needed.

With coal currently accounting for around 65% of total primary energy supply (TPES) today, special attention should be given to the more efficient use of coal in power generation and industry as well as CCS.

Industry accounts for the largest share of China’s energy use and CO₂ emissions. Measures to improve energy efficiency and reduce CO₂ emissions in key energy-intensive sectors such as iron and steel, cement and chemicals should be a priority.

The transport sector is evolving very rapidly, in terms of vehicle sales, infrastructure and the introduction of new technologies. The eventual shift to electric vehicles (EVs) and the electrification of other transport modes will play an important role. Channelling more of the travel growth into the most efficient modes (i.e. bus and rail systems) can also help.

In the buildings sector rapid growth in energy use is expected and priority attention should be given to improving the energy efficiency of building shells, the use of more efficient heating and cooling systems, the use of solar thermal for space and water heating, and the use of more efficient lighting systems and appliances.
China has set ambitious energy technology targets in a number of different areas, including energy efficiency, renewables and nuclear power. Actions in these areas will help to reduce the country’s CO\textsubscript{2} intensity, but additional and sustained efforts will be needed to reach the emissions reductions identified in the BLUE Map scenario.

With extensive manufacturing capabilities, China’s industry is well positioned to benefit from a global transition in the energy system. China has already established itself as a leader in the manufacture of a number of low-carbon energy technologies and is the world’s largest producer of photovoltaic (PV) modules and wind turbines.

Regional description

China is the most populous country in the world. With 1 327 million people in 2007, it represents about 14% of the world’s population. An estimated 45% of the population lives in urban areas. Latest estimates suggest that China’s urbanisation rate will increase by nearly 1% annually in the next 15 to 20 years, as a result of which around 300 million people will move from rural areas into cities (China Daily, 2009). Of the total working population, 41% is involved in agriculture, 27% in industry and 32% in services (NBS and NDRC, 2008).

China covers a land area of 9.6 million square kilometres (km\textsuperscript{2}), making it the fourth-largest country. It is characterised by three climatic zones, tropical, subtropical and temperate.

In 2007, China’s GDP reached USD 2 400 billion, twice as large as it was in 2000. With China’s rapid economic development, the income of Chinese residents has risen steadily. In 2007, the GDP per capita reached USD 1 809, equivalent to USD 7 509 in purchasing power parity terms.

Recent trends in energy and CO\textsubscript{2} emissions

Over the last two decades, China has moved from being a minor and largely self-sufficient energy consumer to become the world’s fastest-growing energy consumer and a major player on the global energy market. Soaring energy use is both a driver and a consequence of the remarkable growth of the country’s economy.

China’s energy system is predominantly based on indigenous coal supplies. Oil and natural gas supplies are partly dependent on foreign imports. Proven coal reserves in China are 114.5 billion tonnes (t), 14% of the world total. At current production levels, they would last 46 years. Oil reserves in China are less than 2% of the total world’s reserves and at current production rates would last just over 17 years. China’s imports of oil will continue to grow in importance as demand from the transport sector rises sharply with higher income levels. China holds a relatively small share of the world’s proven natural gas reserves (Table 10.1).

Regionally, the country’s main coal reserves are concentrated in the north, while water or hydro resources are concentrated in the east and most of the country’s oil reserves are located in the west. The distribution of energy resources makes energy transportation a particular issue for the Chinese energy supply system.
Table 10.1  Proven energy reserves in China and in the world

<table>
<thead>
<tr>
<th></th>
<th>Coal (bt)</th>
<th>Crude oil (bt)</th>
<th>Natural gas (bcm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proven reserves: China</td>
<td>114.5</td>
<td>3.3</td>
<td>2 455</td>
</tr>
<tr>
<td>Proven reserves: World</td>
<td>826</td>
<td>171</td>
<td>185 020</td>
</tr>
<tr>
<td>Production 2007: China</td>
<td>2.5</td>
<td>0.19</td>
<td>69.2</td>
</tr>
<tr>
<td>Reserve-to-production ratio: China</td>
<td>45.8</td>
<td>17.4</td>
<td>35.5</td>
</tr>
</tbody>
</table>

Note: Reserve-to-production ratio indicates the length of time that the proven reserves would last if production were to continue at current rates and if no additional reserves could be recovered.

Sources: BP (2009); NBS and NDRC (2008).

Energy production and supply

Energy production in China has increased rapidly in recent years, with TPES reaching 1 994 million tonnes of oil equivalent (Mtoe) in 2007, a 79% increase over production in 2000 of 1 116 Mtoe. Figure 10.1 shows the growth of primary energy production since 1971. This shows a sharp acceleration from 2000 owing to rapid growth in demand for industrial materials production. Since 2000, primary energy production has risen by an average of 8.7% a year, compared to just 2.2% a year in the 1990s and 5.3% a year in the 1980s. The majority of the growth in energy supply since 2000 has come from coal, which has led to significant increases in overall CO₂ emissions.

Figure 10.1  Total primary energy supply in China

Note: Unless otherwise indicated, all material derives from IEA data and analysis.

Key point

Total primary energy supply has risen fivefold since 1971 and almost all of the growth since 2001 has been from coal even though other fuels, notably natural gas, have risen rapidly.
Coal is the most widely used energy source in China. Its share in TPES has decreased since the 1970s, but is still relatively high at 65% with more than half used for power generation. Levels of oil production have been relatively steady, so that the overall share of crude oil has declined in the energy production mix. In 2007, oil represented 18% of TPES, up from 10% in 1971. Natural gas production has been rising steadily over the last decade and in 2007 reached 59 Mtoe, representing almost 3% of TPES, up from less than 1% in 1971.

**Figure 10.2** Energy production, imports and exports for China

Note: Nuclear production refers to the heat produced in nuclear reactors, irrespectively of whether the nuclear fuel used is from domestic sources or imported.

**Key point**
China’s energy production is dominated by coal, and rapidly increasing demand for oil has turned the country from a net exporter to a net importer of oil.

**Box 10.1** Unconventional gas in China

Demand for natural gas in China has been growing sharply over the past years and current domestic production is roughly in line with consumption. Natural gas represents a small share of total energy supply today, the majority of which is used in the residential sector. Because of strong increases in demand for natural gas, China started to import liquefied natural gas (LNG) in 2006. A natural gas pipeline from Turkmenistan is expected to bring in 40 billion cubic metres (m$^3$) per year by 2015 and a number of LNG terminals are also being built. Attention has also recently been focused on the development of unconventional gases such as coal-bed methane and shale gas.

---

1. China’s own energy statistics, which exclude traditional biofuels that are included in IEA energy statistics, put coal’s share at nearly 70% (NBS, 2008).
China’s coal-bed methane potential is estimated at 37 trillion m$^3$ of geological resources and 134.3 trillion m$^3$ of proven resource, the third-largest in the world. Most of the resources are found in Shanxi province and Xingjiang autonomous region. The government plans initially to increase the extraction of coal-bed methane to 40 billion m$^3$ a year by 2020. Estimates for shale gas resources are 26 trillion m$^3$ which is more or less equivalent to those of the United States. The Chinese Ministry of Land and Resources has announced a strategic goal of reaching a production target of 15 billion m$^3$ to 30 billion m$^3$ a year by 2020.

The development of domestic unconventional gas reserves and greater imports of natural gas could help to reduce energy use and CO$_2$ emissions in sectors such as ammonia production as gas-based ammonia production is less energy-intensive than coal-based production. Even with these large supply additions, gas will remain a small part of China’s energy supply.

Energy consumption

Energy consumption in China has increased rapidly in the last decade as a result of tremendous economic growth fuelled by the export of manufactured goods and high rates of domestic investment (Figure 10.3). Since 2000, total final energy consumption has nearly doubled from 776 Mtoe in 2000 to 1 297 Mtoe in 2007, an average annual increase of 8%. Over the same period, electricity consumption rose by a factor of 2.8 from 1 116 terawatt-hours (TWh) in 2000 to 3 114 TWh in 2007. Rapid industrial growth over the last decade has transformed the country’s energy security situation, making it one of the world’s largest importers of energy. As recently as 1992, China was a net exporter of energy. In 2007, imports represented 10% of China’s primary energy supply. Oil accounts for the largest share of imports, as domestic reserves are relatively low, but large amounts of natural gas and even coal are also imported to meet energy demand.

Figure 10.3  Final energy consumption by fuel and by sector for China

Note: Industry includes coke ovens, blast furnaces and feedstocks. Transport includes international aviation and marine bunkers. Other sectors include agriculture, fishing, and forestry as well energy use for pipeline transport.

Key point

Industry represents the largest share of total energy use today and has experienced rapid demand growth since 2000 with a doubling in energy consumption.
End-use efficiency improvement

In 2007, China’s energy intensity was 0.2 tonnes of oil equivalent (toe) per USD 1 000 of GDP, 50% less than the world average of 0.30 toe/USD 1 000 of GDP. Chinese per-capita consumption of electricity and energy is lower than in the OECD regions, but significantly higher than in most developing countries. During the 11th Five-Year-Plan (2006-2010) the Chinese government plans to reduce energy use per unit of GDP by 20%. A total cumulative reduction of 12.5% has been achieved from 2006 to 2008 (NBS, 2009).

Analysis based on end-use data shows that the overall improvement in energy intensity in China was 5.8% a year between 1990 and 2007. Without energy savings resulting from these improvements, total final energy consumption would have been 30% higher in 2007. The largest contribution to the energy savings from efficiency was from the manufacturing sector which improved by 3% a year over this period.

Carbon dioxide emissions

The near-doubling in energy consumption since 2000, fuelled primarily by additional coal use, has resulted in a doubling of China’s energy-related CO₂ emissions. In 2007, with CO₂ emissions of 6.2 Gt, China became the world’s largest CO₂ emitter, for the first time overtaking the United States which reported 5.9 Gt of emissions. Although China’s CO₂ intensity per capita is still relatively low (4.6 t per capita) compared to the United States (18.9 t per capita) and OECD Europe (7.5 t per capita), China’s CO₂ intensity per unit of GDP is one of the world’s highest at 0.62 gCO₂/USD 1 000 GDP on a purchasing power parity basis.

China’s economy is dominated by the manufacturing sector with two-thirds of emissions attributed to industry. A significant share of industrial production can be related to final products which are exported and highlight the importance of China’s export- and investment-driven economy and the impact it has had on energy use and emissions. The buildings sector, which accounts for the largest share of emissions in the United States, represents only 23% of total emissions in China. Emissions from transport represent 8% of China’s emissions, but this share is expected to rise quickly in the future as the country’s economic growth spurs the demand for vehicles.

Overall energy policy framework

Many government agencies have a hand in shaping China’s energy and climate change policies. In this they are supported by many research organisations and private firms. The government bodies charged with overseeing energy and energy policy are comparatively small.

The highest policy-making body is the 23-member National Energy Commission (NEC), chaired by the Premier and including heads of all the main agencies
concerned with energy supply, transport, end-use, safety, security, sustainability, trade and finance. The distribution of energy sector responsibilities over numerous agencies has impeded co-ordination, formulation, implementation, and the enforcement of energy strategy, policies and regulations. The announcement in January 2010 of the membership and duties of the NEC is seen by many as the latest attempt to create an effective national-level energy authority that can co-ordinate across agencies and offer a counterweight to the considerable power of the large, state-invested energy companies.

The National Energy Administration (NEA), associated with the National Development and Reform Commission (NDRC), also plays a particularly important role. The NEA’s responsibilities mainly relate to the energy supply sectors, and include the drafting of near- to long-range plans, developing and setting policy, and policy implementation through setting regulations, reviewing and approving investment projects, and issuing guidance. Nine separate departments look after the NEA’s various portfolios (Table 10.2). In the discharge of its responsibility for energy security, NEA oversees the construction and operation of the nation’s strategic oil reserves. Some NEA staff are concurrently assigned to the office of the NEC. This office is chaired by the NDRC Chair, with the NEA Administrator serving as deputy.

The NDRC has significant responsibilities, including overall authority for energy efficiency and leadership on climate change through a dedicated department. The NDRC is also home to China’s Price Bureau, which has authority over electricity tariffs and oil prices, with major changes subject to approval of the State Council, the government’s highest executive body. The NEA and other agencies provide input to the Price Bureau but do not have decision-making powers. The NDRC and NEA departments are replicated in provincial, municipal and many country administrations, and responsibility for implementation rests with these local branches except where issues concern centrally administered state-invested enterprises.

A range of other agencies have important roles in energy supply and demand. The Ministry of Finance and the State Bureau of Taxation are involved in directing investment and designing and implementing incentive policies. The Ministry of Land and Resources has control over mineral rights and is, thus, a key player for all fossil fuels. The State Administration for Work Safety oversees the critical issue of mine safety. The State Electricity Regulatory Commission provides guidance on power sector rate setting, grid operation, the development of power markets and other areas of utility policy.

Responsibility for energy technology research and development (R&D) is shared between the Ministry of Science and Technology and the Chinese Academy of Sciences. The NDRC leads on climate change. The Ministry of Environmental Protection is responsible for regional and local pollution stemming from energy use, including particulates, sulphur dioxide (SO₂) and acid rain. The NDRC takes the overall lead for energy efficiency, although sectorally focused agencies play an important part in setting regulations for buildings, industry and transport. Energy issues in rural areas, where the majority of the population still live, are overseen by the Ministry of Agriculture.
### Responsibilities of China’s National Energy Administration departments

<table>
<thead>
<tr>
<th>General administration</th>
<th>Policy and legislation</th>
<th>Development and planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manages the Administration’s daily operations, including personnel, Chinese Communist Party, financial management, asset management and press affairs.</td>
<td>Studies important energy problems, organises the drafting of energy legislation, and conducts administrative auditing and review.</td>
<td>Studies and provides suggestions on energy development strategy; organises the drafting of macro-level energy development programmes, yearly plans and industrial policy; and undertakes energy industry reform work.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy conservation and scientific equipment</th>
<th>Power</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directs energy conservation and comprehensive resource use, promotes energy-saving technologies and equipment, and prepares standards.</td>
<td>Plans thermal and nuclear power development, manages the national power network, and handles nuclear power station crisis management.</td>
<td>Manages the coal industry, drafts plans for coal mining, undertakes system reform, and develops advanced technology for reducing pollution caused by coal burning.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Oil and natural gas</th>
<th>New and renewable energy</th>
<th>International co-operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manages the oil and gas industry, plans oil and natural gas development, promotes industry reform, and manages national and commercial oil reserves.</td>
<td>Directs and co-ordinates rural energy development and plans the use of new and renewable energy.</td>
<td>Undertakes international energy co-operation, drafts strategies, laws and policies for opening up China’s energy sector and co-ordinates the development and use of overseas energy.</td>
</tr>
</tbody>
</table>

Source: Downs (2008).

---

**Current status of energy policies and climate change initiatives**

Energy targets have long figured in China’s national plans. In the 1980s, goals for energy production were joined by goals for efficiency and environmental improvements. Each successive Five-Year Plan (FYP) has seen more ambitious targets. The current 11th FYP (2006 to 2010) required that the energy intensity (primary energy demand per unit of GDP) of the national economy in 2010 be 20% below the level in 2005, and mandated a 10% absolute reduction in SO₂ emissions to the air and chemical oxygen demand (COD) emissions to surface waters. A variety of then-current and newly formulated policies and regulations were harnessed to achieve these targets, and, according to Chinese sources and analysis by outside observers, the country is largely on track to meet them (Levine et al., forthcoming 2010).

China’s energy efficiency policies for over two decades have leaned heavily on measures to increase overall plant efficiency through the building of new plants and the closure of older, less efficient plants. These measures have to some extent been undermined by economic stimulus measures that have financed continued high levels of investment in infrastructure. Some targeted measures seem to have been successful. Programmes to shut down the smallest, often most inefficient and polluting industrial facilities and power plants have achieved their targets ahead of time. This, combined with investment in larger new facilities, has resulted in average
process efficiencies rising very quickly, in many cases approaching levels typical in OECD countries and even surpassing the performance of some developed nations.

The Top-1 000 Programme, under which the country’s largest energy-consuming power plants and factories signed agreements to improve energy performance and gained access to supporting measures, has provided a large proportion of the energy savings achieved in recent years. A cluster of efficiency initiatives, termed the Ten Key Projects, has achieved nearly as much in energy savings as the Top-1000 Programme. Implementation was spurred by the incorporation of energy intensity goals into the performance criteria for local officials from provincial governors downwards. Programmes and standards to improve the efficiency of appliances, lighting, buildings, vehicles and industrial equipment have had a great impact. At the same time, China has invested in the capacity needed to track the progress of these initiatives, appointing more than 2 000 additional government energy statisticians since 2005.

The 12th FYP (2011 to 2015) promises to be even more challenging. It will need to put China on a path to comply with the target announced in November 2010, just prior to the 15th Conference of the Parties (COP-15) to the United Nations Framework Convention on Climate Change (UNFCCC), to reduce its CO₂ emissions intensity by 40% to 45% in 2020 compared to 2005. The Plan must also make progress towards targets for the deployment of non-fossil energy sources, which are to supply 20% of China’s primary energy by 2020.

Several targets for generating capacity have been announced by officials. Current official targets for installed capacity in 2020 call for 70 GW of nuclear power, 100 GW of wind and 1.8 GW of solar. Most of the renewable energy generating capacity would be hydropower, as is the case now. It is targeted to exceed 300 GW by 2020. A new Renewable Energy Law and a series of regulations designed to support nascent renewable energy industries have had significant impact, but important challenges remain in deploying these technologies on the scale contemplated for the next decade. In terms of energy efficiency, some senior Chinese analysts feel that most of the easy gains in efficiency have already been exploited and that, even with the stronger deployment of renewables, CO₂ intensity reduction targets will not be easy to achieve.

**Overview of scenarios and CO₂ abatement options**

GDP and population projections are the same in both the Baseline and BLUE scenarios. The different levels of energy supply and consumption in the two scenarios indicate different levels of decoupling of energy and economic activity over time (Table 10.3).

---

2. Chapter 2 provides a full description of the different scenarios.
### High-level indicators for China

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2007</th>
<th>2030</th>
<th>2050</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total primary energy supply (Mtoe)</strong></td>
<td>1 116</td>
<td>1 994</td>
<td>3 827</td>
<td>5 176</td>
<td>3 181</td>
<td>3 759</td>
</tr>
<tr>
<td><strong>Electricity consumption (TWh)</strong></td>
<td>1 290</td>
<td>3 114</td>
<td>5 556</td>
<td>10 630</td>
<td>5 872</td>
<td>8 632</td>
</tr>
<tr>
<td><strong>CO₂ emissions (Gt)</strong></td>
<td>3.05</td>
<td>6.15</td>
<td>11.62</td>
<td>15.87</td>
<td>7.85</td>
<td>4.31</td>
</tr>
<tr>
<td><strong>GDP (2000 USD billion using exch. rates)</strong></td>
<td>1 368</td>
<td>2 623</td>
<td>8 944</td>
<td>18 857</td>
<td>8 944</td>
<td>18 857</td>
</tr>
<tr>
<td><strong>GDP (2000 USD billion using PPP)</strong></td>
<td>5 150</td>
<td>10 156</td>
<td>37 127</td>
<td>78 278</td>
<td>37 127</td>
<td>78 278</td>
</tr>
<tr>
<td><strong>Population (millions)</strong></td>
<td>1 269</td>
<td>1 327</td>
<td>1 471</td>
<td>1 426</td>
<td>1 471</td>
<td>1 426</td>
</tr>
<tr>
<td><strong>TPES/GDP</strong> (toe per thousand 2000 USD using PPP)</td>
<td>0.22</td>
<td>0.20</td>
<td>0.10</td>
<td>0.07</td>
<td>0.09</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>TPES/population</strong> (toe per capita)</td>
<td>0.88</td>
<td>1.50</td>
<td>2.60</td>
<td>3.63</td>
<td>2.16</td>
<td>2.67</td>
</tr>
<tr>
<td><strong>Electricity consumption/population</strong> (kWh per capita)</td>
<td>1 017</td>
<td>2 347</td>
<td>3 777</td>
<td>8 795</td>
<td>4 816</td>
<td>7 173</td>
</tr>
</tbody>
</table>

Sources: IEA (2009b and 2009d); IEA analysis.

### Energy and CO₂ emission scenarios

In the Baseline scenario, TPES supply in China is expected to nearly double from 2007 to 2030 and rise by 165% by 2050. Oil, gas, nuclear and other renewables all grow strongly but coal remains the dominant fuel. Current policies aimed at increasing energy security in China will result in significant growth in nuclear, wind and solar energy. As China’s average GDP per capita more than doubles over this period, strong growth in car ownership boosts demand for oil, which more than triples from 2007 to 2050. In the Baseline scenario, most of the demand for light-duty vehicles (LDVs) will be based on conventional internal combustion engine (ICE) technology.

Baseline CO₂ emissions double by 2030 as coal continues to dominate in the industry and power sectors. Growth in emissions will slow as the economy matures and in 2050 reaches 15.9 Gt, a 158% increase compared to current levels. The largest absolute increase in emissions will come from the power sector which rises from 3.1 Gt in 2007 to 8.5 Gt in 2050. Transport will see the highest rates of growth in emissions rising from 0.5 Gt in 2007 to 2.7 Gt in 2050, an increase of more than fivefold.

In the BLUE Map scenario, higher rates of energy efficiency result in a 27% reduction in TPES in 2050 compared to Baseline levels. Total primary energy supply in China nearly doubles compared to current levels reaching 3 814 Mtoe in 2050. The demand for coal declines significantly by 2050, falling by 36% compared to current levels and by 70% compared to the Baseline scenario. Oil demand rises significantly less than in the Baseline scenario, but is still 60% above current levels owing to strong growth in car ownership. In the BLUE Map scenario, the demand for vehicles is met by a combination of conventional ICE technology and low-carbon vehicle technologies, including EVs, biofuels and fuel-cell vehicles (FCVs).

The share of non-fossil energy supply rises significantly in the BLUE Map scenario, reaching 48% in 2050 compared to 16% in 2007 and 15% in the Baseline.
scenario. Coal accounts for the largest share of the primary energy supply mix. Biomass and waste more than triples compared to current levels reaching 707 Mtoe, representing the second-largest share, followed closely by nuclear at 683 Mtoe. Energy supply from wind, solar and geothermal reaches 274 Mtoe, up from 5 Mtoe in 2007. A mix of increased energy efficiency and fuel switching helps to improve the country’s energy security as lower energy demand and a switch to more renewables and nuclear power helps to reduce imports of oil.

High growth in non-fossil energy supply, coupled with a sharp decrease in coal use, leads in the BLUE Map scenario to significant reductions of CO₂ emissions in China. They fall from 6.2 Gt CO₂ in 2007 to 4.3 Gt CO₂ in 2050. Emissions in the BLUE Map scenario show a peak by 2020 as the wider deployment of low-carbon technologies allows China to reduce future emissions. China’s recent announcement to reduce CO₂ intensity by 40% to 45% by 2020 would put the country on an emissions path between the trends in emissions intensity in the Baseline and BLUE scenarios.

**Figure 10.4** Total primary energy supply, Baseline and BLUE Map scenarios by fuel for China

![Graph showing energy supply by fuel from 2007 to 2050 for China, comparing Baseline and BLUE Map scenarios.](image)

Note: Other includes non-combustible renewables and heat. Oil includes international marine bunkers. Sources: IEA (2009a and 2009b); IEA analysis.

**Key point**

While coal and oil dominate in the Baseline scenario, nuclear and renewables play an important role in the BLUE Map scenario.

**Carbon dioxide abatement options**

Emissions in China need to peak by 2020 if significant reductions in CO₂ emissions are to be achieved by 2050. Investments made in infrastructure and equipment over the next two decades will determine the carbon footprint of the Chinese economy.

China is already taking important steps, but as in other countries further urgent action is needed to transform the way energy is used and produced.
In the BLUE Map scenario energy-related CO₂ emissions are very much lower between 2007 and 2050 than in the Baseline scenario (Figure 10.5). Energy efficiency and measures to reduce the carbon intensity of electricity production dominate the short- and medium-term options. A strategy for reaching a nearly decarbonised power sector by 2050 will be critical. This could be achieved through a combination of renewables, nuclear and CCS.

To achieve even deeper emission cuts by 2050 will require the deployment of CCS in the fuel transformation and industry sectors from 2030 to 2050. Additional technologies to reduce the CO₂ intensity in industry and transport will also be needed. These will have to include greater levels of electrification and other end-use fuel switching options.

**Figure 10.5** Contributions to emissions reduction in China

End-use efficiency savings and CCS are the largest contributors to emissions reduction in China; nuclear and renewables are also important.

**Sectoral results**

**Power sector**

The Chinese electricity system today

In 2007, total installed power capacity in China reached 718 GW, with 556 GW of almost entirely coal-based thermal power, 148 GW of hydro-power, 8.8 GW of nuclear power, 4.2 GW of wind power and 0.86 GW of other renewable power generation. The country’s reliance on coal for its electricity production, which accounted for 81% of total electricity generation in 2007, means that the
average CO₂ intensity of its power generation is among the highest in the world at 777 g/kWh compared to a world average of 507 g/kWh (Figure 10.6).

Since 2000, because of strong growth in electricity demand from the manufacturing sector, China has been adding new, predominantly coal-fired, power generation capacity at an unprecedented rate (Figure 10.7). In 2007 alone, 104 GW of new capacity was added although since then the pace of construction has slowed. Much of the growth in new coal-fired capacity has been based on the deployment of larger, more efficient technologies. As a result, the average coal consumption per kWh produced has fallen approximately by 13% from 390 grams of coal equivalent (gce)/kWh in 2000 to just over 340 gce/kWh in 2009. The more efficient, newer plants consume less than 290 gce/kWh.

In 2006, China introduced a policy to promote the early closure of smaller, less efficient facilities. As a result, 60 GW of capacity was closed from 2006 to 2009. This has avoided the release of nearly 139 Mt CO₂ from inefficient coal-fired plants over that period (CEC, 2010). The approval for investments in new coal-fired plant is conditional on the early closure of smaller facilities with capacity under 200 megawatts (MW). China now has a policy of building no new plant of less than 300 MW, with much of its new capacity based on supercritical (SC) and ultra-supercritical (USC) units of 600 MW or 1 000 MW capacity.
Developments in renewable power generation

Over the past decade, wind and solar power generation have developed rapidly in China. The installed wind capacity has risen from 28 MW in 1996 to over 25 GW in 2009. As a result of policies promoting the rapid uptake of renewables, China has seen wind capacity rise tenfold since 2005. China’s total onshore wind resources are estimated to be in excess of 3 000 GW, concentrated in the provinces of Hebei and Inner Mongolia (UNEP, 2005). In addition, significant potential for offshore wind also exists in the Eastern coastal provinces. The growth in solar PV has been less significant than in wind, with installed capacity rising fivefold from 19 MW in 2000 to 145 MW in 2008.

Regional electricity supply in 2007

In 2007, total electricity generation in China amounted to 3 300 TWh having shown an annual average growth rate of 14% since 2000. Thermal power supply accounts for 83% of the total, hydro for 14.8%, nuclear for 1.9% and other renewables for just 0.3%. Guangdong, Shandong and Jiangsu provinces are the three largest electricity suppliers (Figure 10.8). Power generating capacity is most developed in the eastern coastal areas and middle-eastern provinces of China. Thermal generating capacity is mainly concentrated in the central-northern and south-eastern provinces of China. Hydropower is mainly located in the central and south-western provinces. Nuclear power is concentrated in the southern coastal area. Wind power has also been developed both in the inland part of China, such as Inner Mongolia and Xinjiang, and the coastal provinces of Shandong and Guangdong.
Electricity production in China is heavily located in the coastal provinces which are also the main centres of electricity consumption.

**Electricity transmission and distribution**

Since 2000, China has invested heavily in expanding its electricity transmission network, particularly in its high-voltage network, which has grown by more than 50% from 2000 to 2007 (Figure 10.9). The high-voltage (≥110 kilovolt (kV)) grid now spans over 500,000 km. Transmission and distribution losses have continued to fall over the last two decades, from 8.9% in 1980 to just under 7% in 2007 (NBS, 2008).

China’s national grid is divided into two parts. The State Grid Corporation of China (SGCC) comprising five sub-grids in the north connected to a sixth Central Grid supplies a population of about 1.1 billion people. The China Southern Power Grid (CSPG) supplies a population of 230 million.
In 1996, with the introduction of the Electric Power Law, the State began to implement preferential policies for rural electrification, giving major support for the rural electrification of ethnic minority, remote and poverty stricken areas. The State encouraged and supported the use of solar energy, wind energy, geothermal energy, biomass and other energy sources so as to increase the power supply in rural areas. As a consequence of these efforts, China’s electrification rate in 2009 reached 99.4%, with urban areas fully electrified and rural areas reaching 99% electrification (IEA, 2009b).

**Electricity demand scenarios**

Electricity consumption in China has increased by 144% between 2000 and 2007, fuelled by strong industrial demand. Industry’s share of total electricity demand has risen from 48% in 2000 to 70% in 2007. As higher electricity demand is expected from other sectors, by 2050 the share of industrial electricity consumption declines to 65% in the Baseline scenario and 62% in the BLUE Map scenario (Table 10.4).

In both scenarios, electricity consumption continues to rise rapidly as China’s economy continues to develop. In the Baseline scenario in 2050, final electricity consumption is about four times higher than in 2007. In the BLUE Map scenario, consumption grows to 8 632 TWh in 2050, more than three times higher than in 2007. This is 19% lower than in the Baseline scenario as the growth rate of electricity consumption is slowed by higher levels of industrial energy efficiency and more efficient lighting and air conditioners in the buildings sector. Electricity consumption for transport in the BLUE Map scenario is higher than in the Baseline scenario as a result of the deployment and commercialisation of plug-in hybrid electric vehicles (PHEVs) and EVs, which represent a 12% share of the sale of new vehicles in 2050.
Table 10.4  ▶ Current and projected final electricity demand for China by end-use sector

<table>
<thead>
<tr>
<th>(TWh/yr)</th>
<th>2007</th>
<th>2030</th>
<th>2050</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>372</td>
<td>1 337</td>
<td>2 440</td>
<td>978</td>
<td>1 582</td>
</tr>
<tr>
<td>Commercial</td>
<td>348</td>
<td>805</td>
<td>1 300</td>
<td>541</td>
<td>864</td>
</tr>
<tr>
<td>Industry</td>
<td>1 872</td>
<td>5 117</td>
<td>6 720</td>
<td>4 024</td>
<td>5 211</td>
</tr>
<tr>
<td>Transport</td>
<td>28</td>
<td>33</td>
<td>53</td>
<td>228</td>
<td>875</td>
</tr>
<tr>
<td>Other</td>
<td>98</td>
<td>221</td>
<td>117</td>
<td>100</td>
<td>101</td>
</tr>
<tr>
<td>Total</td>
<td>2 717</td>
<td>7 513</td>
<td>10 630</td>
<td>5 872</td>
<td>8 632</td>
</tr>
</tbody>
</table>

Sources: IEA (2009b, 2008 and 2009c); NBS and NDRC (2008).

Electricity generation scenarios

China’s installed capacity in the Baseline scenario grows to 2 084 GW in 2050 and in the BLUE Map scenario it grows to 2 307 GW in 2050 (Table 10.5). In the BLUE Map scenario, the share of electricity produced from fossil fuels falls from 83% today to 40% in 2050. Of the share generated by fossil-fuelled plants, almost half of all plants, and almost all of the coal plants, are equipped with CCS in the BLUE Map scenario in 2050.

Table 10.5  ▶ China’s power generation capacity in the Baseline and BLUE Map scenarios, 2050

<table>
<thead>
<tr>
<th></th>
<th>Power generation share</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline (%)</td>
<td>BLUE Map (%)</td>
</tr>
<tr>
<td>Coal</td>
<td>69.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Coal + CCS</td>
<td>0.0</td>
<td>14.8</td>
</tr>
<tr>
<td>Gas</td>
<td>8.4</td>
<td>19.1</td>
</tr>
<tr>
<td>Gas + CCS</td>
<td>0.0</td>
<td>3.7</td>
</tr>
<tr>
<td>Biomass</td>
<td>1.3</td>
<td>3.4</td>
</tr>
<tr>
<td>Biomass + CCS</td>
<td>0.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Oil</td>
<td>0.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Nuclear</td>
<td>7.3</td>
<td>25.6</td>
</tr>
<tr>
<td>Hydro</td>
<td>9.2</td>
<td>12.5</td>
</tr>
<tr>
<td>Solar photovoltaic</td>
<td>0.8</td>
<td>4.4</td>
</tr>
<tr>
<td>Concentrating solar power</td>
<td>0.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Wind onshore</td>
<td>3.1</td>
<td>5.8</td>
</tr>
<tr>
<td>Wind offshore</td>
<td>0.3</td>
<td>5.0</td>
</tr>
<tr>
<td>Other</td>
<td>0.1</td>
<td>0.8</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

©OECD/IEA, 2010
China plans to develop ultra high-voltage transmission systems and is investing heavily in R&D for 1 000 kV AC and 800 kV DC lines. These lines will be developed to transmit electricity, particularly hydropower, from the west to the east. Approval has already been granted for a 5 GW 800 kV DC demonstration project to be developed by the CSPG Company.

*Figure 10.10* Regional electricity generation in the BLUE Map scenario for China, 2050

Different regions in China have varying electricity generation profiles in the BLUE Map scenario in 2050 (Figure 10.10). The largest share of electricity production (40%) in 2050 comes from the western provinces with abundant hydro, coal with CCS, wind and solar electricity generation. The coastal provinces in the east will see electricity production based largely on nuclear, offshore wind and gas. This area which today represents the largest share of electricity production will import a growing share of its electricity from other regions. Gas, nuclear and coal with CCS represent the largest share of electricity production in the central provinces, while in the north-east the largest shares come from nuclear and gas.
Decarbonising the power sector in China

China’s current energy policy envisages a rapid expansion of nuclear, wind and solar capacity with targets of 70 GW of nuclear by 2020, 10 GW of wind by 2020 and 1.8 GW of solar by 2020. The rapid expansion of non-fossil electricity capacity will help to reduce the CO₂ intensity of the country’s power sector. To reach levels of near-decarbonisation will require even higher levels of nuclear and renewable power generation and the development of CCS for coal-, gas- and biomass-fired plants.

It will take time to build up the country’s nuclear and renewable power capacity. As a result, coal will continue to dominate China’s electricity mix for the next 20 years. Investments in new coal-fired capacity and in non-fossil capacity will be needed to keep up with higher electricity demand. Replacing old subcritical plants with the latest state of the art SC, USC and integrated gasification combined cycle (IGCC) coal-fired plants will contribute significantly to reducing the CO₂ intensity of coal-fired generation. This transition to highly efficient coal-fired generation will in principle also allow the retrofitting of plants with carbon capture when the technology becomes available.

In the BLUE Map scenario, non-fossil capacity reaches 46% of all generation capacity by 2030 at 10 GW. Hydropower represents the largest share at 300 GW, while wind rises to 270 GW, solar to 71 GW and nuclear to 120 GW. From 2030 to 2050, the rapid growth of solar, nuclear, hydro and offshore wind will help boost non-fossil capacity to over 1 600 GW, representing 66% of total capacity in 2050. In addition to the rapid growth of non-fossil energy, carbon capture for fossil-fuelled plants will also need to be deployed from 2030 to reach levels of 250 GW by 2050. In the BLUE Map scenario, the CO₂ intensity of China’s electricity sector falls to just 121 gCO₂/kWh from almost 777 gCO₂/kWh in 2007. These developments could be seen to set out a pathway towards the decarbonisation of China’s power sector some time after 2050.

Industry sector

Industrial energy use in China reached 727 Mtoe in 2007, accounting for 60% of total energy used (Table 10.6). Dynamic growth in the country’s manufacturing sector has led to a doubling in industrial energy consumption since 2000. China is the world’s largest industrial energy user, accounting for 24% of global industrial energy consumption. This is 80% more than the United States, the second-largest industrial energy user. The final energy mix of industry is dominated by coal (Figure 10.11). Industry accounts for 74% of total electricity consumption, which is also a high share compared to other countries. Electricity accounts for 22% of industrial final energy use.

China dominates global industrial production and is the largest producer of cement, iron and steel, and aluminium. These three sectors represent 80% of direct emissions in industry which totalled 2.65 Gt in 2007. Total energy consumption for these sectors is equal to 59% of total energy use in Chinese industry.
Figure 10.11 Industrial final energy mix in China and in the world, 2007

China 727 Mtoe

- Coal: 58%
- Oil: 11%
- Natural gas: 4%
- Electricity: 22%
- Other: 5%

World 3 019 Mtoe

- Coal: 27%
- Oil: 23%
- Natural gas: 20%
- Electricity: 20%
- Biomass and waste: 6%
- Other: 4%

Note: Includes coke ovens, blast furnaces and feedstocks.
Sources: IEA (2009a and 2009b).

Key point
Coal dominates industrial energy use in China where it accounts for more than twice the world average share.

Table 10.6 Industrial production, energy use and CO₂ emissions for China, 2007

<table>
<thead>
<tr>
<th>Industry sector</th>
<th>Production (Mt)</th>
<th>Reported energy use (Mtoe)</th>
<th>CO₂ emissions* (MtCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry sector</td>
<td>727</td>
<td>2 649</td>
<td></td>
</tr>
<tr>
<td>Iron and steel</td>
<td>495</td>
<td>276</td>
<td>1 095</td>
</tr>
<tr>
<td>Chemicals and petrochemicals</td>
<td>46</td>
<td>139</td>
<td>214</td>
</tr>
<tr>
<td>Aluminium</td>
<td>16</td>
<td>35</td>
<td>61</td>
</tr>
<tr>
<td>Non-metallic minerals</td>
<td>116</td>
<td>1 099</td>
<td></td>
</tr>
<tr>
<td>Cement</td>
<td>1 354</td>
<td>112</td>
<td>953</td>
</tr>
<tr>
<td>Pulp, paper and printing</td>
<td></td>
<td>17</td>
<td>40</td>
</tr>
<tr>
<td>Paper and paperboard</td>
<td>78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulp</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovered paper</td>
<td>31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>145</td>
<td>141</td>
<td></td>
</tr>
</tbody>
</table>

Note: Iron and steel includes energy use for coke-making. Chemicals and petrochemicals include feedstocks.
* CO₂ emissions are direct energy and process emissions only and do not include indirect electricity emissions.
Sources: IEA (2009a and 2009b); FAO stats (2010); World Steel Association (2009); IAI (2009); USGS (2009); IEA analysis.
Energy and CO₂ savings potential with best available technologies

Significant energy savings in Chinese industry are possible through the implementation of current best available technologies (BATs). The energy efficiency potential for China is similar to that of most industrialised countries. Typically an efficiency gain of 10% to 25% seems feasible, considering the gap between Chinese average energy use and BAT today. Total estimated potential savings for the five sectors analysed is 118 Mtoe per year, equivalent to 16% of energy use in industry in 2007 and 10% of total energy consumption in China.

Part of this gap will be closed as old capacity is scrapped and replaced by current BATs. The country’s capital stock is a mix of large state-of-the-art facilities and small outdated plants. Policies have been implemented in a number of sectors which require the mandatory closure of the smallest most energy-intensive facilities and much progress has been made since 2005, but additional potential still remains. Enforcing and monitoring the closure of some of these facilities has proven difficult in some cases as many of these facilities represent an important source of income for local communities.

China’s high share of primary production makes it one of the most CO₂-intensive industries. As more scrap becomes available, its share of recycling will rise, which will help to reduce the country’s industrial energy use and CO₂ emissions.

The 11th Five-Year Plan, announced in 2005, established an ambitious goal of reducing energy intensity by 20% between 2005 and 2010. One of the key initiatives for realising this goal is the Top-1 000 programme. The energy consumption of these 1 000 enterprises accounted for 33% of national and 47% of industrial energy use in 2004. A number of initiatives have been undertaken as part of this programme, including benchmarking, energy audits, the development of energy-saving action plans, information and training workshops, and annual reports of energy consumption.

Scenarios for industrial energy use and CO₂ emissions

Global industrial production growth over the last decade has been dominated by China and strong growth in many sectors is expected to continue over the next decades. As the economy matures, the consumption and production of energy-intensive materials such as cement and iron and steel are expected to peak over the next decade with a decline in cement production after 2030 as construction levels begin to slow.

---

3. The IEA’s industry indicators analysis has highlighted some inconsistencies between reporting of energy use across countries. Energy data on Chinese industry are collected for all enterprises with sales above CNY 5 million and estimated for smaller enterprises which fall below this threshold, which could lead to under-allocation in different sub-sectors. Following extensive consultation with Chinese experts over the past several years on a variety of industrial sectors, the IEA has calculated energy savings potentials based on adjusted energy use data for Chinese industry.
In the Baseline scenario, energy use is expected to increase to more than double current levels, reaching 1 610 Mtoe (low-demand case) to 1 820 Mtoe (high demand case) in 2050. Higher levels of energy efficiency in the BLUE scenarios will reduce the growth in industrial energy use to between 1 200 Mtoe and 1 380 Mtoe in 2050, 25% below the level of energy use in the Baseline scenario and 65% to 90% higher than in 2007. Coal currently represents 58% of total fuel use in industry. This will decline significantly in the BLUE scenario falling to approximately 35% in 2050. In both the Baseline and BLUE scenarios, electricity consumption rises sharply by 2050 as higher levels of recycling are achieved in many sectors. Measures to reduce the CO₂ intensity of industry in the BLUE scenarios will also result in higher shares of natural gas use, particularly in the chemical sector for the production of ammonia.

Energy use in the BLUE scenarios is 20% to 25% below Baseline scenario levels.
In the Baseline scenario, China’s emissions continue to rise rapidly over the next 20 years, but then rise only moderately as the country’s consumption of the most CO₂-intensive products, such as cement and iron and steel, begins to level off after 2030. Total direct and indirect industrial CO₂ emissions in the Baseline scenario are projected to rise from 4 Gt CO₂ in 2007 to between 8 Gt CO₂ and 8.7 Gt CO₂ in 2050. In the BLUE scenario, total industrial CO₂ emissions fall to just over 2.6 Gt in 2050 as the electricity sector reaches near-decarbonisation levels and indirect emissions from electricity fall to 0.2 Gt CO₂ in the BLUE scenarios in 2050.

Indirect emissions associated with industry in 2007 were 1.4 Gt CO₂. They are projected to reach 4.5 Gt CO₂ to 4.6 Gt CO₂ in the Baseline scenario in 2050. This highlights the benefits of decarbonising the power sector. Direct energy and process CO₂ emissions in China will continue rising in the Baseline scenarios, but at a slower rate than total direct and indirect CO₂ emissions, rising from 2.6 Gt CO₂ in 2007 to 3.5 Gt CO₂ to 4.0 Gt CO₂ in 2050 (Table 10.7). In the BLUE scenarios, direct emissions are 25% lower in 2050 than current levels. The largest reductions in direct emissions will come from the iron and steel and cement sectors.

<table>
<thead>
<tr>
<th>Mt CO₂</th>
<th>2007</th>
<th>Baseline low 2050</th>
<th>Baseline high 2050</th>
<th>BLUE low 2050</th>
<th>BLUE high 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>63</td>
<td>148</td>
<td>194</td>
<td>131</td>
<td>98</td>
</tr>
<tr>
<td>Iron and steel</td>
<td>1 095</td>
<td>1 197</td>
<td>1 326</td>
<td>645</td>
<td>568</td>
</tr>
<tr>
<td>Chemicals</td>
<td>212</td>
<td>557</td>
<td>680</td>
<td>267</td>
<td>296</td>
</tr>
<tr>
<td>Cement</td>
<td>953</td>
<td>640</td>
<td>785</td>
<td>480</td>
<td>427</td>
</tr>
<tr>
<td>Pulp and paper</td>
<td>40</td>
<td>141</td>
<td>203</td>
<td>76</td>
<td>104</td>
</tr>
<tr>
<td>Other</td>
<td>286</td>
<td>863</td>
<td>863</td>
<td>382</td>
<td>405</td>
</tr>
<tr>
<td>Total</td>
<td>2 650</td>
<td>3 545</td>
<td>4 051</td>
<td>1 981</td>
<td>1 898</td>
</tr>
</tbody>
</table>

Sources: IEA (2009a and 2009b); IEA analysis.

A range of measures including energy efficiency, fuel and feedstock switching, higher levels of recycling and energy recovery, and CCS will be needed to reduce China’s industrial emissions (Figure 10.14). Emissions will need to peak by around 2015 and then begin to decline as the benefits of greater energy efficiency and fuel and feedstock switching start to take effect. As the production of many materials will continue to grow strongly, efficiency, fuel and feedstock switching and greater levels of recycling will not be sufficient to offset strong production growth. Other more advanced technologies will be needed further to reduce energy intensity. To achieve a significant reduction in current industrial emissions will require the introduction of CCS technologies. The first carbon capture demonstration plants in industry will be needed from 2015 with wider deployment from 2025. In the BLUE scenarios, CCS alone reduces emissions by 0.5 Gt CO₂ to 0.8 Gt CO₂.
Figure 10.14 Options for reducing direct CO₂ emissions from Chinese industry

Key point
Energy efficiency and CCS represent the most important opportunities to limit growth in industrial CO₂ emissions.

In the BLUE scenario, China is the largest contributor to world industrial emissions reductions with direct industrial CO₂ emissions falling by approximately 0.7 Gt by 2050 compared to current levels. All industry sectors will need to reduce their CO₂ intensity if the industry sector as a whole is to reduce its emissions, but measures taken in the cement and iron and steel sectors will be particularly important as they represent over three-quarters of all emissions today. In both sectors, CCS will be needed to achieve significant reductions in emissions. Realising the potential offered by energy efficiency will require the diffusion of current BAT in both the cement and iron and steel sectors and the closure of small, inefficient, older facilities.

The closure and replacement of wet kilns and vertical shaft kilns in China with 5- and 6-stage preheater/precalcer kilns will reduce both the energy and CO₂ intensity of cement production. In addition, higher levels of alternative fuel use and lower cement-to-clinker ratios could further reduce emissions in the cement sector. In the BLUE scenario, alternative fuel use rises from 2% in 2007 to 31% in 2050, and the cement-to-clinker ratio falls from 0.77 to 0.68.

In the iron and steel sector, as more scrap becomes available, higher levels of recycling will become possible and a larger share of steel production can be based on electric arc furnace technologies which are significantly less energy-intensive than basic oxygen furnaces. As China’s power sector progressively decarbonises, electrification options in steel production will help the sector to reduce its CO₂ intensity. Smelt reduction also offers an attractive opportunity to reduce the energy and CO₂ intensity of primary steel production and is assumed to be widely deployed in China in the BLUE scenario.

China’s chemical sector is unlike that in many other countries because of its heavy reliance on coal for the production of ammonia. In most countries natural gas and to a lesser degree oil is used. An increase in the amount of ammonia production
based on natural gas could significantly reduce emissions in the chemical sector, but this will depend on the development of unconventional gas sources as natural gas production in China is currently relatively low. In the BLUE scenario, high carbon prices lead to a shifting of ammonia production from coal to natural gas.

Buildings sector

The buildings sector, including the residential, commercial and public service sectors, accounts for about 18% of TPES in China. Since 1990, the consumption of coal and biomass has been decreasing in Chinese households while the consumption of electricity, district heating, natural gas and petroleum products has been growing rapidly (Figure 10.15). With the boom in the commercial and service sectors in China since the early nineties, the demand for energy in this sector has also grown very rapidly (Figure 10.15).

Figure 10.15 Residential and service sectors energy consumption by fuel for China

Key point

*Biomass and waste are the dominant sources of energy in the residential sector. Energy demand in the commercial sector has shown much more rapid growth over the last two decades than demand in the residential sector.*

Part of the growth in electricity, gas, heat and oil products is due to the increasing urban population and the improved standards of living that are being driven by rapid economic growth. Between 1990 and 2006, the urban population increased from 302 million to 577 million (91%), and its share of all energy use increased from 26% to 45%.
Energy consumption by end-use

China covers a number of very diverse climate regions. As a result, energy consumption levels and patterns vary widely across the country. Regions in the north-east have significant heating loads, those in the centre have cold winters and warm summers, and those in the south-east have only very modest heating requirements.

Energy consumption by end-use is shown in Figure 10.16. In the residential sector, space and water heating and cooking dominate, while in the service sector space and water heating and lighting dominate. The rapid growth in electric appliances and applications means that the electrical end-uses share of the total is growing quickly, albeit from a low base. The potential growth in demand for cooling and appliances is particularly high.

**Figure 10.16** Residential and service sectors energy consumption by end-use for China, 2007

![Energy Consumption Diagram](image)

Sources: LBNL and IEA estimates.

**Key point**

Energy demand for space and water heating currently represent the majority of energy consumption in the buildings sector.

Scenarios for buildings energy use and CO₂ emissions

China’s population is projected to grow from around 1.3 billion in 2007 to around 1.4 billion in 2050. At the same time, the growth in the number of households will be even higher as the trend towards fewer people per household accelerates. Total households are assumed to grow from 373 million in 2007 to just over 500 million in 2050, with the proportion of urban households rising from 45% to 78% over that period. The floor area of the service sector is expected to grow rapidly as economic growth expands, and is assumed to grow by an average of just over 4.4% a year between 2007 and 2050.
The Baseline scenario

China has experienced rapid growth in energy demand in the buildings sector in recent years, particularly for higher-quality fuels. This rapid growth is driven by increased incomes and urbanisation. The challenge this poses for energy and environmental systems is an area of increasing policy activity in China.

Energy efficiency in the buildings sector has been an emerging priority since the 1980s when China embarked on its large-scale urban construction effort (Huang and Deringer, 2008). Most recently, a revised Energy Conservation Law, released in 2007, has sought to address the issue of energy efficiency in buildings.

China has addressed the energy consumption of appliances by introducing labelling schemes and minimum energy performance standards (MEPs) for a wide range of appliances. The MEP for appliances continues to be tightened over time.

The result of these policy efforts has been to improve energy efficiency and generally to lower life-cycle costs for consumers. Increasing policy efforts have had a significant impact on the outlook for energy consumption in the buildings sector.

Energy demand growth in the Baseline scenario

Energy consumption in the buildings sector increases by 94% between 2007 and 2050 in the Baseline scenario (i.e. by 1.6% per year), from around 386 Mtoe to 749 Mtoe. The consumption of gas is projected to grow at 4.8% a year, electricity at 4% a year, solar at 4.3% a year, purchased heat at 2% a year and oil at 1.8% a year. Coal consumption is projected to decline by 0.5% per year and biomass consumption by 1.7% per year.

The continued rapid growth in the importance of the service sector sees its share of energy consumption in the buildings sector increase from 18% in 2007 to 30% in 2050. The residential sector’s share declines from 82% to 70%, in part owing to slower growth than the service sector, but also in part owing to improved efficiency in the use of biomass through improved stoves, biogas and bio-dimethyl ether.

The BLUE Map scenario

In the BLUE Map scenario, energy consumption in the residential and service sectors is reduced by 38% below the Baseline level in 2050, equivalent to a saving of 286 Mtoe (Figure 10.17). Energy consumption in these sectors is only 20% higher in 2050 than in 2007, despite growing energy service demand, as a result of efficiency measures and fuel switching. Biomass and petroleum products are reduced by the most in percentage terms (64% and 66% respectively) as improved efficiencies, and the increased use of solar water heating and other fuel switching, reduces demand. Electricity demand is reduced by 111 Mtoe, the largest amount in absolute terms, equivalent to a 35% reduction below the Baseline scenario level in 2050. Oil and gas consumption are also significantly reduced in the BLUE Map scenario. Solar thermal water heating increases significantly and solar use increases by 27 Mtoe to a level more than twice as large as in the Baseline scenario in 2050.
Residential energy consumption is reduced by around 203 Mtoe below the Baseline level in 2050 in the BLUE Map scenario (Figure 10.18). Service sector energy consumption falls by 83 Mtoe. In the residential sector, 77% of the savings come from space heating, cooking and water heating, as the very large-scale deployment of efficient cooking stoves and solar thermal water heating systems offers significant energy savings potential. The use of biomass derived DME and liquid biofuels also helps to improve efficiency. The reduction in space heating demand is achieved through a mixture of building shell improvements and heating system improvements. In zones with warm summers and relatively cold winters, highly efficient reversible air conditioners help reduce the energy demand for space heating significantly, while in colder regions ground source heat pumps are also projected to play an important, although not quite so significant, role.

In the service sector, water and space heating account for just under half of the savings. There are very significant savings from the electricity-intensive end-uses of cooling, lighting and other miscellaneous loads.

Residential and service sector CO₂ emissions are reduced by 36% below the Baseline scenario in 2050 in the BLUE Map scenario. Overall CO₂ emissions are reduced by 1 195 Mt CO₂ (excludes the impact of the decarbonisation of the electricity sector) below the Baseline level in 2050, with almost three-quarters of this reduction attributable to the reduced consumption of electricity. The savings...
from electricity are reduced to some extent by the switching from fossil fuels to electricity for cooking and water heating in the BLUE Map scenario, as a result of the substantial decarbonisation of the electricity sector, making electrification an attractive abatement option.

Figure 10.18> Contribution to reductions in energy use in the BLUE Map scenario for China, 2050

<table>
<thead>
<tr>
<th></th>
<th>Residential 203 Mtoe</th>
<th>Services 83 Mtoe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water heating 15%</td>
<td>Water heating 23%</td>
</tr>
<tr>
<td></td>
<td>Cooling 4%</td>
<td>Cooling 22%</td>
</tr>
<tr>
<td></td>
<td>Lighting 2%</td>
<td>Lighting 13%</td>
</tr>
<tr>
<td></td>
<td>Cooking 3%</td>
<td>Space heating 33%</td>
</tr>
<tr>
<td></td>
<td>Other 17%</td>
<td>Other 9%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Space heating 59%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other 17%</td>
</tr>
</tbody>
</table>

Key point

The largest potential for energy savings in the buildings sector comes from energy efficiency measures to reduce energy demand for space heating.

Space and water heating excluding building shell measures accounts for 20% of the reduction in CO₂ emissions below the Baseline scenario in 2050 (Figure 10.19). The assumed continuous tightening of building codes and standards to a low-energy standard of around 50 kWh/m²/year for space heating results in accelerated savings in cold climate regions after 2030. Important contributions are also made from solar thermal, heat pumps and CHP/district heating. Energy efficiency improvements in appliances, lighting and cooking account for 34% of the reduction below the Baseline level.

The CO₂ emissions reductions from cooling are around 9% of the total, with slightly more than two-thirds coming from improvements in the efficiency of ventilation and air-conditioning systems. The balance comes from improvements in building shell and design, including the increased use of shading and active shutters, reflective coatings and insulation. Lighting systems are already estimated to be more efficient today in the residential sector than in many OECD countries thanks to the high use of fluorescent lights, but significant further improvements are possible, particularly in the service sector.
**Figure 10.19** Contribution to reductions in CO₂ emissions in the building sector in the BLUE Map scenario, China

A wide range of options are needed to limit growth in CO₂ emissions in the buildings sector.

**Transport sector**

Transport sector energy use in China was 158 Mtoe in 2007 and accounted for 11% of total final energy use. This share is low compared to OECD countries, but the rapid increase of car ownership levels in China will undoubtedly change this picture in the near term. Passenger transport still accounts for a relatively small share of transport energy use especially for individual vehicles, with two- and three-wheelers, which far outnumber cars, using as much energy as passenger LDVs (Figure 10.20).

**Figure 10.20** Transport sector final energy mix in China and in the world, 2007

Note: Air and shipping includes an estimate of international trips starting from China.
Sources: IEA (2009a and 2009b).

Key point

Transport energy demand from LDVs in China is currently well below global levels.
Modal transport indicators are broken down by activity, intensity and fuel use variables in Table 10.8. An important shortcoming of the Chinese energy use data as reported in the IEA statistics is that road fuel use is not specified in terms of vehicle type. This is estimated by the IEA using data and assumptions on vehicle stocks, efficiency and average travel. These estimates are based on current production levels and energy intensities from a range of sources. There is a need to validate these estimates.

Table 10.8  Transport energy and CO₂ indicators in China, 2007

<table>
<thead>
<tr>
<th></th>
<th>Passenger travel</th>
<th>Freight travel</th>
<th>Stock average energy intensity</th>
<th>Fuel use</th>
<th>Passenger</th>
<th>Freight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(bn pkm)</td>
<td>(bn tkm)</td>
<td>(MJ/pkm)</td>
<td>(MJ/tkm)</td>
<td>(Mtoe)</td>
<td>(Mt CO₂)</td>
</tr>
<tr>
<td>LDVs</td>
<td>621</td>
<td>1.5</td>
<td>22</td>
<td>73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-3-wheelers</td>
<td>144</td>
<td>69</td>
<td>0.8</td>
<td>5.5</td>
<td>21</td>
<td>48</td>
</tr>
<tr>
<td>Buses</td>
<td>1725</td>
<td>0.3</td>
<td>13</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freight trucks</td>
<td>755</td>
<td>1.7</td>
<td>34</td>
<td>144</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rail</td>
<td>639</td>
<td>1814</td>
<td>0.2</td>
<td>0.3</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>Air</td>
<td>385</td>
<td>3.2</td>
<td>30</td>
<td>104</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>24</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td><strong>Total / average</strong></td>
<td><strong>4514</strong></td>
<td><strong>2638</strong></td>
<td><strong>0.8</strong></td>
<td><strong>0.7</strong></td>
<td><strong>158</strong></td>
<td><strong>291</strong></td>
</tr>
</tbody>
</table>

Notes: In totals row, averages are provided for intensity figures and are weighted across modes. pkm: passenger-kilometres; tkm: tonne-kilometres.
Sources: IEA (2009d); IEA analysis.

Scenarios for transport energy use and CO₂ emissions

Although China currently accounts for only a small share of the world’s transport energy use and CO₂ emissions, Chinese travel growth is expected to change this picture rapidly over the next decade and beyond. The Baseline scenario to 2050 envisages almost an order of magnitude increase in passenger travel and goods transport, with accompanying large increases in energy use and CO₂ emissions. Large cuts in the growth of energy use and CO₂ emissions appear possible through efficiency measures, the adoption of new fuels, and directing travel growth towards the most efficient modes.

It will not be possible to achieve these savings immediately. The introduction of efficient technologies will take time, and will be dependent both on reductions in technology cost and on an increase in the capacity of Chinese businesses and consumers to afford these technologies. As new technologies are adopted in new vehicles, it will take many years for these vehicles to account for most of the stock and travel, since car stocks turn over completely only every 15 to 20 years and turnover in truck stocks is even slower.
Investments in sustainable transport, such as building high-quality rapid bus systems for cities and rail transit systems where travel densities are high, along with much better infrastructure for cycling and walking, can begin immediately. Investments in rapid public transit systems can provide important alternatives to private vehicles where motorised travel is needed. Despite rapid motorisation in China, it will be decades before car ownership levels are likely to reach those of Europe or the United States, and in the meantime most people will be dependent on mass transit and non-motorised modes for their mobility. The building of appropriate systems and infrastructure now may result in slower growth in cars, and in particular fewer cars in urban areas, relative to the Baseline scenario. This will result in long-term energy and CO₂ benefits along with lower pollutant emissions and important benefits both for mobility and for the quality of urban life. But even with such modal shifts, car ownership in China is likely to rise by a factor of five to ten in the coming decades.

**Baseline scenario**

Based on recent and expected future trends, in particular related to population and GDP per-capita growth, the Baseline scenario results globally in about a doubling of passenger-kilometres (pkm) of travel worldwide between 2007 and 2050. This results in a near doubling of energy use.

In China, travel growth will be much higher, increasing nearly fivefold by 2050. The growth in freight activity is projected to be even greater. As a result, even with some efficiency improvements in the Baseline scenario, Chinese transport energy use grows by a factor of more than five from about 160 Mtoe in 2007 to 900 Mtoe by 2050 (Figure 10.21). This results in Chinese transport energy use increasing from 8% of the world total today to nearly 20% by 2050.

One reason for this is Chinese car ownership. It is assumed to rise from about 25 cars per 1 000 people to over 300 per 1 000 in the Baseline scenario. This strong growth may continue beyond 2050 in the absence of measures to curtail it, perhaps until ownership is closer to European levels of around 600 cars per 1 000 people or even United States levels of over 700 cars per 1 000 people. In a transport Baseline High demand scenario described in more detail in Chapter 7, China’s energy use in the transport sector exceeds 1 000 Mtoe by 2050, reflecting higher assumed growth in car, truck and air travel than in the Baseline scenario. In the Baseline High demand scenario, Chinese car ownership is assumed to reach 400 cars per 1 000 people by 2050.

The impacts of the Baseline and Baseline High demand scenarios on China’s greenhouse-gas emissions are similar in terms of overall growth to those for energy use (Figure 10.21). Chinese transport greenhouse-gas emissions on a well-to-wheel (WTW) basis, grow from about 0.6 Gt in 2007 to about 3.3 Gt by 2050 in the Baseline scenario and to over 4 Gt in the Baseline High demand scenario. This represents nearly 20% of world transport greenhouse-gas emissions in 2050 in the Baseline scenario, and 25% in the Baseline High demand scenario.
**Figure 10.21** China’s transport energy demand and greenhouse-gas emissions

Emissions in the Baseline could quadruple by 2050 as high growth is expected in energy demand for LDVs, but the wider deployment of low-carbon vehicles and other transport technologies could keep transport emissions below 1.5 Gt in 2050.

**Key point**

The BLUE scenarios: technological pathways for transport in China

As for all regions in the ETP analysis, the BLUE Map scenario for transport in China features strong vehicle efficiency improvements, the aggressive adoption of advanced vehicle technologies after 2020, and a transition to the use of fuels, including electricity, that become increasingly decarbonised between 2030 and 2050. A separate scenario, BLUE Shifts, looks at the energy savings and CO\(_2\) emissions reductions associated with changes in the growth of travel by mode, with slower growth for car and air travel and higher growth for bus and rail mass transit modes. A BLUE Map/Shifts scenario combines the impacts of the BLUE Map and Shifts scenarios, to show the potential for combining vehicle and fuel technology
changes with travel mode changes. These scenarios project different levels of transport energy use and greenhouse-gas emissions for China (Figure 10.21).

In the BLUE Map scenario, greenhouse-gas emissions are cut by about 60% relative to the Baseline scenario in 2050 and are only a little higher than their 2007 levels. This is achieved through:

- A 50% reduction in the energy intensity of LDVs, and 30% to 40% reductions in the energy intensity of truck and air travel relative to current levels. Some much smaller improvement also occurs in the Baseline scenario.

- The introduction of alternative fuels, mainly as a result of the use of EVs and FCVs as LDVs, and up to 30% displacement of fossil fuels by biofuels for trucks, ships and aircraft.

The difference between the Baseline and BLUE scenarios is very significant for China, and highlights the enormous potential for cutting CO₂ emissions through introducing new technologies and fuels into Chinese markets. The greenhouse-gas mitigation potential of the BLUE Map scenario in China amounts to around 2 Gt CO₂ in 2050.

China’s adoption and recent tightening of fuel economy standards puts the country on an initial path to achieve strong reductions in fuel intensity for new LDVs by 2030 consistent with the BLUE Map scenario projections. But the current standards only apply until 2015 and it will be important that standards are continually tightened over time to ensure this trajectory continues. The scenarios also assume that improved fuel economy does not result in reduced fuel prices. As in OECD countries, it is assumed that most Chinese vehicles by 2030 are hybridised or use an advanced propulsion system such as an electric motor.

In the BLUE Map scenario, the sales profile of passenger LDVs by technology type in China changes rapidly (Figure 10.22). The market for EVs and PHEVs grows rapidly after 2015, and reaches combined sales of 11.5 million vehicles in 2030. By 2050, EVs dominate sales. Fast growth in China’s battery manufacturing industry is likely to help the introduction of hybrids, PHEVs and EVs in the near- to mid-term.

China is emerging as one of the most proactive countries in respect of its approach to EVs and battery manufacturing. Electric two-wheelers (mainly e-bikes and mopeds) have achieved sales of over 20 million a year in recent years. Recent joint China-United States announcements of EV deployment programmes underline the willingness of China to play an important role in the electrification of the transport sector, with an interim goal of electric LDV sales of 500 000 a year by 2011 (IEA, 2009d). A critical issue will be the extent to which these EVs provide near-term greenhouse-gas reductions, given the current electricity generation mix in China. The impact will depend as well on the relative efficiency of the EVs, which remains to be seen. Over time, especially in the BLUE Map scenario, Chinese electricity generation becomes much less carbon-intensive. By 2030, when there may be millions of EVs on the road in China, they should provide relatively low CO₂-intensity driving.
**Figure 10.22**  Passenger LDV sales by technology in the Baseline and BLUE Map scenarios for China

![Graph showing Baseline and BLUE Map scenarios for passenger LDV sales by technology.](image)

**Key point**

The BLUE Map scenario envisions rapid successive introduction of new generations of advanced vehicles in China’s rapidly growing market.

Ten million electric two-wheelers were sold in China in 2005 and about 20 million in 2008. The total electric bike stock in China is estimated to be over 100 million units, perhaps three times as many as all other EVs worldwide. Assuming they are displacing sales of gasoline-powered two-wheelers, the growth in electric two-wheelers will have already helped to cut oil use. Many may, however, be replacing bicycles. A number of factors have made e-bikes particularly popular, including price incentives and their generally low cost of operation. They also received a boost when gasoline two-wheelers were prohibited in many city centres to reduce noise and pollution levels. But some big cities have made city centre access to e-bikes difficult or forbidden them, apparently for safety reasons.

China also will likely be well positioned to move towards advanced technologies such as FCVs, although this may take longer to mature. Fuel-cell vehicles are assumed to play an important role for LDVs in China after 2025, assuming a time-frame similar to that for most OECD countries and ahead of most developing countries.

**The BLUE Shifts scenario: advanced rail and bus systems to help steer transport growth**

In the BLUE Shifts scenario, much higher growth in rail and bus travel, coupled with better land-use planning that cuts motorised travel demand growth, leads to significant energy savings by 2030 and still more by 2050. In China, rail will play a particularly important role.
An ambitious national programme for the expansion of high-speed rail (MOR, 2004) involves plans for more than 12 000 km of high-speed rail by 2020. More than 4 000 km are already built or in construction (UIC, 2009), making China one of the leading countries for high-speed rail. Figure 10.23 shows the potential high-speed lines envisaged by the Chinese government.

China’s railways were among the main beneficiaries of a stimulus package of RMB 4 trillion (USD 585 billion) announced in 2009. This will make the rail sector more attractive for passenger travel for medium and long distances, and appears likely to cut air travel growth. The rail sector will need to be further electrified, adding extra pressure on the electricity grid. Although high-speed rail is likely to take away passengers from the air sector, domestic and international air travel will still rise very significantly as demand for domestic and international tourism rises from a growing middle class.

**Figure 10.23** High-speed rail corridors in China, 2009

Source: Freemark (2009).

Key point

China has ambitious plans to develop an extensive high-speed rail network.
In the BLUE Shifts scenario, it is assumed that strong investments in all forms of rail transport continue beyond 2020, and that they help dampen growth in car, truck and air travel. Rail capacity by 2050 would need to be between 50% and 100% higher than in the Baseline scenario, with a similar increase in bus transport, to achieve the 25% reduction in the growth of car and air travel implicit in the BLUE Shifts scenario.

**Urban mobility in China**

Chinese authorities are very proactive in urban planning, and many mass transportation initiatives are under way in China’s biggest cities (Table 10.9). China is becoming a world leader in developing bus rapid transit (BRT) systems, using advanced technologies such as real-time bus schedule information and smart card ticketing systems. But even with strong investments in mass transit systems, urban travel is likely to be dominated by cars in many cities around the country in coming years. The reversal of current trends will depend on very strong policies that combine transit infrastructure with land use planning, on investments in non-motorised travel infrastructure, and on disincentives to car use such as road pricing. Road construction does not appear to be keeping pace in major urbanised areas, leading to growing traffic congestion and air quality problems.

<table>
<thead>
<tr>
<th>Number of cities</th>
<th>Metro</th>
<th>Tramways/LRT</th>
<th>BRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>In operation</td>
<td>9</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Under construction</td>
<td>12 metro and tramways</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Planned</td>
<td>6</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>55</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 10.9: Mass transit in Chinese cities, 2009

Note: Light rail transit (LRT).
Sources: ITDP (2009); CityRailTransit (2010); and RailwayTechnology (2010).

In summary, the Chinese transport sector is evolving very rapidly, in terms of vehicle sales, infrastructure construction, and the introduction of new technologies. Electrification is likely to play an important role in the development of transport in China. Although the total number of EVs will probably not put a significant additional load on the electricity system for some time, especially since most EVs will be recharged mainly at night, China will need to plan for a potentially very high electricity demand from vehicles and to decarbonise power generation in order to mitigate transport-related greenhouse-gas emissions.

**Investment needs in the BLUE Map scenario**

Significant additional investments in energy-efficient equipment, appliances, vehicles and buildings will be needed to transform the way energy is used in China (Figure 10.24). On the energy production side, the power sector will need
to be significantly decarbonised, which will require large investments in nuclear and renewable power generation and CCS. Additional technologies to reduce the CO₂ intensity of transport and industry will also be needed in the medium to long term.

Achieving the 30% emissions reduction in the BLUE Map scenario in 2050 compared to 2007 will require additional investments of USD 10.2 trillion between 2010 and 2050. Of this total, USD 5.2 trillion is required in the transport sector. Most of this will be needed after 2030 for low-carbon vehicles, extensive rail networks and biofuels. Additional investment needs in the buildings sector are estimated at USD 1.8 trillion, of which USD 0.64 trillion is required by 2030 and USD 1.16 trillion from 2030 to 2050. Decarbonising the power sector will require an additional USD 2.7 trillion in investments of which more than half is required by 2030 and the remainder from 2030 to 2050. Industry represents the smallest share of additional investment needs at USD 0.5 trillion. Given the large share of electricity use in industry, measures taken to decarbonise the power sector will help to reduce total emissions attributable to industry.

**Figure 10.24** Additional investment needs and fuel savings for China

<table>
<thead>
<tr>
<th>Power sector</th>
<th>Industry sector</th>
<th>Buildings sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010-2030</td>
<td>2030-2050</td>
<td>2010-2030</td>
</tr>
<tr>
<td>USD trillion</td>
<td>USD trillion</td>
<td>USD trillion</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

**Key point**

*Fuel savings offset higher investment costs in China.*

Investments made in energy efficiency, in low-carbon vehicles and in technologies to decarbonise the power sector will yield significant savings in fossil-energy consumption. Many of the investments in energy efficiency are already competitive on the basis of life-cycle costs. Overall, total undiscounted fuel savings from 2010 to 2050 in China are estimated at USD 19 trillion. Investment needs and fuel savings in the BLUE Map scenario are estimated to save USD 8.8 trillion net, undiscounted, from 2010 to 2050. The transition to a low-carbon energy system will help to reduce the country’s dependence on imports of foreign energy resources, leading to increased energy security and also important fuel savings.
Given the large share of additional investment that is needed for the transport and buildings sectors, the majority of these additional investments will be funded by consumers. During the COP-15 negotiations, China announced that it was not seeking direct financial assistance for mitigation efforts. However, international financing mechanisms such as carbon finance or sectoral crediting mechanisms could play an important role in the demonstration and early deployment of low-carbon technologies, particularly in the power sector and for heavy industry. As the world’s largest producer of steel, cement and aluminium, China offers some of the least costly opportunities to reduce CO₂ emissions in heavy industry. It thus has an opportunity to develop solutions that may be applicable elsewhere, thus becoming a provider of low-carbon technologies worldwide.

With USD 220 billion committed to low-carbon technologies, China’s economic stimulus plan is leading the way to a green recovery with more committed than any other country (HSBC, 2009). The bulk of these investments is aimed at expanding the country’s rail network, electricity grid and water infrastructure.

**Transition to a low-carbon energy future**

**Future technology and policy priorities**

Deep emissions reductions in China are achievable through the application of a mix of energy technologies which are already available today and through the development of a number of new technologies currently being developed. Different technologies have different contributions to make to achieve the 30% reduction in energy-related CO₂ emissions compared to 2007 levels that China needs to make in the BLUE Map scenario by 2050 (Figure 10.25). Compared to the Baseline scenario in 2050, this represents a reduction of 11.6 Gt CO₂. Measures to decarbonise the power sector will provide 40% of all emissions reductions. Energy efficiency in different end-use sectors would contribute another 37%. The single largest contribution to emissions reduction in China in the BLUE Map scenario is industrial energy efficiency and recycling which represent 18% of total savings.

China already has one of the most ambitious nuclear power programmes in the world with an official target of 70 GW of new nuclear capacity by 2020. Given the structure of the Chinese electricity market, the high expected growth in electricity demand and the country’s financial strength, nuclear power represents one of the most attractive options to help reduce CO₂ emissions and at the same time improve the country’s energy security. By 2050, nuclear capacity in the BLUE Map scenario reaches 320 GW, supplying 26% of China’s total electricity production. China has the opportunity to develop a significant nuclear industry and once the current build of second-generation (GEN II) plants is completed and third-generation (GEN III and GEN III+) technologies are more widely deployed globally, China is likely to focus its efforts on developing more advanced nuclear technologies.
**Figure 10.25** CO₂ emissions reduction by technology area in the BLUE Map scenario for China, 2050

**Key point**

Decarbonising the power sector contributes to the largest share of emissions reduction in China.

**Table 10.10** China’s current energy technology priorities

<table>
<thead>
<tr>
<th>Resource exploitation technology</th>
<th>High efficiency coal mining technology</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oil and gas exploration technology in complicated geographical conditions</td>
</tr>
<tr>
<td></td>
<td>Ocean oil and gas exploration technology</td>
</tr>
<tr>
<td></td>
<td>Exploration technology for coal-bed gas</td>
</tr>
<tr>
<td>Clean coal technology</td>
<td>Coal washing and depressing technology</td>
</tr>
<tr>
<td></td>
<td>Clean and high efficiency power generation</td>
</tr>
<tr>
<td></td>
<td>Coal-based liquid fuels and coal chemistry technology</td>
</tr>
<tr>
<td>Nuclear power station</td>
<td>Pressurised water reactors with capacity above 1,000 MW</td>
</tr>
<tr>
<td>Super large-scale electricity transmission and distribution network and electricity grid secondary system</td>
<td>Flexible AC transmission systems</td>
</tr>
<tr>
<td></td>
<td>High-voltage transmission systems</td>
</tr>
<tr>
<td></td>
<td>Interim electricity source connecting to grid technology</td>
</tr>
<tr>
<td></td>
<td>Monitoring and controlling electricity quality</td>
</tr>
<tr>
<td></td>
<td>Large-scale interconnected electricity grids security guaranteeing technology</td>
</tr>
<tr>
<td></td>
<td>Electricity dispatching automation technology</td>
</tr>
<tr>
<td>Scaled development of renewable energy with low cost</td>
<td>Large wind power generation units</td>
</tr>
<tr>
<td></td>
<td>Agricultural and forestry biomass power generation technology</td>
</tr>
<tr>
<td></td>
<td>Biogas power generation technology</td>
</tr>
<tr>
<td></td>
<td>Ethanol fuel</td>
</tr>
<tr>
<td></td>
<td>Biodiesel and bio briquette fuel</td>
</tr>
<tr>
<td></td>
<td>Solar energy technologies</td>
</tr>
</tbody>
</table>

The Chinese government’s energy R&D priorities are for the most part consistent with the technology priorities identified in the BLUE Map scenario. One area that has not yet been prioritised in China is transport (Table 10.10). China could also benefit from the development of greater fuel economy, second-generation biofuels and PHEVs and EVs as priority targets.

The wide deployment of different renewable power technologies including wind, solar CSP, solar PV, hydro and biomass technologies will also be needed if China is to decarbonise its power sector. China is already a leading manufacturer of wind turbines and solar PV panels, although the bulk of this production has been geared for the export market. For example, of the 2 GW of PV cells produced in 2008, 95% was exported (IEA, 2010). Only in the last few years has it been focused on domestic deployment. Recent policies aimed at spurring investments in renewable power generation have helped to boost the levels of renewable power, but an even quicker expansion with greater shares of production aimed at expanding the domestic market will be needed if the levels of wind and solar in the BLUE Map scenario are to be achieved.

More detailed renewable power resource assessments are needed in China to help identify and develop a least costly pathway for renewables development. Greater attention will also be needed to extend and reinforce the grid to allow for greater shares of renewables to be integrated into the electricity network. Some of the most attractive renewables potential is located far away from major demand loads. China’s plans to invest RMB 1.1 trillion in 2009/2010 to expand its electricity network shows that the country is aware of, and taking steps to address, these grid issues. Solar technologies in China have focused on solar PV development, but the results of the BLUE Map scenario analysis also show an important contribution from solar CSP. Greater attention should be given to developing both options.

Measures to decarbonise the power sector will have important benefits in all end-use sectors and will enable the development of electrification options in transport and industry. In transport, the development of PHEVs and EVs could contribute an estimated 0.4 Gt CO₂ of emissions reductions. It would also reduce oil consumption by an estimated 125 Mtoe, helping to reduce dependence on foreign oil imports. A decarbonised power sector will help to reduce total industry-related emissions and also provide an incentive to develop electrification options for industry. Indirect emissions in industry reached 1.4 Gt CO₂ in 2007 and are estimated to reach 5.0 Gt CO₂ in 2050 in the Baseline scenario. In the BLUE low-demand scenario, indirect emissions in industry amount to just 0.7 Gt CO₂.

The three largest sectors of iron and steel, chemicals and cement are responsible for about 50% of China’s total emissions. Priority should be given to reducing the CO₂ intensity in these sectors. The demonstration of CCS in these industries is urgent. China’s leading position in many of these industries offers an attractive opportunity for early demonstration, perhaps with international support. Achieving wider deployment may also require the implementation of sectoral crediting mechanisms which would encourage Chinese industries to invest in these technologies.
Key findings

In the Baseline scenario, final energy consumption increases in India by more than 3.5 times by 2050 and carbon dioxide (CO₂) emissions by nearly five times. India remains heavily dependent on fossil fuels. Coal, oil and natural gas use all increase by more than a factor of four. Emissions amount to 6.5 gigatonnes (Gt) of CO₂ in 2050.

In the BLUE Map scenario, CO₂ emissions in 2050 are only 10% higher than in 2007. The share of fossil fuels declines to 49% of total primary energy supply (TPES) in 2050. The deployment of a wide range of low-carbon fuels and technologies increases significantly.

Population growth, the modernisation of lifestyles, higher electrification rates and rapidly growing gross domestic product (GDP) drive a large increase in energy demand. Meeting these needs will require huge investments in new infrastructure in both the Baseline and the BLUE Map scenarios.

The BLUE Map scenario entails considerable additional investment compared to the Baseline scenario, but it will also bring substantial benefits. Additional investments of USD 4.5 trillion are required between 2010 and 2050, but these result in fuel savings of USD 8.0 trillion over the same period. Energy security improves very significantly: oil use in 2050 is 56% lower than in the Baseline scenario.

The need for very large investments in new power plants and infrastructure opens up significant opportunities for reducing energy requirements and associated CO₂ emissions while meeting the country’s electricity needs. Priority should be given to deploying wind, solar and nuclear power generation and to deploying clean coal technologies, including coal washing, the development of integrated gasification combined cycle (IGCC), supercritical (SC) and ultra-supercritical (USC) power technologies and carbon capture and storage (CCS).

Significant progress to improve the energy intensity of India has been achieved in the recent past. Despite this improvement, there is still a great potential to improve efficiency and reduce the growth in CO₂ emissions across all sectors by the application of best available technologies (BATs).

India has some of the most efficient industrial plants in the world, but it also has a large share of inefficient plants. Improved energy efficiency has the potential to limit the growth in energy use and CO₂ emissions, but CCS will be required to achieve more significant savings. Other priority areas include moving away from coal-based direct reduced iron (DRI) in iron production and continue the substitution of oil feedstocks in the chemicals sector.
Although the passenger vehicle stock is already relatively efficient in India, improvements in new vehicle technology and the penetration of hybrids, plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs) will be required to limit the growth in transportation energy consumption and reduce the increase in CO₂ emissions seen in the Baseline scenario.

Strong growth in energy demand is also expected in the buildings sector. Increasing standards of living, higher demand for services and migration from rural to urban areas will also play a role in increasing energy consumption. Large efficiency improvements will be essential if the growth in energy consumption is to be restrained. The near decarbonisation of the electricity sector will also need to play an important role in reducing CO₂ emissions.

India already has ambitious targets in a number of technological areas, including energy efficiency, renewable energy and nuclear energy. The short-term priority should be to ensure that these targets are met. In the medium to longer term, they will need to be substantially strengthened and extended into new areas such as CCS and advanced vehicles.

Regional description

The Republic of India is the seventh-largest country in the world. The land area covers 2.97 million square kilometres (km²) with an elevated tableland in the south, deserts in the west, the Himalayan Mountains in the north and flat-to-rolling plains along the Ganges River.

India is the second most populous country after China, with a population estimated to be 1.123 million in 2007, about 17% of the world’s total population; in 2008, 60% of the labour force was involved in agriculture, 12% in industry and 28% in services (CIA, 2010). India has the largest rural population in the world, with 828 million rural inhabitants (UNPD, 2008). In 2008, 71% of India’s total population lived in rural areas. The rate of migration to urban areas, at 2.3% a year, is lower in India than in many other developing countries (UNPD, 2008).

India’s GDP was USD 4.025 billion in 2007 (IEA, 2009a). Average annual growth of GDP has been high, averaging 7.7% from 2000 to 2007. In 2007, services accounted for 52.8% of total GDP, industry for 30% and agriculture for 18% (World Bank, 2009). The share of services in total GDP is much higher than that in most other developing economies.

While economic development has led to an increase in the average standard of living, it has largely bypassed most of the rural poor. So although the Indian economy has grown rapidly, poverty remains a major challenge.

1. In 2000 purchasing power parity (PPP) terms.
Only 65% of the Indian population has access to electricity (IEA, 2009b). Electrification reaches 93% of the urban population but only 53% of the rural population.

Recent trends in energy and CO₂ emissions

India’s energy system is largely coal-based. Coal is the most important and abundant fossil fuel, accounting for about 55% of commercial energy supply in the country (MOC, 2010). About 7% of the world’s proven coal reserve is located in India. Regionally, India’s hard coal reserves are concentrated in the east, in a band that stretches from Chhattisgarh over Orissa, West Bengal, to the Bangladesh border. This band continues further north-east into Assam (Table 11.1).

Only a small share of the world’s proven reserve of crude oil is located in India. About half of India’s reserve is located onshore, with most onshore oilfields being located in Gujarat and Assam (MPNG, 2009). Offshore oilfields are located in the west coast, in the Mumbai area. About 50% of the refining capacity is located in Mumbai, Assam and Gujarat.

Over 75% of India’s natural gas reserves are located offshore, with gas fields on both the west coast and the east coast (MPNG, 2009).

The distribution of energy sources makes the transportation of energy and the generation, transmission and distribution of electricity major issues for the Indian energy supply system.

<table>
<thead>
<tr>
<th>Table 11.1</th>
<th>Proven energy reserves in India and in the world, 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coal (bt)</td>
</tr>
<tr>
<td>Proven reserves: India</td>
<td>58.6</td>
</tr>
<tr>
<td>Proven reserves: world</td>
<td>826</td>
</tr>
<tr>
<td>Production in 2008: India</td>
<td>0.5</td>
</tr>
<tr>
<td>Reserve-to-production ratio: India</td>
<td>122</td>
</tr>
</tbody>
</table>

Note: Reserve-to-production ratio indicates the length of time that the recoverable reserves would last if production were to continue at current rates and if no additional reserves could be recovered.

Sources: BP (2009); MPNG (2009).

Energy production and supply

Primary energy supply in India has increased by 3.8% a year since 1971 (Figure 11.1). The energy supply mix has changed significantly over time. The supply is more diverse today. Oil and coal have increased their joint share of the total supply substantially since 1971, from 37% to 65%, and natural gas and nuclear have become more important in recent years.
Primary energy production in India has increased at a slower rate, 3.3% per year, than energy supply since 1971. As a result, an increasing share of energy supply is now met by imports. In 2007, 32% of the country’s energy supply came from imports, compared to 10% in 1971.

India is a net importer of all fossil fuels. Despite the doubling of domestic coal production between 1990 and 2007, imports have represented an increasing share of total primary coal supply, increasing from 4% to 14% (Figure 11.2). Part of the rapid increase in coal imports reflects the failure of indigenous coal production to keep pace with demand and the fact that the supply costs of indigenous coal on the west coast are higher than those for imported coal. Indigenous coal is also of low quality, with up to 50% ash content. This is detrimental to power plant efficiency and power production capacity.

India’s New Exploration Licensing Policy (1999) was successful in attracting private investment, mainly from domestic investors, and several major oil and natural gas finds have been made since the launch of the policy. Even so, India has needed to import increasing volumes of petroleum and natural gas to meet demand.

All the increase in primary oil supply and about half of the increase in natural gas supply have been met by imports. Import of oil increased almost fivefold between 1990 and 2007.
Figure 11.2  ▶ Energy production, imports and exports for India

![Graph showing energy production, imports, and exports for India](image)

**Note:** Nuclear production refers to the heat produced in nuclear reactors, irrespectively of whether the nuclear fuel used is from domestic sources or imported. Other renewables includes non-combustible renewables.

**Source:** IEA (2009a).

**Key point**

About three-quarters of oil supply was imported in 2007.

**Energy consumption**

Industrial development has contributed significantly to economic growth in India over last few decades. Industrialisation has not been uniform. Large and modern urban centres coexist with a traditional rural and agrarian economy.

Energy use for the generation of electricity, both to sustain economic development and to provide electricity to all households, has increased by 9% a year since 1971. In 2007, one-third of the energy supply was used to generate electricity. About 75% of the coal supply in 2007 was used in power generation. Electricity now provides 12% of the end-use sectors’ energy needs.

End-use energy consumption, including the final consumption of electricity, has also increased rapidly since 1971, at an average rate of 2.8% a year. The growth was mostly driven by the increase in the demand for energy from the agriculture sector which increased by 7.1% a year. Demand from other end-use sectors increased by between 1.9% and 3.4% a year. Since 2004, energy demand from the transport and industrial sectors has grown as much as demand from the agriculture sector. From 2004 to 2007, overall final energy consumption in India increased by 4.3% a year to 393 million tonnes of oil equivalent (Mtoe).

The fuel mix is quite different for different end-use sectors (Figure 11.3). Industry was the largest end user of coal, accounting for 83% of coal used by end-use sectors. The transport sector is a major user of oil, consuming about 40% of total...
final oil consumption. About 75% of the energy requirement of buildings is met by combustible biomass and waste. However, as rural areas become increasingly electrified and as improvements are made to the electricity system, the use of electricity is increasing. In 2007, electricity accounted for 9% of the energy used in buildings, up from 3% in 1990.

The industrial sector shows a more diversified energy mix, mostly related to the different energy requirements of different industries. Natural gas is slowly increasing its share in the industrial sector. The growing availability of natural gas through increased production and imports and the expansion of the chemicals sector, particularly for the production of fertilisers, have played a major role in the increased use of natural gas.

**Figure 11.3** Final consumption by fuel and by sector for India

<table>
<thead>
<tr>
<th>Mtoe</th>
<th>1990</th>
<th>2000</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>0</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>Transport</td>
<td>25</td>
<td>100</td>
<td>125</td>
</tr>
<tr>
<td>Buildings</td>
<td>125</td>
<td>175</td>
<td>200</td>
</tr>
<tr>
<td>Other sectors</td>
<td>50</td>
<td>75</td>
<td>100</td>
</tr>
</tbody>
</table>

**Note:** Other includes non-combustible renewables. Industry includes petrochemical feedstocks and coke ovens and blast furnaces. Transport includes pipelines, international marine bunkers and international aviation. Other sectors include agriculture, fishing and forestry.

**Source:** IEA (2009a).

**Key point**

The energy mix varies widely between end-use sectors.

### End-use efficiency improvement

Final energy intensity in India was 98 kilotonnes of oil equivalent (ktoe) per USD 1 000 in 2007. Energy intensity has improved by 4.3% a year since 2000. This strong improvement in energy intensity is largely attributable to the rapid introduction of modern, efficient technologies and processes, and a structural shift between and within end-use sectors.

In the absence of detailed activity and energy consumption data for all the sectors at the end-use level, preliminary analysis at a more aggregate level suggests that the overall improvement in energy efficiency in India was at least 0.75% a year between
2000 and 2007. Without energy savings resulting from these improvements in energy efficiency, total final energy consumption would have been 10% higher (about 40 Mtoe) in 2007 than it actually was.

Carbon dioxide emissions

Energy-related CO\textsubscript{2} emissions in India increased by 125% between 1990 and 2007 to 1.34 Gt CO\textsubscript{2}. This is much higher than the growth observed in TPES (87%) or in end-use energy consumption (54%), largely as a result of an increase in the share of coal used for the generation of electricity and a reduction in the share of combustible renewables and waste. The increased use of natural gas and oil also increased the overall CO\textsubscript{2} intensity of the fuel mix in end-use sectors.

Overall energy policy framework

India’s energy sector is currently administered and managed through a complex multi-ministerial structure which involves the Union Ministry of Power, the Ministry of Coal, the Ministry of Petroleum and Natural Gas, the Ministry for New and Renewable Energy, the Department of Atomic Energy and the Planning Commission as well as other government bodies and agencies such as the Bureau of Energy Efficiency (BEE). The role of the Ministry of Environment and Forests in energy policy has also increased in recent years.

Reflecting India’s federal governance structure, each of India’s states and Union Territories (UTs) has significant constitutional rights in the power sector. The majority of states and UTs have established a state-level ministry or department for electricity, and some also have ministries or departments for energy. The pace of electricity reform varies considerably between energy sub-sectors and across the Indian states and UTs.

The Electricity Act (GOI, 2003) provides an enabling framework for the development of the power sector. The Act requires the central government to develop, in consultation with state governments and the Central Electricity Authority (under the Union Ministry of Power), a National Electricity Policy (NEP, notified in 2005) and a National Tariff Policy (NTP, notified in 2006). The NEP lays guidelines for accelerated development of the power sector, supplying electricity to all areas and protecting the interests of consumers and other stakeholders. The NTP offers general and uniform parameters to the State Electricity Regulatory Commissions for the formulation of regulation and for fixing tariffs for the respective legal entities, ensuring adequate returns and reasonable user charges.

A Rural Electrification Policy (REP) was also notified in 2006 under provisions in the Electricity Act. The REP sets out ambitious proposals to provide reliable electricity at reasonable rates to all households by 2012. Rural electrification is primarily the responsibility of each state and UT government. This is supported by central government policy funding provided through various financing schemes administered by the Rural Electrification Corporation under the Union Ministry of Power.
Policies on petroleum and natural gas are the sole responsibility of the central government. The Hydrocarbon Vision 2025 (GOI, 1999) set out to liberalise the market in hydrocarbons and to encourage private-sector investment in the upstream and downstream sectors.

Under the Petroleum and Natural Gas Regulatory Board Act (GOI, 2006b) the Petroleum and Natural Gas Regulatory Board was established in 2007 to promote competition and provide for access to pipelines on a non-discriminatory basis. The pricing of petroleum and natural gas is excluded from the Act and will remain under government control. Upstream activities are regulated by the Directorate-General of Hydrocarbons.

The government has also issued a policy for the Development of Natural Gas Pipelines and City or Local Natural Gas Distribution Networks. This is intended to facilitate the growth of the natural gas sector and to promote investment in the expansion of the pipeline infrastructure with a view eventually to creating a nationwide gas grid. The policy also seeks to encourage public and private investments and to protect consumers’ interests. A central feature of the pipeline policy is the proposal to give third parties access to a common carrier on a non-discriminatory basis and the progressive unbundling of transmission and marketing activities.

The Ministry of Coal has overall responsibility for shaping policies and strategies with respect to coal. It also supervises Coal India and its subsidiaries which dominate India’s coal sector. The Indian coal sector is the least reformed of all energy sectors. The coal industry requires huge capital injections and advanced technology deployment to maintain the coal supply needed to support India’s economic growth.

The Ministry of New and Renewable Energy (MNRE) is responsible for the promotion of renewable energy technologies and their adoption throughout India. The ministry is also responsible for the implementation of a scheme which aims to provide electricity from renewable and alternative energy sources through its remote village electrification programme. Ministry of New and Renewable Energy collaborates closely with state-level agencies in creating demonstration projects and incentive schemes for renewable energy.

**Current status of energy policies and climate change initiatives**

Considerable progress has been made with reforms in the energy sector since overall economic reforms were launched in 1991. India’s first Integrated Energy Policy (IEP) (GOI, 2006a) was approved by the government in 2006. It outlines a long-term vision for India’s energy sector which addresses all energy sub-sectors. The broad vision behind the 2006 IEP is reliably to meet the demand for energy in India at the least cost in a technically efficient, economically viable and environmentally sustainable manner (GOI, 2006a). More specifically, the IEP states that:

- *in situ* gasification should be developed to tap the country’s vast coal reserves;
- coal washing should become the norm;
- aggregate technical and commercial losses should be reduced through automated meter reading, Geographic Information Systems, and the separation of feeders for agricultural pumps;
it should be possible to reduce India’s energy intensity by up to 25% from current levels;

the average gross efficiency of power generation should be raised from 30.5% to 34%;

all new plants should adopt technologies that improve their gross efficiency from the prevailing 36% to at least 38% to 40%;

electricity should be generated through wood gasifiers or by burning surplus biogas from community biogas plants;

India needs to substantially augment the resources made available for energy-related research and development (R&D) and to allocate these strategically;

energy policy modelling capability should be improved and modellers should be brought together periodically in a forum to address specific policy issues;

international collaboration on research, development, demonstration and deployment (RDD&D) is required.

A number of actions are currently in hand in all sectors of the economy. The government is mandating the retirement of inefficient coal-fired power plants, and supporting R&D into IGCC and SC technologies. Under the Energy Conservation Act, large energy industries are required to undertake energy audits, and an energy labelling programme for appliances has been introduced. Under the Electricity Act and the NTP, the central and state electricity regulatory commissions must purchase a certain percentage of grid-based power from renewable sources. The Ministry of New and Renewable Energy aims to increase the contribution of renewable energy to 6% of India’s generating capacity and to about 10% of the total electricity mix by 2022.

India’s National Action Plan on Climate Change (NAPCC) was approved in 2008 (GOI, 2008c). The NAPCC identified eight priority national missions to address climate change mitigation and adaptation. Two of these, the National Mission on Enhanced Energy Efficiency (NMEEE) and the Jawaharlal Nehru National Solar Mission, focus specifically on the energy sector.

The NMEEE seeks to upscale efforts to create a market for energy efficiency. The missions will create a conducive regulatory and policy regime to foster innovative and sustainable business models to unlock this market. As a result of the implementation of the NMEEE over the next five years, it is estimated that by 2015 about 23 Mtoe of fuel savings will be achieved every year along with an expected avoided capacity addition of over 19 000 megawatts (MW). The consequential emissions reduction is estimated to be 98.5 million tonnes (Mt) of CO₂ annually.

The Ministry of New and Renewable Energy launched the Jawaharlal Nehru National Solar Mission in late 2009. The goal of the mission is to create an enabling framework for the deployment of at least 20 000 MW of solar power by 2022. The Solar Mission will adopt a three-phase approach: the immediate aim is to focus on setting up an enabling environment for solar technology penetration in the country.
The National Policy on Bio-Fuels (GOI, 2009) developed by MNRE and approved in late 2009 aims to accelerate the development and promotion of the cultivation, production and use of biofuels. The policy sets an indicative target of 20% blending of biofuels from biodiesel or ethanol with petrol and diesel by 2017.

Shorter-term energy policy is mainly driven by India’s Five-Year Plans, prepared by the Planning Commission. The Five-Year Plans are developed from the bottom up with each ministry projecting its main development needs and proposing how best to achieve them. The Planning Commission is then tasked with ensuring that the individual plans result in a co-ordinated approach to meet the government’s development and economic policies. Currently the Eleventh Plan (2007-2012) is being implemented (GOI, 2008b). Like its predecessors, it is predominantly supply-oriented and reflects the competing requirements of the diverse ministerial structure for energy policy.

In December 2009, India announced a 20% to 25% reduction of emission intensity by 2020 from 2005 levels. It is expected that this target will be part of the Low Carbon Growth Plan being embedded in the Twelfth Five-Year Plan.

Overview of scenarios and CO₂ abatement options²

Gross domestic product and population assumptions for India are the same in both the Baseline and BLUE Map scenarios. The different levels of energy supply and consumption between the two scenarios indicate the different degrees of decoupling between energy and economic activity driven by the assumptions in the relevant scenario (Table 11.2).

India’s economic growth over the next 40 years will be one of the strongest worldwide. As a result, India’s share in the world economy will rise considerably. Energy use and associated CO₂ emissions will increase significantly in both absolute and relative terms. In the Baseline scenario for India, GDP increases eightfold, primary energy use almost quadruples and CO₂ emissions grow by a factor of nearly five between 2007 and 2050. India’s share of total global CO₂ emissions more than doubles from 5% to 11% between 2007 and 2050 under the Baseline scenario.

Per-capita consumption of electricity and oil is significantly lower in India than in China, the United States and OECD Europe, and well below the world average. But it is growing. The lower levels of electricity use per capita in the BLUE Map scenario than in the Baseline scenario throughout the period to 2050 reflect greater energy efficiency from all the end-use sectors.

Total primary energy intensity decreases by 1.8% a year in the Baseline scenario and 2.6% a year in the BLUE Map scenario, although primary energy per capita increases by 2.2% and 1.3% in the Baseline and BLUE Map scenarios, respectively.

---

² Chapter 2 provides a full description of the different scenarios.
Total energy intensity improves by 26% and 29% between 2007 and 2015 in the Baseline and BLUE Map scenarios, respectively. In terms of CO₂ intensity, the BLUE Map scenario envisages reductions of 27% in emissions intensity by 2015 and of 66% by 2030. This is much more ambitious than the 25% reductions in the period between 2005 and 2020 announced by the government of India in December 2009 before the 15th Conference of the Parties (COP15) to the United Nations Framework Convention on Climate Change (UNFCCC). The 25% reduction announced by India is assumed to be achieved in the Baseline scenario.

### Table 11.2  High-level indicators for India

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th></th>
<th></th>
<th>BLUES Map</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000</td>
<td>2007</td>
<td>2030</td>
<td>2050</td>
<td>2030</td>
<td>2050</td>
</tr>
<tr>
<td>TPES (Mtoe)</td>
<td>460</td>
<td>600</td>
<td>1 287</td>
<td>2 157</td>
<td>974</td>
<td>1 494</td>
</tr>
<tr>
<td>Total final consumption (Mtoe)</td>
<td>319</td>
<td>394</td>
<td>833</td>
<td>1 468</td>
<td>711</td>
<td>994</td>
</tr>
<tr>
<td>Electricity consumption (TWh)</td>
<td>408</td>
<td>610</td>
<td>2 132</td>
<td>3 440</td>
<td>1 633</td>
<td>3 453</td>
</tr>
<tr>
<td>CO₂ emissions (Gt)</td>
<td>0.98</td>
<td>1.34</td>
<td>3.36</td>
<td>6.45</td>
<td>1.86</td>
<td>1.47</td>
</tr>
<tr>
<td>GDP (billion USD using exchange rates)</td>
<td>460</td>
<td>771</td>
<td>3 131</td>
<td>6 026</td>
<td>3 131</td>
<td>6 026</td>
</tr>
<tr>
<td>GDP (billion USD using PPP)</td>
<td>2 402</td>
<td>4 025</td>
<td>16 340</td>
<td>31 453</td>
<td>16 340</td>
<td>31 453</td>
</tr>
<tr>
<td>Population (millions)</td>
<td>1 016</td>
<td>1 123</td>
<td>1 485</td>
<td>1 614</td>
<td>1 485</td>
<td>1 614</td>
</tr>
<tr>
<td>TPES/GDP (toe per thousand USD at PPP)</td>
<td>0.19</td>
<td>0.15</td>
<td>0.08</td>
<td>0.07</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>TPES/population (toe per capita)</td>
<td>0.45</td>
<td>0.53</td>
<td>0.87</td>
<td>1.34</td>
<td>0.66</td>
<td>0.93</td>
</tr>
<tr>
<td>Electricity consumption/population (kWh per capita)</td>
<td>402</td>
<td>543</td>
<td>1 436</td>
<td>2 131</td>
<td>1 100</td>
<td>2 140</td>
</tr>
</tbody>
</table>

**Note:** GDP is expressed in 2000 USD. Includes international bunkers.  
Sources: IEA (2009a); IEA analysis.

### Energy and CO₂ emission scenarios

Total primary energy supply increases by 260% between 2007 and 2050 in the Baseline scenario and by 149% in the BLUE Map scenario.

In the Baseline scenario, the supply of all individual energy sources more than triples between 2007 and 2050, except for biomass and waste which increase by 35% (Figure 11.4). Nuclear power increases by a factor of 17 and non-combustible renewables by a factor of 11, mostly driven by the increase in demand for electricity. The fivefold increase in demand for oil comes mostly from strongly increased demand from the transport sector. Coal remains the main primary energy supply source in the Baseline scenario with a share of 47% of total supply, followed by oil at 31%.

Total primary energy supply is lower in the BLUE Map scenario than in the Baseline scenario by 2015, and remains so beyond that year. This rapid decrease is mainly
due to a shift away from coal-based DRI in the iron and steel sector and to the increased electrification of the country. In the BLUE Map scenario, higher energy efficiency, the adoption of BATs and the use of more efficient energy sources (such as electricity and natural gas) limits the increase in TPES to 149% between 2007 and 2050, 31% below the Baseline scenario level. The energy mix is also quite different from that in the Baseline scenario. It is much more diverse, with coal, oil, nuclear and biomass and waste each accounting for approximately 20% of the energy mix. The use of non-combustible renewables, such as solar, wind and geothermal, also increases significantly, accounting for 9% of all supply in 2050, up from 0.2% in 2007.

In the Baseline scenario, CO$_2$ emissions from primary energy amount to 6.5 Gt CO$_2$ in 2050. In the BLUE Map scenario, CO$_2$ emissions only increase by 10% to 1.5 Gt CO$_2$ between 2007 and 2050 even though energy use more than doubles. This decrease in the carbon intensity of the energy used results from a significant increase in the use of non-fossil fuels, coupled with a strong decrease in the use of coal.

**Figure 11.4** Total primary energy supply, Baseline and BLUE Map scenarios by fuel for India

![Bar chart showing total primary energy supply by fuel for India from 2007 to 2050.](chart)

**Note:** Other includes non-combustible renewables. Oil includes international bunkers.
**Sources:** IEA (2009a); IEA analysis.

**Key point**

While coal and oil dominate in the Baseline scenario, nuclear and non-combustible renewables play an important role in the BLUE Map scenario.

**Carbon dioxide abatement options**

The achievement of the ambitions of the BLUE Map scenario depends on India’s emissions peaking in around 2030 (Figure 11.5). Given the expected strong growth in the Indian economy and the long lead times before new policies are put in place and have effect, there is an urgent need for effective action to bring this outcome about very soon.
Energy efficiency and fuel switching play an important role in restraining the growth in CO$_2$ emissions in the BLUE Map scenario over the entire period from 2010 to 2050. The increased introduction of zero- and low-carbon energy sources, such as nuclear, biofuels and renewables, will also play an important role, accounting for almost 50% of the reductions in 2030. Beyond 2030, additional measures to reduce the carbon intensity of electricity generation, CCS and the adoption of new technologies to reduce CO$_2$ intensity in industry and transport will also be required if deeper emissions reductions are to be achieved.

If CO$_2$ emissions are to peak around 2030, as envisaged in the BLUE Map scenario for India, CCS will need to play an increasingly important role. Without CCS, emissions will continue to grow throughout the period to 2050.

**Figure 11.5 Contributions to emissions reduction in India**

<table>
<thead>
<tr>
<th>Year</th>
<th>Baseline emissions</th>
<th>CCS</th>
<th>Renewables</th>
<th>Nuclear</th>
<th>Power generation efficiency and fuel switching</th>
<th>End-use fuel switching</th>
<th>End-use fuel and electricity efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>6.5 Gt</td>
<td>17%</td>
<td>22%</td>
<td>10%</td>
<td></td>
<td>9%</td>
<td>36%</td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2025</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2035</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2040</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2045</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2050</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: IEA (2009a and 2009b); IEA analysis.

**Key point**

*In the BLUE Map scenario, CO$_2$ emissions will be 77% lower in 2050 than in the Baseline scenario.*

**Sectoral results**

**Power sector**

*The Indian electricity system today*

India had 143 GW of generation capacity from utilities in 2008, made up of 53% coal, 25% hydro, 10% natural gas, 8% renewable energy sources, 3% nuclear and 1% diesel (CEA, 2009a). In addition, industrial captive stations generated a

---

3. Includes small hydro, wind power, biomass power, biomass gasifier and urban and industrial waste.
4. Captive stations are units set up by industrial plants for their exclusive supply.
further 25 GW for direct use, 47% from coal, 35% from diesel, 17% from natural gas, 1% from wind and 0.2% from hydro. In 2008, India generated 813 TWh of electricity in total (Figure 11.6). The capacity mix is different from the power supply mix because of varying load factors for different fuel sources and technologies.

Figure 11.6  Electricity generating capacity and generation for India, 2007/08

Installed capacity 168 GW

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Capacity Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>52.2%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>11.2%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>2.5%</td>
</tr>
<tr>
<td>Hydro</td>
<td>21.4%</td>
</tr>
<tr>
<td>Oil</td>
<td>5.9%</td>
</tr>
<tr>
<td>Other</td>
<td>6.8%</td>
</tr>
</tbody>
</table>

Electricity generation 813 TWh

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Generation Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>66.6%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>11.7%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>2.1%</td>
</tr>
<tr>
<td>Hydro</td>
<td>14.8%</td>
</tr>
<tr>
<td>Oil</td>
<td>1.7%</td>
</tr>
<tr>
<td>Other</td>
<td>3.1%</td>
</tr>
</tbody>
</table>

Note: Includes capacity and generation from utilities and captive power plants.
Source: CEA (2009a).

Key point

Two-thirds of electricity was generated from coal-fired plants.

The average efficiency of coal-fired public power plants was 32.7% in 2007/08 (CEA, 2009a). The auxiliary consumption of coal-fired plant ranged from 6% to 13% of total gross power produced, with an average of 8.4% (CEA, 2008b).

The Indian power sector has a number of important shortcomings:

- capacity shortages of the order of 15% of peak power demand and 10% of total demand;
- only 60% of households are connected to the grid;
- regular blackouts;
- structural under investment as a result of both market and institutional failures (Mathy and Guivarch, 2009).

---

5. Only includes power plants of 1 MW capacity or more.
In addition, the average price of electricity sold only partly covers the average production cost. The total under recovery of costs was estimated at 431 billion rupees in 2008, the equivalent of around USD 9.4 billion (GOI, 2008a).

Most of these barriers are not technical in nature. But they will have an influence on the effectiveness and efficiency of the required technology transition.

**Developments in renewable power generation**

In 2008, India had a total of 12.6 GW of grid connected and distributed renewable capacity (Table 11.3). Wind power in particular has been growing at a rapid rate. Wind represented 75% of the target renewable power capacity additions, excluding large hydro, anticipated in the Eleventh Five-Year Plan (Verma, 2008).

<table>
<thead>
<tr>
<th>Table 11.3</th>
<th>Indian renewable power generation capacities, status at 31 March 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grid-connected</strong></td>
<td></td>
</tr>
<tr>
<td>Bio-power (agro-residues)</td>
<td>16 881</td>
</tr>
<tr>
<td>Wind power</td>
<td>45 195</td>
</tr>
<tr>
<td>Small hydropower (up to 25 MW)</td>
<td>15 000</td>
</tr>
<tr>
<td>Combined heat and power (CHP): bagasse</td>
<td>5 000</td>
</tr>
<tr>
<td>Waste-to-energy</td>
<td>2 700</td>
</tr>
<tr>
<td>Solar power</td>
<td></td>
</tr>
<tr>
<td><strong>Total grid-connected</strong></td>
<td>84 776</td>
</tr>
<tr>
<td><strong>Distributed renewables</strong></td>
<td></td>
</tr>
<tr>
<td>Biomass power/CHP</td>
<td></td>
</tr>
<tr>
<td>Biomass gasifier</td>
<td></td>
</tr>
<tr>
<td>Waste-to-energy</td>
<td></td>
</tr>
<tr>
<td><strong>Total distributed renewables</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Note: Solar power potential is not included in the total.*

*Source: WEC (2009).*

India added 27.3 GW of electrical capacity between 2002 and 2007, an average of 5.5 GW per year. The country aims to install on average 18.8 GW a year between 2007 and 2012, increasing the rate of capacity addition more than threefold (Verma, 2008).
Electricity transmission and distribution

Since August 2006, four regional grids have been integrated into the northern, eastern, western and north-eastern grid (the NEWNE grid). Only the southern grid, covering the states of Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Pondicherry and Lakshadweep islands, still operates independently. The southern grid is scheduled to be synchronously operated by the end of the Twelfth Five-Year Plan (2012-2017). It is currently connected to the western and eastern grid through a high-voltage direct current (HVDC) link and HVDC back-to-back systems. In 2007/08, power generation in India resulted in emissions of 520 Mt CO$_2$, 78% of which were associated with the NEWNE grid (CEA, 2008a).

Although 80% of India’s villages are electrified, only 65% of the population and 60% of households have access to electricity. Power outages are common, and the unreliability of electricity supplies is severe enough to constitute a constraint on the country’s overall economic development. Power shortages$^7$ increased from 9.9% in 2007/08 to 11.1% in 2008/09. It is estimated that the power shortage will be reduced to 9.3% by the end of 2009/10 (CEA, 2009b).

India’s transmission and distribution losses are among the highest in the world, averaging 26% of total electricity generation in 2008 (Figure 11.7), with some states as high as 62%. When non-technical losses such as energy theft are included in the total, average losses are as high as 50% (Das, 2008).

![Figure 11.7](image_url)

*Figure 11.7* Development of transmission network, and transmission and distribution losses for India

The transmission network is five times longer than it was in 1974; it increased by 4.7% a year from 1974 to 2008.

Improving grids should be a top priority in efforts to mitigate power supply constraints. In large, highly dispersed systems such as in India, the creation of a larger number of lower-capacity sub-stations, together with the conversion of single-

---

7. Total power requirement over total power availability.
phase supply to three-phase supply, can reduce distribution losses substantially. During periods of peak load, losses will be even higher than average. So there is advantage in designing systems with sufficient slack capacity to handle peak loads efficiently. This slack capacity adds to the upfront investment cost, and a balance between investment and distribution losses has to be struck.

Electricity demand scenarios

The power sector plays an especially important role in the growth of the Indian economy as electricity demand is projected to rise by a factor of 6.2 in the Baseline scenario and 5.6 in the BLUE Map scenario (Table 11.4). Within the power sector, coal-fired power generation is the dominant source of emissions.

In the BLUE Map scenario, as the economy grows eightfold, manufacturing activity expands significantly, as does its demand for electricity. Transport becomes the third-largest user of electricity in 2050. This strong increase is driven by the shift towards vehicles and technologies using electricity. The electrification of the entire country is in part responsible for the strong increase in electricity use in the residential sector; but in the BLUE Map scenario, the growth is limited by the penetration of more efficient electricity-using devices.

<table>
<thead>
<tr>
<th>(TWh/yr)</th>
<th>Baseline 2007</th>
<th>Baseline 2030</th>
<th>Baseline 2050</th>
<th>BLUE Map 2030</th>
<th>BLUE Map 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>121</td>
<td>491</td>
<td>1311</td>
<td>384</td>
<td>994</td>
</tr>
<tr>
<td>Commercial</td>
<td>44</td>
<td>269</td>
<td>420</td>
<td>172</td>
<td>283</td>
</tr>
<tr>
<td>Industry</td>
<td>257</td>
<td>965</td>
<td>1506</td>
<td>769</td>
<td>1202</td>
</tr>
<tr>
<td>Transport</td>
<td>12</td>
<td>17</td>
<td>19</td>
<td>48</td>
<td>532</td>
</tr>
<tr>
<td>Other</td>
<td>133</td>
<td>223</td>
<td>257</td>
<td>145</td>
<td>156</td>
</tr>
<tr>
<td>Total</td>
<td>567</td>
<td>1965</td>
<td>3513</td>
<td>1518</td>
<td>3168</td>
</tr>
</tbody>
</table>

Sources: IEA (2009a); IEA analysis.

Electricity generation scenarios

Assuming that transmission and distribution losses can be reduced to 15%, about 3 700 TWh of electricity generation is needed in 2050 in the BLUE Map scenario. At full load, 114 GW of capacity can generate 1 000 TWh per year. However, in practice plants operate on average far below the maximum load. This is partially related to energy resource availability, for example in respect of variable renewables, and it is partially related to fluctuations in demand during the year.

India had 168 GW of total installed capacity in 2008, including captive power plants, with an estimated average load factor of 61%. The installed capacity is expected to grow significantly in both the Baseline and BLUE Map scenarios. Total capacity in 2050 is between 3.8 and 4.5 times the installed capacity in 2008. The generation mix in the Baseline and BLUE Map scenarios is very different (Table 11.5).
Table 11.5 India’s power generation capacity in the Baseline and BLUE Map scenarios, 2050

<table>
<thead>
<tr>
<th>Power generation share</th>
<th>Load factor (%)</th>
<th>Capacity (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline (%)</td>
<td>BLUE Map (%)</td>
</tr>
<tr>
<td>Nuclear</td>
<td>7</td>
<td>27</td>
</tr>
<tr>
<td>Oil</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Coal</td>
<td>70</td>
<td>2</td>
</tr>
<tr>
<td>Coal + CCS</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Gas</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Gas + CCS</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Hydro</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Bio/waste</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Bio + CCS</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Geothermal</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wind</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Tidal</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Solar</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Note: Unless otherwise indicated, all material derives from IEA data and analysis.

Different Indian regions have very different levels of power capacity and demand in the BLUE Map scenario in 2050 (Figure 11.8). Total capacity amounts to 748 GW. The full potential of biomass and wind is used. For hydro, about half of the potential is developed. Total coal-fired capacity is roughly at today’s level, but most of this capacity is equipped with CCS. Solar increases from near zero in 2007 to 191 GW.

Decarbonising the power sector in India

The Indian power sector has a number of characteristics that make it very different from the power sectors in China, OECD Europe and the United States:

- The demand growth in India in percentage terms will be much higher than in the other regions.
- Coal is an important indigenous energy resource, but it is of lower quality in India than elsewhere. This means that Indian coal is not the most economic supply option. Coal imports or other power supply options are often cheaper.
- Indian renewable resources are limited compared to the demand growth that is forecast for the coming decades. Solar is the only option with a very large technical potential, but its use is starting from a very low level of installed capacity.
Figure 11.8 Regional power capacity and electricity demand in the BLUE Map scenario for India, 2050

Note: The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Key point

About 50% of electricity demand, and one-third of the capacity, is from the regions of Calcutta, Delhi and Mumbai.

The government of India recognises the important potential for solar and, in late 2009, approved the Jawaharlal Nehru National Solar Mission. The Solar Mission has twin objectives to contribute to India’s long-term energy security and to establish the country as a global leader in solar energy. By the end of 2022 the Solar Mission foresees total installed solar capacity of 20 GW.

The strong increase in electricity generation and demand means that almost none of India’s power systems in 2050 are yet built. This opens up interesting opportunities for reducing energy requirements and associated CO₂ emissions.

Industry sector

Industry used 150 Mtoe of energy in 2007, accounting for 38% of the final energy used in India. From a global perspective, India is the fourth-largest industrial energy consumer with a 5% share of global industrial energy use, surpassed only by China, the United States and Russia. The final energy mix of industry is dominated by coal.
and oil (Figure 11.9). Industry accounts for 45% of total electricity consumption in India, a high share compared to other countries. In the industry sector, electricity accounts for 15% of the energy consumption. About 30% of the electricity used by industry is generated by captive power plants.

**Figure 11.9** Industrial final energy mix in India and in the world, 2007

![Industrial final energy mix in India and in the world, 2007](image)

Note: Includes coke ovens, blast furnaces and petrochemical feedstock.
Sources: IEA (2009a and 2009d).

**Key point**

The share of biomass used in industry is large compared to other countries.

An important shortcoming of the Indian energy use data reported in the International Energy Agency statistics (IEA, 2009a) is that the consumption of electricity, natural gas and biomass and waste is not allocated to any specific industrial sector. More than 40% of industrial energy use in India is reported in the “non-specified industry”. The IEA has developed estimates of industrial energy consumption for India by industrial sub-sector from a mixture of top-down and bottom-up sources (Table 11.6).

**Energy and CO₂ savings potential with best available technologies**

India, like many other countries, could achieve significant energy and CO₂ savings in industry through the application of BATs. The application of BATs in the five industrial sectors analysed (iron and steel, chemicals and petrochemicals, pulp and paper, cement and aluminium) could reduce final energy use in India by between 10% and 25%. This would save an estimated 17 Mtoe per year, equivalent to 11% of India’s industrial energy consumption and 4% of its total final energy consumption in 2007. The estimated potential in India is slightly lower than that of most industrialised countries. The peculiarities of Indian indigenous resources and industry, such as the high silica content in iron ore, low-quality coal and the existence of numerous small-scale plants, means that these savings might be harder to achieve and may be overstated.
### Table 11.6  Industrial production, energy use and CO\textsubscript{2} emissions for India, 2007

<table>
<thead>
<tr>
<th>Materials production (Mt)</th>
<th>Reported energy use (Mtoe)</th>
<th>Reported electricity use (Mtoe)</th>
<th>Estimated energy use (Mtoe)</th>
<th>Estimated electricity use (Mtoe)</th>
<th>Direct CO\textsubscript{2} emissions (Mt CO\textsubscript{2})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total industry sector</strong></td>
<td>150</td>
<td>22</td>
<td>150</td>
<td>22</td>
<td>413</td>
</tr>
<tr>
<td>Iron and steel</td>
<td>53</td>
<td>33</td>
<td>38</td>
<td>3.3</td>
<td>151</td>
</tr>
<tr>
<td>Chemicals and petrochemicals</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td></td>
<td>48</td>
</tr>
<tr>
<td>Non-ferrous metals</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total aluminium</td>
<td>2</td>
<td></td>
<td>2.9</td>
<td>1.6</td>
<td>3.8</td>
</tr>
<tr>
<td>Non-metallic minerals</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement</td>
<td>170</td>
<td>-</td>
<td>13</td>
<td>1.1</td>
<td>128</td>
</tr>
<tr>
<td>Pulp, paper and printing</td>
<td>1.4</td>
<td></td>
<td>1.4</td>
<td>0.4</td>
<td>8.2</td>
</tr>
<tr>
<td>Paper and paperboard</td>
<td>8</td>
<td>-</td>
<td>1.4</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Pulp</td>
<td>4</td>
<td>-</td>
<td>1.7</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Recovered paper</td>
<td>1</td>
<td>-</td>
<td>0.1</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Food and tobacco</td>
<td>10</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td>Textile and leather</td>
<td>1.3</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>66</td>
<td>15</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>Non-specified industry</td>
<td>65</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Iron and steel includes energy use for coke-making and the energy data for chemicals and petrochemicals include feedstocks. The table has been compiled from a mixture of top-down and bottom-up sources and so the totals may not match.

Sources: World Steel Association (2009); USGS (2009); IAI (2009); IPMA (2010); IEA (2009a and 2009c); IEA analysis.

It will also take time to achieve savings this way. The rate of implementation of BATs in practice depends on a number of factors, including capital stock turnover, relative energy costs, raw material availability, rates of return on investment and regulation. The BAT analysis does not take into account the energy efficiency improvement potential from industrial captive power plants. Analysis of energy efficiency potential of those captive plants would be important to assess the overall potential for reducing energy consumption.

### Scenarios for industrial energy use and CO\textsubscript{2} emissions

If India follows traditional pathways from an agricultural society to a highly urbanised society, the country’s materials needs will be enormous. Production in India of the five key materials covered in this analysis is expected, in the low-demand scenario, to triple by 2030 and to more than quadruple by 2050 compared to 2007. In the high-demand scenario, productions are projected to rise by a factor of over 3.6 by 2030 and 5.4 by 2050 (Figure 11.10). These rates of growth will present issues around the availability of resources.
Figure 11.10  Materials production in India in the low-demand and high-demand cases

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>low 2015</th>
<th>high 2015</th>
<th>low 2030</th>
<th>high 2030</th>
<th>low 2050</th>
<th>high 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper and paperboard</td>
<td>0.0</td>
<td>0.4</td>
<td>1.0</td>
<td>1.6</td>
<td>1.2</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>Cement</td>
<td>0.0</td>
<td>0.2</td>
<td>0.6</td>
<td>0.8</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Aluminium</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Chemical feedstocks</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Crude steel</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

Note: Production of materials is the same for both the Baseline and BLUE scenarios.
Sources: World Steel Association (2009); USGS (2009); IAI (2009); IPMA (2010); IEA (2009a); IEA analysis.

Key point
Production of materials will increase between 4.3 times (in chemical feedstocks) and 19.5 times (in paper and paperboard) between 2007 and 2050 in the high-demand scenario.

Energy use and CO₂ emissions will rise as a result of this increase in industrial production. Industrial energy use reaches 372 Mtoe (low demand) and 428 Mtoe (high demand) in 2030 and 522 Mtoe (low demand) and 632 Mtoe (high demand) in 2050 in the Baseline scenario (Figure 11.11). Total direct energy- and process-related industrial CO₂ emissions are projected to rise from 413 Mt CO₂ in 2007 to between 1 563 Mt CO₂ and 1 852 Mt CO₂ in 2050 in the Baseline scenarios (Table 11.7).

Figure 11.11  Energy use in industry by fuel type in the Baseline and BLUE scenarios for India

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>2030</th>
<th>2050</th>
<th>2030</th>
<th>2050</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass and waste</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Oil</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Coal</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Note: Includes coke ovens, blast furnaces and petrochemical feedstocks.

Key point
Energy consumption is about 23% lower in the BLUE scenarios than in the Baseline scenarios.
The BLUE scenarios: a technological pathway for industry in India

The reductions envisaged in the BLUE scenarios require CO₂ emissions reductions across all industry sectors. But action is particularly crucial in the five most energy-intensive sectors analysed. These sectors currently account for 82% of direct CO₂ emissions and 56% of industrial energy consumption in India. In the BLUE scenarios, Indian energy consumption and emissions are higher in 2050 than in 2007 but lower than in the Baseline scenarios. India’s total industrial energy consumption between 2007 and 2050 is expected to grow between 3.5 and 4.2 times in the Baseline low- and high-demand scenarios, respectively. By implementing measures and policies consistent with the BLUE scenarios, energy consumption in India would be between 121 Mtoe and 140 Mtoe lower in the BLUE scenario than in the Baseline scenario in 2050.

### Table 11.7 Direct energy and process CO₂ emissions by industry sector in India

<table>
<thead>
<tr>
<th>Mt CO₂</th>
<th>2007</th>
<th>Baseline low 2050</th>
<th>Baseline high 2050</th>
<th>BLUE low 2050</th>
<th>BLUE high 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>4</td>
<td>14</td>
<td>21</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>Iron and steel</td>
<td>151</td>
<td>703</td>
<td>858</td>
<td>333</td>
<td>362</td>
</tr>
<tr>
<td>Chemicals</td>
<td>48</td>
<td>132</td>
<td>173</td>
<td>68</td>
<td>77</td>
</tr>
<tr>
<td>Cement</td>
<td>128</td>
<td>422</td>
<td>483</td>
<td>275</td>
<td>291</td>
</tr>
<tr>
<td>Pulp and paper</td>
<td>8</td>
<td>36</td>
<td>62</td>
<td>17</td>
<td>31</td>
</tr>
<tr>
<td>Other</td>
<td>74</td>
<td>256</td>
<td>256</td>
<td>122</td>
<td>129</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>413</strong></td>
<td><strong>1 563</strong></td>
<td><strong>1 852</strong></td>
<td><strong>828</strong></td>
<td><strong>906</strong></td>
</tr>
</tbody>
</table>

Sources: IEA (2009a and 2009b); IEA analysis.

A range of measures will be needed to reduce CO₂ emissions to the level envisaged in the BLUE scenarios, including the application of BATs, energy efficiency measures, fuel and feedstock switching and the application of CCS in the iron and steel, cement, pulp and paper and chemicals sectors (Figure 11.12). The implementation of these measures can also help to reduce India’s rapidly rising dependence on oil and gas. Government policies are needed to facilitate a transition to more efficient and lower-carbon technologies.

### Figure 11.12 Options for reducing direct CO₂ emissions from Indian industry

Energy efficiency and CCS represent the main opportunities for India to limit the growth in CO₂ emissions from the industrial sector.
Each energy-intensive industrial sector has different characteristics. The options available to them, and the contribution of those options in reducing energy consumption and CO₂ emissions, will be different for different industries (Table 11.8).

Table 11.8  
Indian industry status and options for reducing energy use and CO₂ emissions in the BLUE scenarios

<table>
<thead>
<tr>
<th>Sector</th>
<th>Status</th>
<th>Energy efficiency options</th>
<th>Fuel and feedstock switching</th>
<th>Recycling and energy recovery</th>
<th>CCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>Efficiency is currently better than world average with large kilns being among the most energy efficient in the world</td>
<td>Deployment of BATs in smaller units</td>
<td>Expanding the use of clinker substitute</td>
<td>Expanding the use of biomass and alternative fuels</td>
<td>CCS applied</td>
</tr>
<tr>
<td>Iron and steel</td>
<td>Largest DRI producer worldwide and one of few countries that have coal-based DRI</td>
<td>Deployment of BATs; Development of new technologies (e.g. smelting reduction)</td>
<td>Lower use of coal-based DRI; Increased use of CO₂-free electricity and hydrogen</td>
<td>Higher recycling rate</td>
<td>CCS applied</td>
</tr>
<tr>
<td>Chemicals and petrochemicals</td>
<td>Ammonia production accounts for more than half of the energy use in chemicals; unlike in most other countries, oil feedstock plays an important role</td>
<td>Deployment of best practice technologies in the short term and new technologies in the long term</td>
<td>Continue to switch away from oil feedstock</td>
<td>Expand the production of bio-based plastics and chemicals</td>
<td>Improved material flow management; CCS applied</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Average energy intensity currently below the world average</td>
<td>Implementation of energy efficiency measures in refining and smelting; Introduction of new smelting technologies</td>
<td>Increased use of low-carbon electricity sources</td>
<td>Higher recycling rate</td>
<td></td>
</tr>
<tr>
<td>Pulp and paper</td>
<td>High share of small and medium-sized paper mills (about half of all production)</td>
<td>Deployment of BATs (including black liquor and biomass gasification, heat recovery)</td>
<td>Switching to combustible biomass</td>
<td>Increased use of recovered paper</td>
<td>CCS applied</td>
</tr>
</tbody>
</table>

Buildings sector

During the past decades, population growth, the increase in economic development and activity, greater access to diversified energy sources and migration from rural to urban areas has resulted in the buildings⁸ sector experiencing many changes in energy consumption, in both quantitative and qualitative terms.

⁸ The buildings sector collectively refers to the residential and service sectors.
In 2007 the residential\(^9\) and service\(^{10}\) sectors accounted for about 47% of total final energy consumption in India. This was less than the share of 55% in 1990, partly as a result of stronger growth in the manufacturing and transport sectors. Between 1990 and 2007, energy demand grew by 1.7% a year in the residential sector and by 2.1% a year in the service sector.

The use of biomass and waste still accounts for a large share (78%) of final consumption in the residential sector (Figure 11.13). But a move towards commercial, high-quality fuels is increasingly evident. The consumption of oil (mainly liquefied petroleum gas [LPG] and kerosene) and electricity grew rapidly at 4.3% and 8.1% a year, respectively, between 1990 and 2007.

**Figure 11.13** Residential and service sectors energy consumption by fuel in India, 2007

![Residential and service sectors energy consumption by fuel in India, 2007](image)

**Key point**

Biomass represents an important share of the energy used in the buildings sector.

**Box 11.1** Data for the buildings sector in India

Collecting accurate energy statistics for the residential and service sectors is a challenge for any nation, but a particular challenge in India. India has to deal with a large number of small businesses involved in energy supplies other than electricity, as well as a very large proportion of energy coming from traditional biomass for which non-commercial use is very difficult to estimate.

---

9. The residential sector include activities related to private dwellings; it covers all energy-using activities in apartments and houses, including space and water heating, cooling, lighting and the use of appliances. It does not include personal transport.

10. The service sector includes activities related to trade, finance, real estate, public administration, health, education and commercial services such as hotels and restaurants.
For example, IEA statistics for 2005 report residential energy consumption of 157 Mtoe, of which 33 Mtoe was commercial fuels. In its IEP, the government of India reported 135.3 Mtoe of energy use in the residential sector in 1999-2000. In contrast, a bottom-up analysis by Lawrence Berkeley National Laboratory (LBNL) (de la Rue du Can et al., 2009) estimated energy consumption in 2005 at just 116 Mtoe. The Energy and Resource Institute (TERI) estimates that around 77% of household energy consumption is biomass and that the consumption of commercial fuels was 29 Mtoe in 2004/05 (TERI, 2006). The wide disparities in these figures demonstrate the difficulty of establishing robust estimates in this area (Table 11.9).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>1.1</td>
<td>2.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td>16.5</td>
<td>21.1</td>
<td>23.8</td>
<td>20.4</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.6</td>
<td></td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>8.4</td>
<td>8.6</td>
<td>13.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Biomass</td>
<td>109.2</td>
<td>123.6</td>
<td>78.8</td>
<td>96.6</td>
</tr>
<tr>
<td>Total</td>
<td>135.3</td>
<td>156.6</td>
<td>115.7</td>
<td>125.5</td>
</tr>
</tbody>
</table>

Note: Biomass in IEP includes 29.6 Mtoe of dung cake.
Sources: GOI (2006a); TERI (2006); IEA (2009a); de la Rue du Can et al. (2009).

In the service sector, according to the Indian data on energy use as reported in IEA (2009a), coal, electricity and biomass and waste account for 98% of energy use. Liquefied petroleum gas and kerosene are undoubtedly also used. Estimates of oil product consumption in the service sector are around 12 Mtoe (de la Rue du Can et al., 2009). This emphasises the need to improve data collection in this sector to improve the analysis and better inform policy makers.

The IEA is continuously working with its member and non-member countries to improve the breadth, quality and timeliness of collected energy statistics. Such efforts are essential in order to improve the accuracy and utility of analyses and projections in the energy sector.

An understanding of the energy consumption in India associated with different end uses and technologies would enable a proper assessment of the options for reducing energy use and CO₂ emissions. Unfortunately, data that would allow a complete view of energy consumption by end use in the residential and service sectors are not collected systematically in India. Regular, reliable surveys are available for cooking and lighting in the residential sector, but other data are only available from bottom-up estimates or from surveys conducted periodically that are sometimes many years old. More systematic data collection would help analysis of the buildings sector.

The breakdown of the residential and service sectors’ end-use energy consumption that has been used to analyse the energy trends and reduction potential in the Baseline and BLUE Map scenarios is set out in Figure 11.14.
**Figure 11.14** Residential and service sectors energy consumption by end use for India, 2007

Residential 163 Mtoe

- Cooking: 76%
- Lighting: 2%
- Space heating: 10%
- Water heating: 8%
- Other: 3%

Services 20 Mtoe

- Lighting: 20%
- Cooling: 4%
- Space heating: 14%
- Water heating: 1%
- Other: 61%

Sources: IEA (2009a); IEA analysis.

**Key point**

Cooking, mostly using biomass, accounts for three-quarters of residential energy use.

### Scenarios for buildings energy use and CO₂ emissions

Between 1990 and 2007, India’s population grew by 1.7% a year. Population growth is expected to slow to an average of 0.8% a year between 2007 and 2050, but this still means a population increase of 490 million. The average household size in 2005 was around 4.3 persons in urban areas and 4.9 in rural areas (NSSO, 2008). Continued reductions in household size are assumed in the Baseline and BLUE Map scenarios, with the total number of households assumed to increase by 340 million between 2007 and 2050. Floor area in the service sector is expected to grow by 3.1% a year, with growth slowing over time in line with population and GDP growth.

### Box 11.2 Energy efficiency actions taken by the Government of India

Recognising the impact of economic growth and the increased penetration of energy-consuming appliances on the energy sector and the environment, the government of India enacted an Energy Conservation Act in 2001 under which the BEE was established. The BEE is tasked with co-ordinating energy efficiency programmes throughout the country and across all economic sectors through various regulatory instruments. Since its creation in 2002, the BEE has launched various programmes, including the Standard & Labelling Programme in 2006 and the Energy Conservation Building Act in 2007. Both were implemented on a voluntary basis and plans to make them mandatory in a phased manner are discussed. Since January 2009, energy labelling for air conditioners and refrigerator is mandatory.

.../...
The Standard & Labelling Programme covers the most widely used appliances and equipment such as colour TVs, ceiling fans, LPG stoves, refrigerators and air conditioners. Since 2007, the BEE has published an annual report on its performance which is verified by an independent third party, the National Productivity Council.

Under the NAPCC, approved in 2008, the BEE has prepared the NMEEE, implementation of which is expected to commence in April 2010 over a five-year period. The Mission aims to stimulate a market transformation in favour of energy-efficient technologies and products. It builds on existing work undertaken by the BEE but will scale up activities and enlarge the scope of ongoing initiatives and activities.

Four major initiatives are foreseen under the NMEEE. These initiatives will use market-based mechanisms to enhance cost effectiveness of improvements in energy efficiency for energy-intensive large industries and facilities, accelerate the shift to energy efficient appliances, and enable innovative financing and funding for demand-side management initiatives in all sectors.

The Baseline scenario

Energy consumption in buildings grows by 1.8% a year in the Baseline scenario, increasing from 183 Mtoe to 391 Mtoe between 2007 and 2050 (Figure 11.15). Energy consumption in the service sector will be the fastest growing, with a 178% increase over the period. Energy use in the residential sector also grows rapidly, from 163 Mtoe in 2007 to 336 Mtoe in 2050.

In the Baseline scenario, the CO₂ emissions attributable to the residential and service sectors are projected to increase by 4.5% a year between 2007 and 2050 from 281 Mt CO₂ in 2007 to 1 856 Mt CO₂ in 2050. The most rapid growth in CO₂ emissions comes from the increased use of natural gas. Emissions attributable to electricity consumption represent the largest share of the growth, increasing by 1 336 Mt CO₂ between 2007 and 2050. Electricity’s share of overall emissions from the residential sector increases from 63% in 2007 to 82% in 2050.

The BLUE Map scenario: technological pathways for buildings in India

Residential energy consumption in the BLUE Map scenario is reduced by around 72 Mtoe below the Baseline level in 2050, and by 16 Mtoe in the service sector.

11. In this section, for the purposes of assessing current CO₂ emissions and the savings potential, the upstream CO₂ emissions in the electricity and heat generation sector are attributed to electricity consumption in the buildings sector at the 2007 CO₂ emissions intensity of electricity generation (around 930 gCO₂/kWh). Any reduction in the intensity of CO₂ emissions from electricity generation is therefore credited to the electricity generation sector.
**Figure 11.15** Energy use in the buildings sector in the Baseline and BLUE Map scenarios for India

![Graph showing energy use in the building sector](image)

**Key point**

Energy use in 2050 in the BLUE Map scenario is 21% and 29% lower than in the Baseline scenario in the residential and service sectors, respectively.

In the residential sector, about two-thirds of the savings come from cooking and water heating, as the very large-scale deployment of more efficient cooking stoves and solar thermal water-heating systems offers significant energy savings potential (Figure 11.16). The use of biomass-derived dimethyl ether and liquid biofuels also helps to improve the efficiency of energy consumption for cooking and water heating. In the service sector, improvements in the miscellaneous end uses account for about 37% of the reductions (Figure 11.17).

Overall, CO₂ emissions for the buildings sector are reduced by 28%, 528 Mt CO₂, below the Baseline level in 2050. A large share of this reduction is attributable to reduced consumption of electricity. The savings from electricity are somewhat offset by the switching from fossil fuels to electricity for cooking and water heating in the BLUE Map scenario.

The CO₂ emissions reductions below the Baseline scenario in the BLUE Map scenario in 2050 are dominated by savings from electric end uses, particularly appliances and space cooling. Improvements in appliances and miscellaneous end-uses over and above that in the Baseline scenario are estimated to account for 22% of the total CO₂ savings in the BLUE Map scenario. Reduced electricity consumption for space cooling, through the improved efficiency of cooling systems and improvements in building shells, accounts for 19% of the total CO₂ savings. Improvements in the efficiency with which energy is used for cooking account for 7% of the savings. Heat pumps for water heating, CHP in the residential and service sectors and solar heating and cooling also yield significant savings.
**Figure 11.16** Contribution to reductions in energy use in the buildings sector in the BLUE Map scenario for India, 2050

Residential 72 Mtoe
- Lighting 5%
- Cooling 12%
- Water heating 22%
- Space heating 4%
- Cooking 41%
- Other 16%

Services 16 Mtoe
- Lighting 34%
- Cooling 20%
- Water heating 10%
- Space heating 0.1%
- Other 36%

**Key point**
While reductions will be achieved in all end uses, cooking in residential and other equipment in services offer the largest potential for energy reduction.

**Figure 11.17** Contribution to reductions in CO₂ emissions in the buildings sector in the BLUE Map scenario for India, 2050

Residential
- Baseline emissions 1.5 Gt
- BLUE Map emissions 0.2 Gt

Services
- Baseline emissions 0.36 Gt
- Fuel switching to biofuels
- Other efficiency
- Building shell
- Space and water heating
- Electricity decarbonisation

**Key point**
More than 60% of the direct emissions reductions in the buildings sector come from improvements in energy efficiency. However, achieving important emissions reductions will require a near-decarbonisation of the electricity sector.

**Transport sector**

In India, transport energy use is dominated by buses and freight trucks, with smaller but fairly equal shares for most other modes except rail (Figure 11.18). The light-duty vehicle (LDV) share of energy use is far smaller than the world average.
This reflects the current dominance of trucks over cars on India’s roads and the
dominance of bus and two-wheeler travel over LDV travel for urban, regional and
intercity passenger travel.

**Figure 11.18** Transport sector final energy use by mode in India and in the world, 2007

<table>
<thead>
<tr>
<th></th>
<th>India 46 Mtoe</th>
<th>World 2 220 Mtoe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buses</td>
<td>33%</td>
<td>6%</td>
</tr>
<tr>
<td>Road freight</td>
<td>17%</td>
<td>17%</td>
</tr>
<tr>
<td>LDV</td>
<td>13%</td>
<td>23%</td>
</tr>
<tr>
<td>2-3-wheelers</td>
<td>15%</td>
<td>3%</td>
</tr>
<tr>
<td>Air</td>
<td>9%</td>
<td>11%</td>
</tr>
<tr>
<td>Shipping</td>
<td>2%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Source: IEA Mobility Model database.

**Key point**

India has much higher shares of bus and two- and three-wheeler energy use than the world average.

The energy mix of Indian transport is dominated by gasoline and especially diesel
fuel (Figure 11.19). Although some other fuels such as biofuels and compressed
natural gas (CNG) are used in transport, their shares are a small fraction of total
energy use.

**Figure 11.19** Transport sector final energy mix in India and in the world, 2007

<table>
<thead>
<tr>
<th></th>
<th>India 46 Mtoe</th>
<th>World 2 220 Mtoe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>45%</td>
<td>33%</td>
</tr>
<tr>
<td>Diesel</td>
<td>54%</td>
<td>45%</td>
</tr>
<tr>
<td>Jet fuel</td>
<td>8%</td>
<td>11%</td>
</tr>
<tr>
<td>Heavy fuel oil</td>
<td>1%</td>
<td>8%</td>
</tr>
<tr>
<td>Biofuels</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Electricity</td>
<td>2%</td>
<td>1%</td>
</tr>
<tr>
<td>CNG and LPG</td>
<td>1%</td>
<td>1%</td>
</tr>
</tbody>
</table>

Source: IEA Mobility Model database.

**Key point**

Diesel fuel accounts for more than 50% of Indian transport fuel use.
A breakdown of transport indicators by mode, including activity, intensity and fuel use variables, is shown in Table 11.10. A significant shortcoming of the data on Indian energy use as reported in the IEA statistics is that road fuel use is not specified in terms of vehicle type. Fuel use is allocated to types of transport by the IEA using data and assumptions on vehicle stocks, efficiency and average travel. These estimates are based on current production levels and energy intensities from a range of sources. These data need to be validated.

In 2007, buses carried more than half of all motorised passenger-kilometres (pkm) of travel in India, with urban, regional and national rail accounting for the second-largest amount. Two- and three-wheelers carry more passengers than LDVs. Rail carries more freight in tonne-kilometres (tkm) than trucks, although trucking volumes are growing much faster. Light-duty vehicle average energy intensity per pkm is about twice that of two- and three-wheelers, and four times higher than that of buses. Freight trucks are about ten times more energy-intensive than rail.

Table 11.10 Transportation energy and CO₂ indicators in India, 2007

<table>
<thead>
<tr>
<th>Passenger travel (bn pkm)</th>
<th>Freight travel (bn tkm)</th>
<th>Stock average energy intensity (MJ/pkm)</th>
<th>Fuel use (Mt Jaco)</th>
<th>Passenger (Mt CO₂)</th>
<th>Freight (Mt CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDVs</td>
<td>180</td>
<td>1.6</td>
<td>6</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>2-3-wheelers</td>
<td>419</td>
<td>6</td>
<td>0.7</td>
<td>5.5</td>
<td>7</td>
</tr>
<tr>
<td>Buses</td>
<td>1 612</td>
<td>0.4</td>
<td>15</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>Freight trucks</td>
<td>157</td>
<td>2.3</td>
<td>8</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Rail</td>
<td>565</td>
<td>385</td>
<td>0.3</td>
<td>0.2</td>
<td>5</td>
</tr>
<tr>
<td>Air</td>
<td>64</td>
<td>27</td>
<td>5</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>Water</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Total/average</td>
<td>2 840</td>
<td>548</td>
<td>0.6</td>
<td>0.9</td>
<td>46</td>
</tr>
</tbody>
</table>

Note: n.a. = not applicable.
Source: IEA Mobility Model database.

Scenarios for transport energy use and CO₂ emissions

Although India currently accounts for a small share of the world’s transport energy use and CO₂ emissions, travel growth is expected to change this picture rapidly. In the Baseline scenario, passenger travel and goods transport increases by an order of magnitude between 2007 and 2050, with accompanying large increases in energy use and CO₂ emissions (Figure 11.20). The growth in travel is driven largely by increasing car ownership and air travel, both being driven by rising incomes. By 2050, India consumes about 12% of the world’s energy consumption for transport in the Baseline scenario. It will be imperative for economic, energy security and environmental reasons that India finds ways to enable the travel growth it needs while restraining the consequent increases in fuel use and CO₂ emissions.
In the Baseline scenario, the mix of fuels remains fairly constant, with petroleum fuels dominant and complemented by the growth of synthetic fuels based on fossil resources, as well as natural gas and biofuels. The use of coal- and gas-to-liquids (CTL and GTL) reflects an expected reduction in the availability of conventional sources of crude oil and the need to produce synthetic liquid hydrocarbons. These fuels may be competitive in the future, but have very high CO₂ emissions.

**The BLUE scenarios: technological pathways for transport in India**

To change the direction of future energy use and CO₂ trends in India, it will be necessary to significantly alter trends in transport activity and technology adoption. The IEA has explored several scenarios which envisage a low-CO₂ future. Three of these scenarios are reviewed in respect of India. These are the BLUE Map scenario, which is largely optimistic for technology change, the BLUE Shifts scenario, which assumes a shift in travel patterns towards more efficient modes, and a combined BLUE Map/Shifts scenario, which applies the assumptions in both the BLUE Map and the BLUE Shifts scenarios together.

**Figure 11.20** Transport energy use by fuel in the Baseline and BLUE scenarios for India

![Figure 11.20](image)

Source: IEA Mobility Model database.

**Key point**

Compared to the Baseline, energy use in 2050 is cut by nearly 25% in the BLUE Shifts scenario, 42% in the BLUE Map scenario, and 52% in the BLUE Map/Shifts scenario.

Each scenario has different impacts in terms of the reductions in transport energy use in India in 2050 compared to the Baseline scenario (Figure 11.21). Worldwide, the BLUE Map scenario projects a 70% reduction in well-to-wheel CO₂ emissions in 2050 compared to the Baseline scenario in that year. For India, the BLUE Map scenario projects a 42% reduction in energy use compared to the Baseline scenario in 2050, but still nearly a sixfold increase in energy use compared to 2007 levels.
This reflects the very strong growth in Indian transport activity and energy use in the Baseline scenario. Cutting this growth from a factor of nearly twelve to a factor of less than seven will be a considerable achievement.

**Figure 11.21**  Transport energy use by mode in the Baseline and BLUE scenarios for India

![Transport energy use by mode in the Baseline and BLUE scenarios for India](image)

Source: IEA Mobility Model database.

**Key point**

*LDVs offer the largest opportunity to limit the increase in energy consumption.*

Improvements in incremental transport energy efficiency offer the largest and least expensive reductions in Indian energy use for transport, at least over the next 10 to 20 years. Adoption of advanced vehicle technologies and new fuels also provide important contributions, especially after 2030.

**Vehicle efficiency improvements**

Most Indian cars, trucks and two-wheelers are typically cheaper, smaller and less powerful than similar vehicles in most other countries, particularly in the OECD member countries. As a result, the cost-effective level of efficiency improvement in India may be less than that of many other countries. That said, the Baseline scenario assumes that by 2050 or well before, India will have large numbers of vehicles of similar size, weight, power and perhaps cost, as those in most other parts of the world. This suggests that technological advances are likely to become increasingly cost effective in India as elsewhere.

A 30% to 50% improvement in new vehicle efficiency across modes by 2030 is not out of the question for India, despite its relatively efficient starting point of about 6.6 litres (L) of fuel per 100 km. In the BLUE Map scenario, efficiency improvements and advanced technologies for vehicles (Figure 11.22) help to slow the growth of energy use and CO₂ emissions in India.
Data on the efficiency of Indian trucks suggest that they tend to be small and fairly energy intensive. In practice, many are also overloaded and unsafe. So they may achieve better energy intensity than the statistics would suggest. There is likely to be a great potential for cutting fuel use per tkm by moving to larger trucks with modern, high efficiency diesel engines. Similarly, aircraft in India are likely to become more efficient as newer, larger models are introduced. As with most countries, an estimated 30% to 50% improvement potential exists for trucks, ships and aircraft in India.

**Advanced vehicles and fuels**

Figure 11.22 shows the changes in LDV sales in the Baseline and BLUE Map scenarios. In the Baseline scenario, the share of diesel and gasoline vehicles grows rapidly to 2020, after which hybrid vehicles begin to be sold in increasing numbers. Compressed natural gas vehicles also account for a small but growing share of vehicles over time. In the BLUE Map scenario, hybrid vehicles begin to be sold in large numbers after 2015, and EVs and PHEVs start to make a serious impact on the market after 2020. Electric vehicles may play a particularly important role in India if the dominance of small cars continues, as EV technologies are particularly well suited to smaller cars.

**Figure 11.22** Passenger LDV sales by technology for the Baseline and BLUE Map scenarios for India

Source: IEA Mobility Model database.

**Key point**

In the BLUE Map scenario, new technology vehicles such as EVs reach significant sales shares after 2020.

The impact of EVs on CO₂ emissions depends on the CO₂ intensity of electricity generation. It would therefore make sense to deploy EVs first in those parts of India with relatively low-CO₂ power generation. But EVs provide other important benefits
besides CO₂ reduction, including a complete elimination of tailpipe pollutants. In India’s cities this is extremely important and valuable, and decisions regarding the timing and location of EVs deployment in India should take this into account.

For those modes that are more difficult to electrify such as trucks, ships and planes, biofuels will need to play a role in helping to reduce emissions. They are assumed to be blended up to 30% with petroleum fuels by 2050. Biofuels such as cane ethanol may be produced in a large volume in India but probably only if food security is achieved first. Advanced, sustainable biofuels such as ligno-cellulosic ethanol and biomass to diesel may be widely available from global markets from a variety of sources.

The BLUE Shifts and BLUE Map/Shifts scenarios

The BLUE Shifts scenario looks at the potential to cut energy use and CO₂ emissions through changes in the pattern of future travel growth, directing more travel towards the most efficient modes such as rail, bus and non-motorised travel. This is coupled with policies to reduce overall travel demand by, for example, more efficiently organising and interconnecting cities and regions, thereby lowering the volume and length of trips undertaken.

Substantial investment in sustainable transport, such as high-quality bus and rail transit systems, and building much better infrastructure for cycling and walking, can help put India on the path to a sustainable future. It can also help improve mobility for millions of people in the near term. The need to ensure that India’s cities are not clogged with traffic, and that people without access to private vehicles can have full mobility, are important considerations beyond energy and CO₂ emissions. The overwhelming evidence is that cities that develop urban transport systems that facilitate walking and cycling and reduce the need for motorised transport are more sustainable and better to live in than cities dominated by private vehicles. These features may help slow the growth in car use, particularly in urban areas, relative to the Baseline scenario. The BLUE Shifts scenario assumes 25% lower levels of car and air travel in 2050 than in the Baseline scenario, with fuel savings of about 20% in 2050. But even with such modal shifts, car ownership in India is likely to rise by a factor of five to ten in the coming decades.

If the approaches in the BLUE Map and BLUE Shifts scenarios are pursued in parallel, car and air travel will be reduced and shifted to more efficient modes, and strong improvements in vehicle efficiency and the adoption of new technology vehicles and new fuels will be pursued. Such an approach underpins the BLUE Map/Shifts scenario. In this scenario, India cuts its transport energy use by about half, and its fossil energy use by about three-quarters in 2050 compared to the Baseline scenario. CO₂ emissions are cut by around 70%.

Investment needs in the BLUE Map scenario

India’s GDP is projected to increase by 5% a year from 2007 to 2050. This growth in the economy is expected to drive higher demand for goods, services and leisure activities requiring energy. Given this expected strong growth in energy demand, reducing CO₂ emissions in India will be difficult, although the rapid deployment of low-carbon technologies will help to limit the growth in emissions. Significant
investments will need to be made in energy-efficient equipment, appliances, vehicles and buildings. The power sector will need to be significantly decarbonised, which will require large investments in nuclear, clean coal technologies, renewables and CCS. In the medium and long term, additional technologies will also be needed to reduce the CO₂ intensity of transport and industry.

Limiting the growth in India’s CO₂ emissions in the BLUE Map scenario in 2050 to 10% above 2007 will require additional investments of USD 4.5 trillion between 2010 and 2050 (Figure 11.23). Of this total, USD 2.8 trillion is required in the transport sector and USD 1.2 trillion in the power sector, almost all of it after 2030. For transport, most investments are for low-carbon vehicles and biofuels. Additional investment needs in the buildings sector and the industry sector are estimated at USD 0.3 trillion each.

Additional investment in efficient and low-carbon technologies will also enable a reduction in fuel requirements\textsuperscript{12} estimated at USD 8.0 trillion from 2010 to 2050. If the fuel savings are taken into account, net savings from the additional investments from 2010 to 2050 are USD 3.5 trillion. As fuel savings from the additional investments will continue beyond 2050, in practice the long-term net additional savings are likely to be higher than this.

As most additional investments are required in the transport sector, it is expected that the financing will be funded by consumers. Beyond that, however, there will be a need for India to engage with others internationally to secure the benefits of RDD&D, technology transfer and appropriate financing mechanisms, especially in the power and industry sectors.

**Figure 11.23** Additional investment needs and fuel savings for India

- **Key point**
  
  The fuel savings in the transport sector will significantly more than offset the additional investments required in that sector.

---

\textsuperscript{12} The estimations are based on undiscounted fuel savings.
Transition to a low-carbon energy future

For India to play its part in realising the global goals of the BLUE Map scenario, it will need to achieve rapid economic development over the next 40 years with only a very small increase in CO₂ emissions. Currently there is no precedent for such a low-CO₂ development path. It will need to be based on meeting the increasing energy needs of India’s growing population through the widespread deployment of a range of existing and new low-carbon technologies (Figure 11.24). Compared to the Baseline CO₂ emissions in 2050, the BLUE Map scenario envisages a reduction of 5.0 Gt CO₂.

**Figure 11.24** CO₂ emissions reductions by technology area in the BLUE Map scenario for India, 2050

Key point

About 40% of the reductions in the BLUE Map scenario come from the power sector.

Improved energy efficiency across both supply and end-use sectors is the single largest source of CO₂ reductions. But even in the BLUE Map scenario, energy use in India still grows 2.5 times over the period to 2050. The challenge will therefore be to move to sources of energy and technologies that have much lower CO₂ emissions than those used today and to achieve a near decarbonisation of the power sector. On a sectoral basis, the largest potentials for reducing CO₂ emissions lie in the power generation and transport sectors, with 38% and 27% of the overall reductions in 2050, respectively.
In the power sector, the development of solar energy, nuclear power and efficiency improvement in generation from fossil fuels represents about 65% of the reductions from the sector. The recently announced Solar Mission sets ambitious targets for photovoltaic and concentrating solar power by 2022. But deployment will need to increase even faster after this date. The BLUE Map scenario suggests that by 2050 almost 200 GW of solar capacity will be required. The prospects for nuclear power in India have improved with the 2008 agreement with the United States and the consent of the Nuclear Suppliers Group. But India may still need to deploy new reactor designs if it wants to expand its nuclear production capacity to levels significantly higher than 100 GW.

Electricity access for poor rural areas may be improved through decentralised solar systems with storage and other types of decentralised renewable supply options. Improving transmission and distribution efficiency should be a priority. Fundamental to this will be moves to make sure that prices reflect supply costs. Proper electricity pricing, together with steps to support more energy-efficient equipment and lighting, may result in substantial savings and reduced demand growth.

Steps to increase oxyfuelling and to accelerate the work on IGCC technologies for Indian coal can help improve the efficiency of coal-fired generation. It will also provide a useful step towards applying CCS in the longer term. The development of a CCS technology in the power generation sector that is suited to Indian coal will require particular attention. The complexity of this technology and its impact on electricity cost make this one of the less attractive abatement options for India. Even so, CCS will have to play a vital role in helping India to decarbonise its electricity system.

In transport, the development of new technologies such as PHEVs and EVs will be essential in realising emissions reductions. However, the emission benefits of these technologies depend on the successful decarbonisation of the power sector. In the BLUE Map scenario, the growth in electricity demand for transportation occurs after 2030, so there is still some time for India to increase the share of low-emission generation technologies. Vehicles fuelled on natural gas and, in the longer term, hydrogen could also be important.

**Box 11.3 ▶ India’s technology innovation targets**

A number of plans and strategies have been developed in recent years by the government of India and its agencies and institutes relevant to energy-related technology planning. India has recently allocated a budget of over USD 1 billion from its stimulus package for clean energy and other climate-related measures.

---

13. The Nuclear Suppliers Group is comprised of 46 nuclear supplier states, including China, Russia and the United States, that have voluntarily agreed to co-ordinate their export controls governing transfers of civilian nuclear material and nuclear-related equipment and technology to non-nuclear-weapon states.
India recognises the power sector as a key driver for the overall social-economic development of the country and as a major input for delivering targeted levels of GDP growth. Numerous policies and programmes have been put in place, or are being developed, to increase the availability, accessibility and affordability of electricity for all the sectors of the economy. Current technology priorities in India include:

- development of clean coal technologies;
- development of nuclear power through a three stage nuclear programme;
- energy efficiency in industry and buildings through such approaches as audits, trading schemes and labelling;
- increased use of biodiesel and ethanol in transportation fuels;
- improved electricity transmission and distribution networks.

In the industrial sector, the application of BATs and the development of breakthrough technologies will help in reducing emissions. CCS will be needed in both the industry and the transformation sectors to keep the increase in emissions in line with the overall reduction targets.

The three largest industrial sectors of iron and steel, chemicals and cement are responsible for about 25% of India’s total emissions and priority should be given to reducing the CO₂ intensity in these sectors. Special attention should focus on coal-based DRI, pulp and paper making and small-scale cement kilns. These three areas offer interesting opportunities to increase efficiency and limit the growth in energy consumption. These industries also offer attractive opportunities, with international support, for the early demonstration of CCS. Achieving wider deployment may also require the implementation of sectoral crediting mechanisms which would encourage Indian industries to invest in these technologies.

The increase in living standards anticipated in India as it grows richer will place a strong upward pressure on energy consumption in the residential and service sectors. The higher penetration of energy-using appliances and equipment will more than offset the energy efficiency gains seen in the BLUE Map scenario. The greater use of commercial energy sources, such as electricity and kerosene, will play a major role in restraining the growth in energy consumption for buildings, as the efficiencies associated with these fuels are much higher than traditional biomass. However, a substantial decarbonisation of electricity generation will be required to limit the increase of CO₂ emissions from greater electricity use. Development of more efficient cooking stoves, lighting and air conditioners will be key in restraining the growth in energy consumption and CO₂ emissions.

The development of many of these low-carbon technologies has already been identified in India’s technology innovation targets. More is required to limit the growth in emissions to 10% over the 2007 level. In addition to the priorities that have been identified, more focus should be placed on the development of CCS, deployment of wind power, greater fuel economy in vehicles and RDD&D for PHEVs and EVs.
In identifying the step towards achieving energy security and carbon reductions in India, national technology roadmaps for the most promising low-carbon technologies should be developed. Achieving the ambition of the BLUE Map scenario will also require international collaboration on a number of initiatives. Enhanced international co-operation for research, development, sharing and transfer of technologies will be required. International carbon reduction mechanisms such as the Clean Development Mechanism (CDM) will need to play a role in the deployment of low-carbon energy technologies in India.