PART 2 THE TRANSITION FROM PRESENT TO 2050

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Key findings

A step change is needed in the pace and scale of low-carbon energy technology development and deployment across all sectors. Global climate change goals cannot be achieved without all technologies in the low-carbon portfolio making a full contribution.

Although some low-carbon and energy-efficient technologies are competitive today, many others are considerably more expensive than their fossil-based alternatives. Carbon pricing will be important in helping to redress this gap, but it will not be sufficient on its own. To avoid the lock-in of high-emitting, inefficient technologies during the next decade, governments will need to intervene on an unprecedented level with targeted technology policies to address the cost-competitiveness gap.

Policies should be tailored to reflect the maturity and market competitiveness of individual technologies. Where appropriate, they will need to include support for research, development, demonstration and deployment (RDD&D).

Government, industry and civil society need also to enable technology transition by:

• facilitating greater industry leadership through the development of sector-specific roadmaps and public-private partnerships;

• investing in training and education to develop and deploy the human capacity that will be needed to exploit the low-carbon energy technologies of the future;

• engaging the public and communicating to them the urgency of the need to deploy low-carbon energy technologies on a large scale, and the costs and benefits of doing so;

• strengthening international technology collaboration to accelerate RD&D, diffusion and investment.

There is a significant gap between the current level of investment in low-carbon technology RD&D and the investment needed to bring forward the technologies that will underpin the successful achievement of the BLUE Map outcomes. Addressing this gap will require annual public-sector spending two to five times as high as current levels. There is a need for governments, in close collaboration with industry, to reassess their spending priorities for low-carbon energy technology RD&D.

Governments also need to accelerate innovation by implementing best practices in energy RD&D programme 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 increasing the linkages between the basic science and applied energy research communities to accelerate innovation.
The BLUE Map scenario provides a sense of the scale on which low-carbon energy technologies will need to be deployed to meet global climate change goals. Such an energy technology “revolution” will require major improvements in energy efficiency, the near-decarbonisation of the electricity sector and the introduction of new low-carbon technologies in the industry, buildings and transport sectors. Although there are signs that some of the necessary changes may be starting to happen, sustaining and accelerating this transition will depend on a very significant expansion in the development and deployment of all available low-carbon technology options. It will require unprecedented intervention by governments in developing policies that work with and influence energy and consumer markets to achieve this outcome.

Current rates of investment in capital plant fall well short of the annual rate of investment necessary to achieve the 50% reduction in energy-related carbon dioxide (CO₂) emissions by 2050 envisaged in the BLUE Map scenario. Figure 12.1, which addresses low-carbon investment needs for the electricity sector, shows that for emerging technologies such as offshore wind and coal-fired power generation with carbon capture and storage (CCS), more than 40 times the current annual rate of investment needs to be achieved. Even in more mature technologies such as onshore wind, rates of investment need significantly to increase. Only in respect of hydroelectric power is the current rate of investment, if sustained, anywhere near sufficient. Low-carbon transport, smart grids and end-use energy efficiency also require significant increases in annual investment from today’s levels. For example, under the BLUE Map scenario, about 100 million electric and plug-in hybrid vehicles will be sold annually in 2050, compared to virtually none today. This is about 10% over the expected baseline level of investment in light-duty vehicles of USD 140 trillion between 2010 and 2050. For solar thermal water heating, the annual rate of installation is currently about 20 GWth (Weiss, Bergman and Stelzer, 2009), but this increases in the BLUE Map scenario to an average rate of 88 GWth per year between 2010 and 2050, just for the residential and service sectors.

Governments and industry, therefore, need to accelerate the transition to a portfolio of energy solutions which must include energy efficiency in all end-use sectors, renewable energy, nuclear power, low-carbon transportation options, CCS, and low-carbon industrial strategies. Enabling technologies such as smart grids and utility-scale energy storage will also be important. The failure effectively to develop any one of these options could potentially result in additional costs or delays in the achievement of the overall mitigation goals, with negative consequences for the global climate.

**Improved energy efficiency.** In the BLUE Map scenario, the largest share of the total emissions reduction (38%) comes from an increase in energy efficiency. To achieve this, the annual rate of improvement in global final energy intensity will need to increase from 1.7% to 2.6%. This will require a doubling of the rate of energy efficiency improvement, from 0.7% a year in the Baseline scenario to 1.5% a year in the BLUE Map scenario. Such rapid improvements in end-use efficiency
will require the immediate implementation of stronger national energy efficiency policies and measures (IEA, 2009a). In the industrial sector, national policies and measures and international sectoral agreements will be needed to encourage the implementation of best available technologies (BATs) to deliver further substantial savings in emissions (IEA, 2009b).

**Figure 12.1** Annual capacity additions needed in the electricity sector to achieve the BLUE Map scenario

<table>
<thead>
<tr>
<th>Source of Energy</th>
<th>Present Rate</th>
<th>Gap to Reach BLUE Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal-fired with CCS</td>
<td>35 plants (500 MW)</td>
<td>30 plants (1,000 MW)</td>
</tr>
<tr>
<td>Gas-fired with CCS</td>
<td>20 plants (500 MW)</td>
<td>12,000 turbines (4 MW)</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Historical high</td>
<td>325 million m² solar panels</td>
</tr>
<tr>
<td>Hydro</td>
<td>50% of France’s hydro capacity</td>
<td>50% of France’s hydro capacity</td>
</tr>
<tr>
<td>Biomass plants</td>
<td>200 plants (50 MW)</td>
<td>45 units (100 MW)</td>
</tr>
<tr>
<td>Wind onshore</td>
<td>3,600 turbines (4 MW)</td>
<td>55 CSP plants (250 MW)</td>
</tr>
<tr>
<td>Wind offshore</td>
<td>12,000 turbines (4 MW)</td>
<td>12,000 turbines (4 MW)</td>
</tr>
<tr>
<td>Geothermal</td>
<td>45 units (100 MW)</td>
<td>50% of France’s hydro capacity</td>
</tr>
<tr>
<td>Solar PV</td>
<td>325 million m² solar panels</td>
<td>325 million m² solar panels</td>
</tr>
<tr>
<td>Solar CSP</td>
<td>55 CSP plants (250 MW)</td>
<td>55 CSP plants (250 MW)</td>
</tr>
</tbody>
</table>

Notes: Unless otherwise indicated, all material derives from IEA data and analysis. Current rates of capacity additions for gas-fired and coal-fired CCS plant, nuclear plant, and hydropower are taken from IEA (2008a); renewable energy rates are taken from REN21 (2009).

**Key point**

Annual rates of investment in low-carbon technologies must be significantly increased from today’s levels.

**Widespread introduction of CCS.** The second-largest share (19%) of least-cost emissions savings in the BLUE Map scenario comes from the rapid and widespread introduction of CCS in power generation, emission-intensive industry and fuel transformation. Given the long life of boilers and power generating equipment, CCS capacity will need to be retrofitted to some existing facilities to achieve the levels of penetration needed. Other plants will need to be built with CCS fitted from the outset. The BLUE Map scenario envisages the completion of 100 large-scale projects by 2020 and 3,400 projects by 2050.

**Increased deployment of renewable energy.** The third-largest share (17%) of the overall reduction in emissions in the BLUE Map scenario comes from the substantial further deployment of renewable energy technologies. By 2050, almost half of total electricity generation comes from renewable energy sources, up from 18% today. Wind, solar photovoltaic (PV), concentrating solar power (CSP), biomass and hydro will all have to make an important contribution. For example, the BLUE Map scenario envisages the bringing onstream of an average of 48 gigawatts (GW) of onshore wind every year for the next 40 years. Over the same period an average
of 325 million square metres (m²) of PV panels would need to be installed every year, totalling more than 13 billion m² of panels by 2050.

**A renewed focus on nuclear power.** An important part of the emissions reductions in the BLUE Map scenario comes from an increase in the share of nuclear power. This would require around 30 nuclear plants, each of 1 000 megawatts (MW) capacity, to be built every year from 2010 to 2050.

**Addressing transport.** Despite very significant increases in transport volumes, the transport sector will need to reduce its emissions well below 2007 levels worldwide if overall emissions are to be halved by 2050. Reducing emissions from the sector will require rapid advancement in three areas: achieving a 30% to 50% reduction in energy intensity by 2050 for all transport modes; rapidly adopting new technologies including plug-in hybrid electric vehicles (PHEVs) and full electric vehicles (EVs) after 2015 and fuel-cell vehicles (FCVs) after 2025; and producing around a quarter of transport fuel from sustainable biofuels by 2050. Sustainable transport systems will also be critical to the enabling of much wider use of the most efficient travel modes such as rail, air, shipping, bus, and non-motorised travel.

**Support for enabling technologies.** A number of important cross-cutting enabling technologies will be needed to underpin these transformations. For example, to make the maximum use of energy efficiency, renewable power generation and EVs, substantial investment will be needed in smart electricity grids and in utility-scale energy storage. It will be critical for investors, together with national and regional regulators and planning experts, to develop an integrated vision for the role of smart grids at national and regional levels (see Chapter 4).

One of the main obstacles to these technology transitions is cost. Many low-carbon technologies currently cost more than conventional alternatives. One way to help redress this balance is to establish a price on CO₂ emissions. Countries are pursuing this goal through a range of multilateral and regional/national schemes, including through the United Nations Framework Convention on Climate Change (UNFCCC) process. A number of new and innovative financing products are also being developed, as described in Chapter 14.

A firm, predictable carbon price is likely to be an important driver of change. But it is unlikely to be sufficient on its own to drive short-term investment in the more costly technologies that have longer-term emissions reduction benefits (Stern, 2007). A truly global carbon market is also likely to be many years away. Many energy-efficient and some low-carbon energy supply technologies are available today at zero or low additional net cost. But a number of other technologies will not enter the market in a substantial way until prices are between USD 25 per tonne (t) of CO₂ and USD 75/tCO₂. This is much higher than the CO₂ prices seen today (Figure 12.2). Therefore, to avoid locking in inefficient, carbon-intensive technologies during the next decade, governments will need to intervene with targeted policies to bring down the cost of low-carbon alternatives and to create markets for technologies that are not yet fully commercial.
Key point

There is currently a sizeable gap between CO₂ prices and the mitigation costs of many low-carbon technology options.

The need for energy technology policies

To achieve a halving of CO₂ emissions by 2050, governments will need to complement carbon pricing measures with an integrated set of energy technology policies and RD&D programmes that are tailored to the different stages of development of individual technologies. International collaboration will be fundamental to achieving these outcomes cost-effectively. Issues of public engagement and workforce development also need to be tackled.

Markets, companies and governments pursue energy technology innovation through a number of parallel and interrelated pathways (Figure 12.3). Most existing government programmes focus on technology development. Governments also have a much wider role to play in ensuring the integration of market development measures, regulation and steps to ensure the creation of strong private-sector business models for technology. Small and medium-sized firms developing low-carbon technologies need to grow their capabilities in marketing and fund-raising, management and operations, supported by government efforts to develop regulatory standards for safety and performance which can command public support. In addition, governments can help achieve cost savings in the transition from R&D to demonstration by providing funding for important activities such as small-scale and component testing before technologies move to full-scale demonstration. Increased investments are also needed to improve research
infrastructures, especially laboratories and test facilities that are available to a wide range of industry and research institutions.

**Figure 12.3** Pathways for low-carbon technology development and deployment

<table>
<thead>
<tr>
<th>Technology pathway</th>
<th>Basic research</th>
<th>Applied research</th>
<th>Early demonstration</th>
<th>Full demonstration</th>
<th>Niche market/early deployment</th>
<th>Commercialisation and refinement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company pathway</td>
<td>Actively “mine” public and private research innovations for energy applications</td>
<td>Invest in early demos</td>
<td>Communicate results to stakeholders</td>
<td>Support regulatory development by providing data from demos</td>
<td>Engage affected stakeholders in project design</td>
<td>Bring technology to market, communicate remaining barriers to government</td>
</tr>
<tr>
<td>Market pathway</td>
<td>Technology “push” by public research</td>
<td>Identify markets</td>
<td>Perform market trial, communicate results to stakeholders</td>
<td>Support early adopters/niche markets</td>
<td>Start “market pull” policies</td>
<td>Technology and market evolution</td>
</tr>
<tr>
<td>Regulation pathway</td>
<td>Strategic planning and assessment of public health and safety infrastructure needs</td>
<td>Development of public consultation plans</td>
<td>Develop technology-specific incentives</td>
<td>Perform public consultation</td>
<td>Transition to technology-neutral incentives</td>
<td>Identify and address remaining barriers</td>
</tr>
</tbody>
</table>


**Note:** Processes are presented in a linear way. In practice, a number of non-linear feedbacks occur along the transition pathway that accelerate innovation.

**Key point**

Low-carbon technology development and commercialisation requires integrated support from markets, companies and governments.

**Tailoring policies to the stage of technology development**

Technologies at different stages of development need different types and levels of support:

- **For promising but not yet mature technologies** (Stage 1), governments need to provide financial support for additional research and/or large-scale demonstration and to start to assess infrastructure and regulatory needs.

- **For technologies that are technically proven, but require additional financial support** (Stage 2), governments need to provide support with capital costs, or to introduce technology-specific incentives such as feed-in tariffs, tax credits and loan guarantees, and appropriate regulatory frameworks and standards, to create a market for the relevant technologies.

- **For technologies that are close to competitive** (Stage 3), governments need to move towards technology-neutral incentives that can be progressively removed as technologies achieve market competitiveness.
For technologies that are competitive (Stage 4), governments can best help scale up public and private investment by tackling market, informational and other barriers and by developing effective intervention policies and measures.

Many technologies in practice straddle two or more stages of development. Government intervention needs to be tailored accordingly, in some cases providing support to all four phases of technology development simultaneously (Figure 12.4 and Box 12.1).

Figure 12.4 Policies for supporting low-carbon technologies

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
<th>Policies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Development and infrastructure planning</td>
<td>Low cost gap (e.g. fuel cells, 2nd generation biofuels, EV, CCS)</td>
<td>RD&amp;D financing, capital cost support for large-scale demonstration</td>
</tr>
<tr>
<td>2. Niche markets</td>
<td>High cost gap (CSP, PV, hybrid vehicles)</td>
<td>Feed-in tariffs, tax credits, loan guarantees</td>
</tr>
<tr>
<td>3. Achieving competitiveness</td>
<td>Mature technology (energy efficiency, industrial CHP)</td>
<td>Mature technology (energy efficiency, industrial CHP)</td>
</tr>
<tr>
<td>4. Mass market</td>
<td>Mature technology (energy efficiency, industrial CHP)</td>
<td>Mature technology (energy efficiency, industrial CHP)</td>
</tr>
</tbody>
</table>

Source: Adapted from IEA (2008b).

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

Key point

Government support policies need to be appropriately tailored to the stage(s) of development of a technology.

A number of energy technologies such as CCS, second-generation biofuels, EVs and smart grids are at Stage 1 on this spectrum. They offer very good promise but require large-scale demonstration, together with the development of regulatory frameworks, the strategic planning of appropriate infrastructure needs and public outreach and engagement (Box 12.2).
Box 12.1 Wind energy technologies span development categories

Wind is a good example of the way in which government support needs to be tailored to the stage of a technology’s development.

- **Stage 1: Promising but not technically proven wind technologies – deep offshore**
  Floating subsurface structures are being tested to support wind turbines at water depths greater than around 60 metres.

- **Stage 2: Technically proven, but strong financial support needed – shallow offshore**
  High investment costs compared to onshore, and low wind availability relative to onshore, signal a continuing need for capital investment in shallow onshore R&D to drive cost reductions.

- **Stage 3: Close to market competitiveness but some support still needed – onshore**
  Significant potential remains for incremental reductions in the cost of electricity from existing technology, equivalent to around 23% by 2050. This can be driven by continued incentives or other financial support.

- **Stage 4: Competitive technology – onshore**
  Although onshore wind technology is competitive in many markets, public support is still needed to ensure its deployment. Governments need to ensure that permitting procedures, trade controls, grid access, and public support enable further growth in capacity.

Box 12.2 Examples of policies to support promising but not yet mature technologies

The development of “early adopter” EV cities and driving corridors. A number of cities and regions are actively developing corridors to accelerate EVs from niche markets to competitive production and use. In Yokohama Japan, a detailed plan has been developed to support EV use and operation throughout the city with a range of recharging options. In Sweden, the Green Highway venture will create a green transport environment that includes municipal and utility investment in EVs, charging infrastructure, renewable fuels, testing and development. The initiative is taking place in an area between the Gulf of Bothnia and the Norwegian Sea which is home to 350 000 inhabitants and 150 000 vehicles.¹

Box 12.2  Examples of policies to support promising but not yet mature technologies (continued)

The strategic development of smart grids. An international collaborative project in Denmark called the Cell Project is designed to help the Danish power system adapt to future requirements. The overall electricity grid is divided into smaller cells in which all generation and substation switches are monitored and controlled individually. Combining cells results in a large system with more flexibility and reliability, for example by enabling a cell to be isolated from the rest of the system in the event of a fault. This approach could be extended to include the monitoring and control of loads in addition to generation. Consideration is being given to technological, market and environmental aspects to ensure that any barriers to such an approach will be removed when carried out on a full-scale basis.

Strategic planning to link major CO₂ sources to storage sites. The Port of Rotterdam in the Netherlands is taking an integrated and incremental approach to CO₂ pipeline planning. This involves the collection and transport of CO₂ from existing small-scale sources that emit pure CO₂. The scheme will expand to include demonstration CCS power plants and commercial-scale power plants, and in due course industrial sources. At the end of 2020, up to 20 Mt CO₂ will be stored in the Dutch continental shelf (Rotterdam Climate Initiative, 2009).

Offshore wind transmission and distribution systems. The Dutch government has prepared a draft National Water Plan that seeks to integrate wind power development in the North Sea alongside fisheries, shipping, nature conservation and coastal defences (IEA, 2009c). The Danish government has produced an action plan for offshore wind power which plans 26 potential sites for wind farms comprising 5 200 megawatts (MW) in total. The Danish plan is part of the larger North Sea Countries Offshore Grid Initiative, which involves nine EU member states and the European Union.

Forward-looking regulation to ensure a safe, effective low-carbon economy. Governments need to begin developing forward-looking, adaptive regulations to facilitate the effective and safe use of low-carbon energy technologies. For example, the United Kingdom Health & Safety Executive’s (HSE) Emerging Energy Technologies Programme (EET) has recognised that the transfer to new technologies will require rapid and effective health and safety regulation. The EET seeks to provide guidance that enables the safe introduction and expansion of new energy technologies, including renewable energy, CCS, small-scale distributed generation, natural gas storage and liquefied natural gas (LNG) imports, and cleaner coal technologies. The HSE is developing advance health and safety standards to ensure that the risks from these new energy systems can be managed. The EET also includes an element of skills development, to ensure that the people needed to regulate the industry are available as new energy systems reach the market (UK HSE, 2009).

As the capabilities of technologies become proven through R&D and start to enter the market (Stage 2), they need government support that is technology-specific. Solar PV, offshore wind and biomass power are technologies that are at the beginning of this phase. They currently need support in the form of tax credits or incentives for generators or customers and from regulations that mandate energy suppliers to purchase the output of a specific type of technology at higher-than-market rates, for example through feed-in tariffs or renewable energy portfolio standards. These mechanisms seek to establish a financial return from renewable generation that is competitive with other energy sources and sufficient to attract private investment. Government policies and programmes should target support on initial costs, recognising that many of these renewable energy technologies are more capital-intensive than their conventional fuel counterparts, but with lower variable costs in operation.

As technologies become competitive (Stage 3), governments should look to support them through market mechanisms which, while supportive of lower-carbon technologies in general, become progressively more technology-neutral. These would include such mechanisms as tradable green certificates or greenhouse-gas emissions trading. At this stage, governments should reduce technology-specific support.

Regardless of the type of support, government mechanisms should satisfy certain design principles:

- Policies should be transparent, stable and predictable in the long term to minimise investor uncertainty. They should also be easy to unwind or remove when the technology has achieved set competitiveness milestones.

- Incentives and mandates should reflect the maturity of different technologies. Levels of support should decrease over time as the technologies become competitive.

- Policies should encourage the development of both generation and transmission technologies.

- Technology push and market pull incentives should be part of a coherent, strategic framework and supported by measures that address administrative or other barriers faced by technologies.

- Governments should encourage energy output rather than the installation of technology. This will encourage investors to maximise energy output and greenhouse-gas emissions reductions over the lifetime of the project.

- Policies should be easy to implement and enforce, with appropriate penalties for non-compliance.

Above all, the objective should be to reduce risk and stimulate deployment while encouraging technologies to reduce costs and become more market-competitive.

A further group of technologies – including energy efficiency, industrial combined heat and power (CHP) and onshore wind in some markets – are already commercially viable (Stage 4), particularly where emissions trading systems create a cost for greenhouse-gas emissions. But they are susceptible to market and other barriers that prevent their full use. For these technologies, government support
should include specific measures to address information, market, legal, regulatory or financial barriers. Examples of government policies and actions taken in these respects include:

- Regulatory or control mechanisms such as energy building codes or minimum energy performance standards for appliances through which governments can impose requirements to invest in energy-efficient technologies and infrastructure.

- Fiscal or tax policies through which governments offer consumers tax incentives for investment in energy-efficient technologies or procure energy-efficient technologies themselves.

- Promotion and market transformation programmes through which governments or energy providers influence consumers to purchase energy-efficient technologies.

- Financial remediation measures through which governments or energy providers offer special financing or lines of credit for energy-efficient technology investments.

- Commercial development and industry support mechanisms through which governments or energy providers partner with the private sector to increase the deployment of energy-efficient commercial buildings (IEA, 2008b).

Enabling actions: addressing the business and human aspects of a low-carbon technology revolution

In addition to tailoring policies to the stage of a technology’s development, there are other important enabling actions that need to be taken to ensure wider industry and public support for low-carbon technologies, and to ensure that these technologies rapidly diffuse throughout the world. These include:

- fostering industry leadership;

- developing a skilled low-carbon energy workforce;

- expanding public outreach and engagement;

- strengthening international collaboration.

Fostering industry leadership

As discussed in Chapter 13, the IEA has been working with government and industry to develop roadmaps for many of the low-carbon technologies. Many of the roadmaps recommend accelerating private-sector innovation and greater industry leadership to address technology development goals. Public-private partnerships aimed at speeding the transition from demonstration to the commercial deployment of clean energy technologies can play a part in this respect. Such partnerships may be particularly appropriate for technologies such as CCS and EVs that will depend on the development of new business models for industries and technologies (Box 12.3). There is evidence that a large proportion of breakthrough innovations come from new firms that challenge existing business models. Government steps to remove barriers to the entry, exit and growth of new firms may have an important part to play in low-carbon energy technology development.
The IEA roadmaps have also identified a need for governments and industry to work more closely together in support of technologies that have a large future potential but are currently unable to attract significant investment. For example, the oil and gas industry has extensive knowledge about the prospects for CO\textsubscript{2} storage in oil and gas fields. The industry may be willing to offer reduced-cost geologic modelling and prospecting capabilities to help governments improve their knowledge of prospects of geologic CO\textsubscript{2} storage in exchange for accelerated access to promising CO\textsubscript{2} storage sites. Increased government/financial sector risk-sharing to support small-scale energy technology companies, on the lines of the United Kingdom’s Carbon Trust, also warrants further examination.
Companies within industry sectors can help advance low-carbon energy technologies by working collaboratively with each other to develop sector visions for the future. The publication in 2009 of the joint IEA-cement industry roadmap shows how industry can provide leadership and guidance to government and civil society about the actions that need to be taken to transition to a low-carbon future (Figure 12.5). This may be particularly important when considering technology solutions such as CCS that add significant costs. There may be considerable value in other emission-intensive sectors undertaking similar initiatives to help identify and progress low-carbon pathways.

**Figure 12.5** Cement sector emissions reduction pathway

![Cement sector emissions reduction pathway](image)

Source: IEA (2009d).

**Key point**

*Industry can help to define practicable low-carbon technology pathways.*

**Developing a skilled low-carbon energy workforce**

Many roadmaps have identified human workforce development as an important near-term priority. Governments need to create educational incentives and to work with industry to foster viable career paths for skilled people in low-carbon technology fields. This includes the development of academic curricula and training of experts, including geologists to facilitate CO₂ storage, nuclear power technicians, and people with expertise in renewable energy and smart grids. There is also a need to adapt existing vocational and higher education institutions to develop the energy skills that will be needed. Several governments and non-governmental organisations (NGOs) are actively pursuing these training opportunities. These efforts need to be accelerated and replicated globally (Box 12.4).
Box 12.4  Examples of low-carbon training programmes

Capacity building and training activities in CCS are undertaken by several international bodies. The IEA Greenhouse Gas Programme has developed a CCS Summer School geared towards young scientists from developed and developing countries. The course was held for the first time in 2007 in Germany. At the national level, a CCS School was started by research centre CO2CRC in Australia in July 2008.

The United States Solar Instructor Training Network was launched in October 2009 to address the need for training in solar system design, installation, sales and inspection. The programme has been designed in partnership with the United States Department of Energy (US DOE). In addition to increasing the number of trained workers in the solar industry, US DOE finances the accreditation of solar training programmes, the certification of solar installers, and the distribution of best practices for training programmes. US DOE plans to invest USD 27 million over five years in the network of regional resource and training providers.

The California Green Corps programme utilises USD 10 million in federal economic stimulus funding from the United States Department of Labor and an additional USD 10 million from public-private partnerships to help stimulate green technology while helping to place more than 1 000 at-risk young adults into jobs. The programme consists of ten regional Green Corps in different parts within California. Participants receive a stipend and must complete job training focused on green jobs, continue their education and contribute to their communities through community service.

The Joule Centre, funded by the United Kingdom Northwest Regional Development Agency, aims to increase the Northwest region’s RD&D capacity in key disciplines in the energy sector and to build the skills that are needed to support the work of the Northwest Energy Council on energy policy and economic development.

The Green Jobs Initiative started in 2007 as a joint initiative by the International Labor Organization (ILO), the United Nations Environmental Programme (UNEP), the International Employers Organization (IOE) and the International Trade Union Confederation (ITUC) to help countries to realise the potential for green jobs. In Bangladesh, the ILO initiative will partner with the Grameen Shakti programme, which is currently providing training, particularly to women, on servicing and repairing renewable energy technologies such as solar PV. The initiative will also introduce entrepreneurship and skills training for men and women promoting the use of renewable energy technologies.

In China, the government adopted a 2003 to 2010 National Rural Biogas Construction Plan, which provides new employment opportunities for many unemployed farmers in rural areas. In order to meet the shortage of technical capacity for the operation and maintenance of the digesters in Shanxi Province, 40 training courses were held. By 2005 over 4 000 people had been awarded the National Biogas Professional Technician Certificate (Kuhndt and Machiba, 2008).

6. See www.co2captureandstorage.info/summerschool/organisation%202008.html.
Expanding public outreach and engagement

Achieving the technology transitions envisioned in the BLUE Map scenario will depend, among other things, on people supporting and adopting low-carbon technologies. The roadmaps point to a need for expanded public outreach and engagement to facilitate the transition to a low-carbon energy system. A first priority should be for governments, industry and civil society to develop a common vision for the transition to low-carbon energy. The process of developing the vision should involve sharing information and views on the importance of using a portfolio of low-carbon technologies, the costs and benefits of various technology options, and the need for infrastructure and technology change. This shared vision will be important in helping to secure public support for low-carbon technology spending and subsidies.

Some countries have developed transition strategies on these lines that include:

- Analysis of the need for a process of transition management that identifies stakeholders, processes and institutions to support the development of low-carbon technologies (Kemp and Rotmans, 2005; Loorbach and Kemp, 2008).

- Implementation of an energy transition programme that involves public and private actors working in partnership to develop transition pathways and experiments for key technologies. These experiments provide critical learning about the feasibility and social acceptability of particular technologies (Energy Transitions Task Force, 2006; Dietz, Brouwer and Weterings, 2008).

Governments and the private sector will need to complement this with expanded community engagement. When announcing major investments in technologies such as CCS, wind energy and nuclear power, governments and companies often fail to explain to the public why they are doing so and to secure the support of critical stakeholders. This has led to local opposition to planned projects. Communities near, for example, CO₂ transport and storage sites, wind or solar farm developments, and nuclear waste disposal projects need to be engaged early in the process of site selection. NGOs, together with local environmental and public health officials, may have an important role to play. There are a number of proven principles and procedures which can help to incorporate public concerns into project design and development, and some good examples of projects in which these principles have been very effectively followed (Table 12.1).

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### Table 12.1 Examples of public engagement projects

<table>
<thead>
<tr>
<th>Project name</th>
<th>Applications</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>European Union Create Acceptance project</td>
<td>Energy projects</td>
<td>Includes the ESTEEM tool, which proposes a six-stage framework for public engagement</td>
</tr>
<tr>
<td>World Resources Institute (WRI) Breaking Ground public engagement guide</td>
<td>Extractive and infrastructure projects</td>
<td>Presents seven principles for effective community engagement</td>
</tr>
<tr>
<td>US National Institute for Standards and Technology’s Communicating the Future study</td>
<td>All science and technology projects and/or programmes</td>
<td>Presents a set of best practices for communicating science and technology to the public</td>
</tr>
<tr>
<td>University of Calgary, IISD, Canada – Climate Change Central CCS Communication Workshops</td>
<td>CCS projects</td>
<td>A guide to communicating CCS to the public from a range of different perspectives. Discusses how to build trust via actions designed to ensure commitment, accountability, disclosure and acknowledgement</td>
</tr>
<tr>
<td>Centre for Low Emission Technology, CSIRO, An Integrated Roadmap of Communication Activities around CCS in Australia and Beyond</td>
<td>CCS projects</td>
<td>Recommendations to industry on how to devise communication strategies on CCS, including proactivity, partnering with credible organisations, developing education tools, engaging public figures, and linking CCS to larger climate change solutions such as renewable energy</td>
</tr>
<tr>
<td>US National Wind Coordinating Committee, Wind Siting Case Studies – Community Response</td>
<td>Wind projects</td>
<td>Uses an access study approach to evaluate public acceptance of local wind development projects and identifies approaches used by developers to successfully address community concerns</td>
</tr>
</tbody>
</table>

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### Designing new models for international collaboration

A number of roadmaps have also identified an urgent need for greater international collaboration to accelerate the global diffusion and adoption of low-carbon energy technologies. There is a common need for greater knowledge sharing and RD&D collaboration among countries to accelerate technology advancement along the curve from demonstration to commercialisation. There is also a need to target some emerging and developing economies with specialised approaches to ensure capacity building and appropriate enabling environments (see Chapter 15).
Shared international learning may also help to lower the costs of technology demonstration and commercialisation by enabling national budgets to be co-ordinated in a more efficient manner. There are many models for collaboration, from broad, multilateral cross-cutting efforts to technology-specific efforts. An early need is to develop an inventory of existing low-carbon technology activities to identify areas of duplication and potential opportunities to make better use of investments.

The Asia-Pacific Partnership on Clean Development and Climate (APP) brings together seven leading developed and developing nations to address climate change, energy security and air pollution challenges in a way that encourages economic development and reduces poverty. The members are Australia, Canada, China, India, Japan, South Korea and the United States. This grouping represents around half the world’s emissions, energy use, gross domestic product (GDP) and population, and engages many of the largest greenhouse-gas emitters in the Asia-Pacific region. Eight task forces have been established, covering cleaner fossil energy; aluminium; steel; cement; coal mining; renewable and distributed energy; buildings and appliances; and power generation and transmission. These task forces have both government and private-sector members and are responsible for progressing the work of the Partnership. For example, the APP Steel Task Force promotes the effective reduction of emissions by compiling a collection of high-performance technologies, developing a methodology to assess energy efficiency, analysing reduction potentials and identifying areas for improvement.

The Major Economies Forum on Energy and Climate (MEF) uses a similar structure. The Forum, which comprises 17 major developed and developing economies, was launched in March 2009. Its goal is to advance the exploration of initiatives and joint ventures that increase the supply of clean energy and cut greenhouse-gas emissions. At the UNFCCC Conference of the Parties to the Convention, 15th session (COP-15) in Copenhagen in 2009, the MEF countries published a series of Technology Action Plans for a number of specific low-carbon technologies, including advanced vehicles, solar energy, ocean energy and CCS.

Negotiations on a new climate change treaty under the UNFCCC are addressing the need for greater international collaboration across the technology development cycle. Progress was made at COP-15 to establish a new technology mechanism that would promote and channel finance to national and collaborative technology initiatives, catalyse the development and use of technology roadmaps or action plans at international, regional and national levels through co-operation between relevant stakeholders, and enhance co-operation between national, regional and international technology centres and institutions.

At the request of G8 leaders and IEA countries’ energy ministers, the IEA is taking forward plans for an international low-carbon energy technology platform. The platform will bring together policy makers, business representatives and technology experts to discuss how best to encourage the spread of clean energy technologies. It will pull from lessons learned from the 42 IEA Implementing Agreements, which have been operating for more than 30 years with a focus on technology-specific research, development and deployment (see Annex B).

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Energy technology research, development and demonstration

More investment in low-carbon energy technology RD&D is needed at all stages of technology development. This should include direct government funding, grants and private-sector investment. After years of stagnation, government spending on low-carbon energy technologies has risen. But current levels still fall well short of what is needed to deliver significant greenhouse-gas emissions reductions in the longer term. Private-sector spending is very uncertain.

Current public-sector low-carbon RD&D expenditure

Government energy RD&D budgets in IEA member countries declined between the early 1980s and the 1990s from USD 19 billion in 1980 to USD 8 billion in 1997. The decline was associated with the difficulties of the nuclear industry and with the decrease in oil prices from 1985 to 2002. Since 1998, government expenditures on energy RD&D have started to recover, particularly between 2005 and 2008. Expenditure in 2008 was about USD 12 billion. The share of energy RD&D in total RD&D in IEA member countries declined from 11% in 1985 to about 3% in 2006 but appears to be rising again (Figure 12.6).

Figure 12.6 Government RD&D expenditure in IEA member countries, 1974-2008

Note: PPP = purchasing power parity.

Key point

There are signs of increases in government energy RD&D budgets following a period of stagnation.

Countries spend very different amounts on low-carbon energy technology RD&D, and devote their investment to different ranges of technology in different proportions (Figure 12.7). Nuclear technologies\(^\text{15}\) attract around 40% of public RD&D spending.

\(^{15}\) The statistics in this paragraph refer to spending on all types of nuclear energy (fusion and fission); Figures 12.7 and 12.8 and Table 12.2 only include nuclear fission spending, as the BLUE Map scenario only includes nuclear fission.
This remains the largest single share, although it is down from about 50% in 1992. Government expenditure on fossil fuel research experienced the largest drop in share from 1992 to 2006 although annual expenditure in this sector increased by 12% between 2006 and 2008 as a result of increased interest in CCS. There were also increases in annual budgets over this period for renewables (28%), energy efficiency (17%), hydrogen and fuel cells (10%) and, for the first time in many years, nuclear technologies (12%). The countries in the MEF and the IEA member countries have announced their intention to at least double RD&D budgets.

**Figure 12.7** Low-carbon energy technology: public-sector spending (million 2008 USD) in major countries by technology, 2007

![Bar chart showing low-carbon energy technology public-sector spending in major countries by technology, 2007.](chart.png)

**Note:** Amounts in parentheses at left are total expenditures in million 2008 USD. Spending amounts for Australia, Canada, Germany, Russia and the United States are 2009 estimates based on country submissions. The table includes all of those IEA member countries and other major economies for which data are available. No data are available for Greece, Luxembourg, the Netherlands, Poland and the Slovak Republic. Only includes nuclear fission spending.

**Source:** IEA statistics and analysis.

**Key point**

Countries have very different low-carbon energy RD&D portfolios as a result of policy goals and resource availability.
There are significant differences in national energy RD&D expenditures as a proportion of gross domestic product (GDP), population and CO₂ emissions. For example, in Figure 12.8, which shows public-sector low-carbon energy RD&D spending on a per-capita basis, Finland, Japan and Australia spend the highest proportion (between 0.07% and 0.08% of GDP in 2008) of all IEA countries for which information is available. Korea, Denmark and France spent about 0.04% of GDP on low-carbon technology RD&D in 2008. In terms of levels of low-carbon RD&D investment compared to CO₂ emissions, Switzerland, France and Finland spend most, closely followed by Japan, Denmark and Sweden. Scandinavian countries have RD&D expenditures on a per-capita basis that are up to ten times higher than those of countries such as the United Kingdom or Spain. Overall average expenditure on energy RD&D in IEA countries is about 0.03% of GDP.

Figure 12.8 ▶ Public-sector low-carbon RD&D spending per capita as a function of GDP per capita and CO₂ emissions

Note: The size of the bubble indicates public spending on a per-capita basis. GDP and population statistics are taken from the World Bank; RD&D spending data are taken from the most recent IEA statistics (2009/2010). All data expressed in 2008 USD. CO₂ emissions from IEA CO₂ Emissions from Fuel Combustion, 2009 edition.

Key point
There are significant national differences in public-sector low-carbon energy RD&D expenditures.

Private-sector RD&D spending
Data on private energy RD&D investments is more limited than on government spending because it is not widely reported. Where it is, it is usually reported at the level of industry sector. This does not allow for a breakdown by low-carbon technology area. Similarly, much private RD&D is reported at an aggregate level, making it difficult to identify the share of energy RD&D within a company’s full range of RD&D activities.
Surveys of major companies with combined total assets valued at over USD 37 trillion in 2009 suggest that private industry expenditure on energy RD&D increased year-on-year between 2005 and 2008 but has started to drop away in the last year as a consequence of the economic downturn (Figure 12.9). Total global private low-carbon energy RD&D investments totalled nearly USD 15 billion in 2009, with companies headquartered in Europe, the Middle East and Africa accounting for over half of this. There are some uncertainties in these data as it is very difficult to define what is energy RD&D and what is not, other than for companies in the oil and power generation sectors, and different companies may report different activities as RD&D expenditure.

Assessing the gap: global low-carbon energy technology RD&D needs

Global energy RD&D expenditure needs to increase substantially if the energy revolution necessary to address the challenges of climate change and energy security is to be achieved. Current low-carbon energy technology RD&D spending falls well short of the investment needed to achieve the ambitions of the BLUE Map scenario (Table 12.2).16 The estimating method suffers from some limitations, particularly in relation to the assumptions on the relationship between RD&D and deployment investment needs and the ratio between public and private expenditures. But the results give at least a feel for the scale of investment needed. They should be refined as more data become available.

16. A similar analysis was included in IEA (2009e); the amounts in Table 12.2 are different because they include a wider range of countries and nuclear fission spending.
### Table 12.2  
Estimated public-sector low-carbon energy technology current spending, needs and gap to achieve BLUE Map outcomes in 2050

<table>
<thead>
<tr>
<th>Technology</th>
<th>Annual investment in RD&amp;D needed to achieve the BLUE Map scenario outcomes in 2050 (USD million)</th>
<th>Current annual public RD&amp;D spending (USD million)</th>
<th>Estimated annual RD&amp;D spending gap (USD million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced vehicles (includes EVs, PHEVs + FCVs; energy efficiency in transport)</td>
<td>22 500 – 45 000</td>
<td>1860</td>
<td>20 640 – 43 140</td>
</tr>
<tr>
<td>Bioenergy (biomass combustion and biofuels)</td>
<td>1 500 – 3 000</td>
<td>740</td>
<td>760 – 2 260</td>
</tr>
<tr>
<td>CCS (power generation, industry, fuel transformation)</td>
<td>9 000 – 18 000</td>
<td>540</td>
<td>8 460 – 17 460</td>
</tr>
<tr>
<td>Energy efficiency (industry)</td>
<td>5 000 – 10 000</td>
<td>530</td>
<td>4 470 – 9 470</td>
</tr>
<tr>
<td>Higher-efficiency coal (IGCC + USCSC)</td>
<td>1 300 – 2 600</td>
<td>850</td>
<td>450 – 1 750</td>
</tr>
<tr>
<td>Nuclear fission</td>
<td>1 500 – 3 000</td>
<td>4 030</td>
<td>0</td>
</tr>
<tr>
<td>Smart grids</td>
<td>5 600 – 11 200</td>
<td>530</td>
<td>5 070 – 10 670</td>
</tr>
<tr>
<td>Solar energy (PV + CSP + solar heating)</td>
<td>1 800 – 3 600</td>
<td>680</td>
<td>1 120 – 2 920</td>
</tr>
<tr>
<td>Wind energy</td>
<td>1 800 – 3 600</td>
<td>240</td>
<td>1 560 – 3 360</td>
</tr>
<tr>
<td>Total across technologies</td>
<td>50 000 – 100 000</td>
<td>10 000</td>
<td>40 000 – 90 000</td>
</tr>
</tbody>
</table>

1. RD&D investment needs derived using 10% to 20% of average deployment costs for BLUE Map scenario and adjusted by a factor of 90% to reflect country coverage.
2. IEA 2007 data with the following exceptions: Australia (2009-2010 estimated); Canada (2009 estimated); France (2007 revised via direct submission); Germany (2009 estimated); USA (2009 estimated). The non-member country data were taken from IEA (2009e). When necessary, spending calculated using 2008 exchange rates.
3. Estimates for buildings energy efficiency RD&D needs were not available.
4. Integrated gasification combined cycle and ultra-supercritical steam cycle.
5. The gap for nuclear fission is assumed to be zero excluding any additional RD&D for Gen IV technologies. Therefore the sum of the estimates for the gap by technology do not sum to the total.

The shortfall between the investment estimated to be required for RD&D and existing levels is between USD 40 billion and USD 90 billion, of which half is assumed to come from public sources. Therefore, if current annual public spending is USD 10 billion, achieving the BLUE Map scenario will require a twofold to fivefold increase in public RD&D spending. The gap appears to be much larger for some technologies, including advanced vehicles, CCS and smart grids, than for others such as bioenergy and nuclear fission.

While these results are somewhat incomplete — data are lacking for some important countries, and industry spending levels are not considered — other analyses are consistent with this conclusion. The UNFCCC has proposed a doubling in global expenditure on energy R&D to about USD 20 billion a year. A recent publication (IEA, 2009e) highlights other studies that recommend between two and ten times current energy RD&D expenditures.
Further work is in hand at the IEA and elsewhere better to understand the levels of RD&D expenditure needed to achieve a given level of technology deployment. The quality and availability of global low-carbon energy RD&D spending and investment data suffer from a number of very significant constraints (Box 12.5). Much more should be done at an international level to improve the relevance, quality and comparability of international energy RD&D statistics.

**Box 12.5  Quality and availability of RD&D spending data**

To help the public and private sectors focus on future low-carbon energy technology priorities, it is important first to understand the current status of low-carbon energy RD&D expenditure data. The quality and scope of energy RD&D spending data are constrained by a number of factors, including:

- **Countries use different definitions/methods in their RD&D reporting:**
  - Countries often report budget and expenditure data in the same year, making it unclear whether there is double-counting. It also makes it difficult to assign a single year to the spending activity, resulting in significant year-to-year changes for a particular energy technology area.
  - Some technology areas (particularly smart grids and advanced vehicles) are insufficiently disaggregated.
  - There are discrepancies between governments in the way in which they report multi-year projects. The budget is often defined for the whole project period rather than being reported on a yearly basis.
  - The degree (and transparency) to which regional and local expenditures are included varies considerably. Some countries reliably report non-national RD&D expenditures, while others do not.

- **There are gaps in IEA time series RD&D data for some countries owing to a lack of reporting.**

- **There is no centralised, reliable source of RD&D spending data for non-OECD countries.**

- **There is a lack of reliable data on private RD&D spending and trends:**
  - In some technology areas such as energy efficiency, the private sector is believed to be the largest funder of RD&D. However, there is no internationally accepted source of private-sector low-carbon energy RD&D data.
  - The fraction of venture capital and private equity investment dedicated to RD&D rather than deployment alone is difficult to identify.

**Accelerating energy technology RD&D**

Successfully addressing the RD&D investment gap presents a major challenge, particularly in the light of the current financial crisis. A number of national stimulus packages include important new commitments to public-sector low-carbon energy RD&D spending. These amount to at least USD 38 billion (IEA, 2009e). Some of this funding is for one-time stimuli, but other commitments reflect the increasing importance of clean energy and emissions abatement. Even so, these commitments do not amount to the sustained level of public investment that will be needed.
There are historical precedents for the rapid acceleration of RD&D efforts to meet pressing national objectives. For example, the United States has undertaken a number of so-called “crash” RD&D programmes, including the Manhattan Project (1940 to 1945) and the Apollo Project (1963 to 1972) that focused on the defence and space sectors, respectively. A recent study for the US Congress (Stine, 2009) has compared these projects with the US DOE technology programmes over the period 1974 to 2008. Peak expenditure on the Apollo Project was about twice that of the US DOE programmes in real terms and more than five times today’s level of spending. However, while these examples offer positive lessons, the scope of RD&D needed to successfully make a transition to a low-carbon economy is arguably much greater than historical precedents.

Research, development & demonstration best practices

The availability of sufficient funding is not all that is needed for the acceleration of global low-carbon energy technologies. RD&D programmes and policies also have to be improved by adopting best practices in design and implementation. New policies or programmes need to demonstrate the following features if they are to be effective (IEA, 2007):

- A **strategic, long-term focus** that takes into account national policy objectives, energy resource availability, human and manufacturing skills availability, international collaboration and outreach to the public on the costs and benefits of different energy pathways.

- A **supportive policy framework** in which government programmes, venture capital and markets all support tailored and consistent policy frameworks with sustained, higher levels of funding.

- A **portfolio approach** that recognises that a mix of technologies will be needed in the longer term and that no one research project or programme is guaranteed to succeed.

- **Flexibility** to adapt and modify RD&D programmes in the light of scientific and policy developments, viewing RD&D priority setting as an ongoing process.

- The **monitoring and evaluation** of outputs.

- **Strong linkages between basic science and applied energy research communities** to maximise the chance of material breakthroughs.

The existence of a clear national energy policy is the most important precondition for a successful public energy RD&D strategy. Energy RD&D should be seen as an important instrument to achieve larger climate change, economic development and energy security goals. Targets should be clear and quantified and preferably categorised by short-, medium- and long-term objectives. Many of these features are shown in the Swiss government’s 2006 top-down stakeholder process to develop a coherent national energy R&D policy that would achieve its higher-level goal of a “2000 Watt Society” (Figure 12.10).
A vision of a 2000 Watt Society

This vision serves as a long-term aim to direct R&D activities and a Swiss climate change strategy. “2000 Watt Society” is seeking to bring about the gradual introduction of a way of living and working that requires only one-third of current energy consumption but still delivers an improved quality of life. Using a phased approach, it will use the latest efficient technology and draw on experience from the world of economics, social sciences and politics.”


Key point

A successful national energy technology policy has a clear linkage between energy policy and other policy priorities, including national security, economic development and sustainability.

Similarly, the Norwegian government has established a broad, co-ordinated RD&D strategy to achieve its climate and energy goals known as Energi21. This started with a stakeholder process to set a baseline of current resource use, emissions and performance. It followed this with a set of recommendations to achieve climate and energy goals, including clearly identified R&D goals, a doubling of national R&D spending, skilled workforce development, funding for demonstration and commercialisation, and the establishment of a government body to oversee greater co-ordination on energy RD&D and to ensure that the targets are achieved. Since its launch, the Norwegian government has established Energi21 as a permanent advisory body on strategic energy RD&D questions, and funding for energy R&D has been more than doubled over the last two years. The Research Council Norway has implemented this funding increase through national R&D programmes and

17. See www.energi21.no.
through the establishment of eight Centres of Excellence covering renewable energy and CCS. These centres include clusters of main industrial actors, R&D institutions and universities. Long-term funding (up to eight years) ensures that the centres can focus on ambitious R&D goals in technology areas where Norway has a strong position.

Governments should also be strategic in targeting their limited energy RD&D funds. Countries need to decide their particular areas of strength, based on existing natural and human resources, geography and international partnerships. Future policy goals are also important in this assessment. The Australian government’s 2004 Energy Technology Assessment is a good example of a strategic approach, in which the government determined the technologies it wanted to be a market leader for, those in respect of which it wanted to keep up-to-date with developments, and those in respect of which it was content simply to monitor progress (IEA, 2005). The government is currently updating this assessment.

In addition to strategic planning and funding, the performance of programmes needs to be effectively monitored and evaluated. New programmes should specify performance milestones and demonstrate their consistency with national policies. Existing efforts also need to be re-evaluated on a regular basis, and modified, redirected or terminated depending on whether they are meeting their milestones and indicators for success.

Evaluation may include self-evaluation by programme managers, evaluations by external experts, or a hybrid of these two approaches. Statistical data may be collected, together with more qualitative measures such as interviews of key stakeholders to gain a more comprehensive view. The Board on Energy and Environmental Systems of the United States National Academies has developed an assessment framework to evaluate the qualitative and quantitative costs and benefits of energy technology R&D. It is designed to capture public and private economic, environmental and energy security benefits. The framework further distinguishes among three levels of benefit: realised benefits, i.e. those that result from the full commercialisation of a technology innovation; option benefits, i.e. those that accrue from the successful development of a technology without commercialisation; and knowledge benefits, i.e. advances in scientific, technological or other knowledge that may aid future innovation (National Science Foundation, 2010).

Other external indicators may also prove useful in assessing the success of technology RD&D. For example, energy patents are seen as an important output measure from R&D, as they are evidence of a technology’s progression along the innovation chain. The year-by-year patenting rate in PV, wind, CCS, CSP, biomass and cleaner coal technologies demonstrates rapid growth in the number of patents from 1998 onwards, with wind and PV showing the greatest increase (Figure 12.11). The increase in patent activity is not driven solely by RD&D. It is also driven by the commercial value associated with the patent and the ability of new competitors to enter the market (Chatham House, 2009). The use of patents as a measure of innovation is, however, subject to limitations, particularly when comparing between countries. Some countries have more positive attitudes than others towards patenting and there are also different barriers to patent applications.
Figure 12.11 - Number of patents in six energy technology fields, 1977-2007

Source: Chatham House (2009).

**Key point**

Low-carbon energy patents, an important R&D output measure, have risen dramatically in the last decade.

Patent activity is directly relevant to only one part of the innovation chain. For wind and PV, there is evidence that the number of patents and deployment are positively correlated (Chatham House, 2009). Other studies have suggested that market interventions to accelerate deployment do not always lead to increased R&D or patenting activity. A study of the implications of increased funding for onshore wind deployment in California found little evidence of increased wind-related patenting activity among California-based companies and research institutes, although it is possible that additional RD&D was stimulated in other parts of the United States or in other countries (Nemet, 2008). Many companies patent only those technologies or elements of technologies that have the potential to produce returns that outweigh the annual costs of patent registration. Patenting can also disclose a company’s R&D strategy and may attract unwelcome competition. Some companies will offer details of particular technologies freely, relying on their company’s unique capacity to build and sell the technology to maintain their market advantage.

Other energy technology innovation metrics include the number of published articles in peer-reviewed journals or the share of new products in the total number of products in a marketplace. Analysis of R&D outputs may also be based on the transfer or export of a technology to another country, although this may overstate national production as it may include foreign affiliates. In addition, many companies that appear to be national, such as Vestas in Denmark, are actually transnational, with many primary and component facilities located not only outside the country of origin but also in some cases even in a different region.

One indicator of the commercial viability of a particular technology is the extent to which it can attract venture capital. There may be a correlation between the amount of private capital invested and the stage in the technology R&D process that the
technology has reached. More robust and commonly acceptable approaches to energy technology RD&D evaluation need to be developed.

Advances in basic science will be the foundation for progress in a number of energy technologies. Promising technologies such as advanced solar PV, advanced materials for energy storage and batteries, and the storage of CO₂ from bioenergy sources offer potential opportunities for breakthroughs in the longer term (Box 12.6). The US DOE has identified in the US Climate Change Technology Program a set of strategic basic science and energy research priorities (Figure 12.12). For longer-term technologies such as these, government involvement should be focused on expanding R&D, on linking basic science with applied energy research, and on defining the most pressing priorities in order to ensure the effective allocation of human and financial resources.

**Box 12.6**  
Examples of recent funding announcements for basic science in the area of energy

The European Commission’s Communication “Investing in the Development of Low-Carbon Technologies” [COM(2009)519/4], published on 7 October 2009, estimates that an additional investment of EUR 50 billion in energy technology research will be needed over the next ten years. This means almost tripling current levels of annual investment in the European Union, from EUR 3 billion to EUR 8 billion. Investment should cover basic and applied research, pilot projects (small-scale trials), demonstration programmes (large-scale trials) and market replication measures to achieve the successful transfer into fully viable, profitable low-carbon technologies available for public use. The costs of deployment are excluded in these estimates.

In addition, the Communication recommends that a further investment of around EUR 1 billion should be made in basic research in energy-related programmes. The bulk of the funds required will have to come from the private sector and from member states, with a contribution from the EU budget towards some of it.

President Obama has committed to doubling United States federal investment in basic research over a ten-year period. The US DOE has announced USD 377 million to initiate 46 Energy Frontier Research Centers (EFRCs) to accelerate the rate of scientific breakthroughs needed to create advanced energy technologies for the 21st century. The EFRCs will pursue the fundamental understanding necessary to meet the global need for abundant, clean and economical energy.¹⁸

To maximise the pull-through of opportunities from fundamental research into the market, basic science and applied energy researchers need to work more closely together to share information. Many governments are beginning to recognise the need for increased linkages to speed up the time from basic research to market. Possible strategies to enhance basic scientific research for energy may include bringing private corporations more directly into the basic research process, thereby

leveraging their creativity and experience to identify and maximise the potential of advances in energy science and technologies, and informing basic researchers about the most pressing needs of industry.

Figure 12.12 US Climate Change Technology Program: Integrating basic science and applied energy research

<table>
<thead>
<tr>
<th>Fundamental research area</th>
<th>Strategic research area</th>
<th>Goal 1: Energy end use</th>
<th>Goal 2: Energy supply</th>
<th>Goal 3: Capture and sequestration</th>
<th>Goal 4</th>
<th>Goal 5</th>
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<tr>
<td><strong>Physical sciences</strong></td>
<td>Materials: high temperature</td>
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<td>Materials: tailored mechanical/chemical properties</td>
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<td>Materials: tailored electrical/magnetic properties</td>
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<td>Heat transfer and fluid dynamics</td>
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<td>Combustion</td>
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<td>Condensed matter physics</td>
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<td>Geosciences and hydrology</td>
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<td>Chemical catalysis</td>
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<td>Plant &amp; microbial genomics (biotechnology)</td>
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<td>Bio-based % bio inspired processing</td>
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<td><strong>Environmental sciences</strong></td>
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<tr>
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<td>Atmospheric science</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Advanced scientific computing</strong></td>
<td>Computational sciences (models and simulations)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fusion sciences</strong></td>
<td>Plasma sciences</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Enabling research</strong></td>
<td>Strategic research for sensors and instrumentation</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>


Key point

Best-practice energy RD&D policy links basic science to applied energy research across low-carbon energy technologies.
International collaboration in basic science has the potential to enable cost-sharing and cost-reductions, to scale up research efforts, and to build up pools of common knowledge. For more than 30 years, the IEA Implementing Agreements (IAs) have allowed interested member and non-member governments or other organisations to pool resources in a network of international technology collaborations, including basic science research for energy. The IEA Expert Group on Science for Energy (EGSE), whose focus is on bridging the gap between basic science and applied energy R&D, is working to identify and document examples of international collaboration in basic science for energy.\(^\text{19}\)

\(^{19}\) Additional information on EGSE’s activities can be found at: http://www.iea.org/about/egse.as
Key findings

- A full portfolio of energy technology solutions is needed to address energy security and climate change. Roadmaps can help to develop a common vision that can be implemented by different stakeholders at international and national levels, thereby maximising the net benefit of investment in the research, development, demonstration and deployment (RDD&D) of new technologies.

- To address the need for greater international collaboration on specific technologies, the International Energy Agency (IEA) is developing a series of low-carbon energy technology roadmaps. The seven completed roadmaps are summarised in this chapter. The IEA is developing several more that will be published in 2010 and 2011.

- The international energy technology roadmaps completed to date reveal a number of cross-cutting issues that need to be addressed to maximise the prospects of the successful exploitation of a range of technologies. These include:
  - The need for the international community to improve co-ordination and knowledge sharing to accelerate the transition from demonstration to commercialisation for many low-carbon technologies.
  - The need to help emerging economies to exploit the potential of clean energy technologies. They require technology-specific capacity building and tailored approaches that properly reflect their individual needs, challenges and opportunities.
  - The need strategically to plan capital-intensive low-carbon infrastructure such as carbon dioxide (CO₂) pipeline networks and smart grids on a regional basis.
  - The need for early consultation with local communities on plans for proposed large-scale, low-carbon demonstration and infrastructure projects, in order to ensure that their needs are taken into consideration in the design of the project.
  - The need for increased outreach and public education to communicate the scale of the changes required to achieve low-carbon energy outcomes and the associated costs and benefits over the next 40 years.

A portfolio of technologies is needed

The results in Chapter 2 demonstrate the tremendous challenge that the global economy faces, if CO₂ emissions are to be halved by 2050, in making a rapid transformation to low-carbon energy production, transmission, distribution and use. Chapter 2 also concludes that achieving this transformation at lowest cost will depend on the deployment of all the relevant technologies that are available. The absence or failure of any will increase overall mitigation costs.
Governments and industry therefore need to pursue a portfolio of energy solutions which must include energy efficiency in all end-use sectors, renewable energy, nuclear power, low-carbon transportation options, carbon capture and storage (CCS), and low-carbon industrial strategies. Enabling technologies such as smart grids and utility-scale energy storage will also be important. Long-term research into breakthrough technologies such as biotechnology, nanotechnology and advanced materials will need to be pursued to provide cross-cutting benefits to help many technologies achieve cost and efficiency targets.

Figure 13.1 shows the contribution different technology options need to make to achieve a 50% reduction in energy-related CO₂ emissions by 2050 compared to 2005 levels. The chart on the left shows the BLUE Map scenario results in terms of the cumulative emissions reductions from the Baseline scenario attributable to different low-carbon energy solutions in 2030; the one on the right shows the contributions in 2050. The current and planned roadmaps closely match these technology families.

**Key point**

A wide range of low-carbon technologies will be needed.

Table 13.1 shows the aggregate investment needed from 2010 to 2050 in RDD&D to achieve BLUE Map scenario results for the different roadmap technologies, along with the annual CO₂ emissions reduction potential in 2050.

Each country and each region has a unique set of energy resources, climate, technology and market development and regulatory frameworks. And each group of low-carbon technologies presents a unique set of technological challenges and opportunities. These need to be tackled appropriately if each is to achieve its maximum potential. Energy technology roadmaps are a tool to help policy makers, industry and civil society to understand the optimal pathways through which individual technologies can cost-effectively be pursued.
Table 13.1  ►  CO₂ emissions reductions and RDD&D spending needs¹
in the BLUE Map scenario

<table>
<thead>
<tr>
<th></th>
<th>Annual CO₂ savings in 2050 (Gt)</th>
<th>RDD&amp;D spending needs (USD bn) (2010-2050)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Buildings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy efficiency in buildings</td>
<td>5.1</td>
<td>n.a.²</td>
</tr>
<tr>
<td><strong>Industry²</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCS – industry and fuel transformation</td>
<td>4.2-5.0</td>
<td>1 700-2 200</td>
</tr>
<tr>
<td>Cement</td>
<td>0.3-0.4</td>
<td>n.a.²</td>
</tr>
<tr>
<td>Chemicals</td>
<td>1.0-1.4</td>
<td>n.a.²</td>
</tr>
<tr>
<td>Iron and steel</td>
<td>0.7-0.9</td>
<td>n.a.²</td>
</tr>
<tr>
<td><strong>Power generation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCS – power generation</td>
<td>4.4</td>
<td>1900-2200</td>
</tr>
<tr>
<td>Biomass for heat and power production</td>
<td>0.3</td>
<td>250-350</td>
</tr>
<tr>
<td>Cleaner, high-efficiency coal</td>
<td>1.0</td>
<td>500-700</td>
</tr>
<tr>
<td>Concentrating solar power (CSP)</td>
<td>1.2-3.1</td>
<td>400-600</td>
</tr>
<tr>
<td>Geothermal</td>
<td>0.4</td>
<td>90-110</td>
</tr>
<tr>
<td>Nuclear power</td>
<td>2.6-7.5</td>
<td>650-750</td>
</tr>
<tr>
<td>Smart grids⁴</td>
<td>0.8-2.2</td>
<td>2 000-3 000</td>
</tr>
<tr>
<td>Solar photovoltaic (PV) power</td>
<td>1.0-2.7</td>
<td>250-350</td>
</tr>
<tr>
<td>Wind energy</td>
<td>1.5-4.8</td>
<td>750-900</td>
</tr>
<tr>
<td><strong>Transport</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric and plug-in vehicles</td>
<td>2.6-3.1</td>
<td>6 000-9 000</td>
</tr>
<tr>
<td>Natural gas, hydrogen and fuel-cell vehicles</td>
<td>1.7</td>
<td>2 000-3 000</td>
</tr>
<tr>
<td>Second-generation biofuels</td>
<td>2.0</td>
<td>320-480</td>
</tr>
<tr>
<td>Vehicle efficiency (all modes)</td>
<td>3.1</td>
<td>n.a.²</td>
</tr>
</tbody>
</table>

1. Table 13.1 shows the contribution of select technologies/sectors; it does not cover all of the technologies included in the BLUE Map analysis.
2. Estimating RDD&D investments for energy efficiency in buildings, industry and vehicles is problematic owing to the wide range of technologies and applications involved, as well as regional differences in costs. Further analysis will be required before these figures can be calculated with confidence. Total investment figures for these individual end-use sectors can be found in Chapters 5, 6 and 7.
3. For the industrial sectors, the CO₂ savings exclude reductions from CCS which have been included in CCS – industry and fuel transformation.
4. Smart grids emissions reductions and RDD&D spending needs overlap with other technology categories, so there is some double-counting in the totals.
The role of roadmaps

Energy technology roadmaps provide a solid analytical footing that enables the international community to move forward on specific technologies. Each roadmap presents the growth path for a particular technology from today to 2050, and identifies milestones in terms of technology development, financing, policy and public engagement that need to be achieved to realise the technology’s full potential. Given the expected growth in energy use and related emissions outside IEA member countries, the roadmaps also identify needs for technology development and diffusion in emerging economies. International collaboration will be critical to achieve these goals. In this respect, the roadmaps can play an important role in facilitating greater collaboration among governments, business and civil society in both industrialised and developing countries.

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

Roadmaps are an important strategic planning tool for governments and industry to address future challenges, including energy security and climate change. A number of governments, industry organisations and other groups have developed energy technology roadmaps. The IEA low-carbon energy technology roadmaps build on, and add value to these roadmaps by establishing the basis for an international consensus about the priority actions and milestones that must be achieved to reach a technology’s full potential. The roadmap process brings together experts from government, industry and civil society to develop a common vision for achieving the levels of a technology’s growth identified in the BLUE Map scenario.

There are several common elements to a low-carbon energy technology roadmap, including:

- **Rationale**: why is the technology important for climate change mitigation and energy/economic growth?
- **Baseline**: how does the technology perform today (in terms, for example, of USD/kWh, energy conversion efficiency and installed capacity)? Which countries are leaders in research, development and demonstration (R&D) and deployment?
- **Vision for deployment and CO₂ abatement potential**: what is the pathway from 2010 to 2050 for the technology to achieve its climate change mitigation potential? How much investment does this require? How many projects will this require? Which countries and regions hold the greatest potential?
- **Technology development milestones and actions**: what performance and cost reduction milestones must the technology achieve to meet this vision? Which stakeholders can best make sure those milestones are achieved?
- **Policy framework milestones and actions**: what types of policy and regulation will be needed to advance the technology? Are there regulatory frameworks that must be developed?
- **Financing milestones and actions**: are there near-term demonstration funding requirements? For more competitive technologies, what is the role for greenhouse-gas markets and other incentives?
- **Public outreach and engagement**: what role does the technology play in climate change mitigation? What are other air, water or land use impacts related to the technology? What role can governments play in educating the public? Are there public engagement needs related to large infrastructure projects?
- **International collaboration**: what are the opportunities to share the technology across borders? Are existing collaboration mechanisms sufficient, or do new approaches need to be taken?
Roadmaps are providing important input to climate change mitigation initiatives, including the Major Economies Forum Technology Action Plans released in December 2009, and multilateral banks’ Clean Technology Fund investments. The technology milestones, and specific actions, can serve as a checklist to help ensure that technology RD&D, financing, policy/regulatory, public engagement and international collaboration aspects are given proper consideration. In addition, the IEA is beginning to tailor international technology roadmaps for use as a strategic planning tool in some emerging economies.

To date, the IEA has published the following low-carbon energy technology roadmaps:
- carbon capture and storage;
- cement sector;
- electric/plug-in hybrid electric vehicles;
- nuclear power;
- concentrating solar power;
- photovoltaic power;
- wind energy.

The IEA is developing additional roadmaps that will be published in 2010 and 2011. These roadmaps include:
- biofuels;
- biomass for heat and power generation;
- cleaner, high-efficiency coal;
- efficient industry processes in other emissions-intensive sectors;
- energy efficient/low-carbon buildings: heating and cooling;
- energy efficient/low-carbon buildings: design and operation;
- geothermal energy;
- hydrogen production and fuel-cell vehicles;
- smart grids;
- vehicle efficiency.

These technologies were selected for their CO₂ emissions reduction potential, market readiness, and coverage of demand-side and supply-side emissions in the buildings, industrial and power sectors. The IEA will revisit this list and update the roadmaps on an ongoing basis.

Roadmap summaries¹

Each roadmap summary provides the reader with a summary assessment of the featured technology and the steps needed to accelerate the technology’s adoption as required to deliver the outcomes in the BLUE Map scenario. Each roadmap summary includes:
- key findings;
- current status of technology development;
- potential CO₂ reduction achievable by 2050;
- projected distribution of the technology by region in 2050;
- technology, policy, financing and public engagement/outreach milestones;
- international collaboration opportunities.

¹ The roadmap summaries were developed using the ETP 2008 BLUE Map scenario, with the exception of solar CSP, solar PV and nuclear power. These roadmaps are consistent with current ETP 2010 scenarios: solar PV and CSP on the BLUE high Renewables variant, nuclear on the BLUE Map scenario (see chapter 3). As a result, the numbers in the roadmap summaries may differ slightly from the results reported in other chapters of this book.
Carbon capture and storage roadmap

Carbon capture and storage (CCS) will need to contribute nearly one-fifth of the necessary emissions reductions to achieve cost-effective greenhouse-gas stabilisation. If CCS technologies are not used, the overall cost to achieve stabilisation will increase by 70%. Achieving rapid CCS demonstration and deployment is a tremendous global challenge. While five commercial-scale operational CCS projects are providing evidence that these technologies are viable at scale, several dozen additional commercial-scale projects are needed in a variety of countries and sectors.

During the next decade, to achieve the targets included in the CCS roadmap, governments, industry and public stakeholders must:

- finance 100 large-scale demonstration projects and integrate CCS into greenhouse-gas policies;
- address higher costs and efficiency penalties through accelerated research and demonstration;
- explore, develop and finance adequate CO₂ storage capacity and pipeline infrastructure;
- develop appropriate legal and regulatory frameworks to ensure safe, permanent CO₂ storage;
- provide public communication efforts about CCS, with a priority on public engagement at planned projects;
- foster expanded international collaboration, particularly via expanding capacity and awareness in developing countries with large fossil fuel use.

CCS follows an ambitious growth pathway to 2050

©OECD/IEA, 2010
Key findings

► CCS is an important part of the lowest-cost greenhouse-gas mitigation portfolio. Without CCS, overall costs to halve emissions by 2050 rise by 70%. This roadmap envisions 100 projects globally by 2020 and over 3,000 projects in 2050.

► This roadmap’s level of project development requires an additional investment of over USD 2.5 to USD 3 trillion from 2010 to 2050, which is about 6% of the overall investment needed to achieve a 50% reduction in greenhouse-gas emissions by 2050.

► The developed world must lead in the next decade by investing an average of USD 3.5 to USD 4 billion annually between 2010 and 2020. However, CCS technology must spread rapidly to the rest of the world through expanded international collaboration and financing for CCS demonstrations in developing countries at an average annual level of USD 1.5-2.5 billion between 2010 and 2020.

► CCS is more than a strategy for “clean coal”. CCS technology must be adopted by biomass and gas power plants, in the fuel transformation and gas processing sectors, and in emissions-intensive sectors like cement, iron and steel, and chemicals manufacturing.

► The milestones in this roadmap will only be achievable via expanded international collaboration. New efforts to provide developing country knowledge/technology transfer are needed. Industry sectors with a global reach should also expand their CCS collaborative efforts.
## CCS roadmap milestones

### Technology

<table>
<thead>
<tr>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 projects</td>
<td>850 projects</td>
<td></td>
</tr>
</tbody>
</table>

- **Prove technologies at large scale**
- **Identify industrial applications**
- **Demonstrate retrofit at 85% capture**
- **Fund R&D for biomass CO\(_2\) capture**
- **Reduce CO\(_2\) capture energy penalty to 7% points**
- **Demonstrate H\(_2\) combustion with high-efficiency CCGTs**
- **Widespread availability of commercial plant (new and retrofit)**
- **Reduce capital costs by at least 10%**
- **Demonstrate chemical looping for coal and gas, pressure and electrical swing absorption, cryogenics**
- **Prove technologies at large scale**
- **Identify industrial applications**
- **Demonstrate retrofit at 85% capture**
- **Fund R&D for biomass CO\(_2\) capture**
- **Reduce CO\(_2\) capture energy penalty to 7% points**
- **Demonstrate H\(_2\) combustion with high-efficiency CCGTs**
- **Widespread availability of commercial plant (new and retrofit)**
- **Reduce capital costs by at least 10%**
- **Demonstrate chemical looping for coal and gas, pressure and electrical swing absorption, cryogenics**

### Regulatory

- **Regulatory frameworks in place for CCS demonstration**
- **Comprehensive regulatory frameworks in place for commercial deployment**
- **Continue to review and refine legal and regulatory frameworks in all regions as CCS experience increases**

### Finance

- **Provide an average of USD 3.5-4 billion annually for CCS demonstration in OECD countries**
- **Provide USD 1.5-2.5 billion annually for CCS demonstration in non-OECD countries**
- **Continue to monitor and adapt CCS financing strategies as experience increases**

### Public engagement

- **Provide greater governmental resources**
- **Develop and apply a toolkit of best practice public engagement techniques to CCS demonstration projects**
- **Refine public engagement strategies in all regions as CCS experience increases**
Demonstrate chemical looping for coal and gas, pressure and electrical swing absorption, cryogenics

Commercial systems with gas separation membranes
Continue to reduce energy penalty
Continue to review and refine legal and regulatory frameworks in all regions as CCS experience increases
Continue to monitor and adapt CCS financing strategies as experience increases
Refine public engagement strategies in all regions as CCS experience increases
Cement sector roadmap

Carbon dioxide emissions from cement production currently represent about 5% of global anthropogenic CO₂ emissions. The Cement Technology Roadmap 2009 outlines a possible transition path for the sector to make continued contributions towards a halving of global CO₂ emissions by 2050. As part of this halving, this roadmap estimates that the cement industry could reduce its emissions by 18% from 2005 levels.

The next 10 to 15 years are critical for developments in the cement sector; milestones include:

- phasing-out of inefficient long-dry kilns and wet production processes in both developed and developing countries;
- developing and implementing international standards for energy efficiency and CO₂ emissions in the cement industry;
- reviewing and updating regional, national and local level legislation, to ensure the use of alternative fuels and biomass is encouraged by policy, not limited;
- developing new or revising existing cement standards and codes in some countries to allow more widespread use of blended cement;
- government support for funding of cement sector carbon capture pilot and demonstration projects, leading to commercial scale demonstration plants and storage site accessibility.

Global cement production, 2006 to 2050

<table>
<thead>
<tr>
<th>Year</th>
<th>Production (Mt cement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>low high low</td>
</tr>
<tr>
<td>2015</td>
<td>high low high</td>
</tr>
<tr>
<td>2030</td>
<td>low high low</td>
</tr>
<tr>
<td>2050</td>
<td>low high high</td>
</tr>
</tbody>
</table>

Canada and United States
European Union 25
Other OECD Europe
OECD Pacific
China
India
Economies in transition
Other developing Asia
Latin America
Africa and Middle East
Key findings

Four distinct “reduction levers” are available to the cement sector to reduce CO₂ emissions:

1. **Thermal and electric efficiency**: deployment of existing state-of-the-art technologies in new cement plants, and retrofit of energy efficiency equipment where economically viable.

2. **Alternative fuels**: use of less carbon-intensive fossil fuels and more alternative (fossil) fuels and biomass fuels in the cement production process.

3. **Clinker substitution**: substituting carbon-intensive clinker, an intermediate in cement manufacture, with other, lower-carbon materials with cementitious properties.

4. **Carbon capture and storage (CCS)**: capturing CO₂ emissions in cement production.

- Cement is a key material for building society’s infrastructure. Demand reduction and/or substitution are not realistic options given growth in developing countries, increasing urbanisation and climate change adaptation needs.

- Existing options to reduce emissions in the sector, while helpful, are not sufficient to counteract growth in demand. New products and technologies are needed, including CCS and new cement types.

- These new technologies will require a step change in RD&D efforts; the roadmap provides a vision for what is needed between today and 2050.

- CCS is a particularly important technology for the cement sector, required to deliver up to half of the emissions reductions needed by 2050. This will require advancement of demonstration projects in the cement sector over the next decade, to learn in parallel with other sectors how best to apply CCS technology at the scale necessary.

- The high cost of reducing CO₂ emissions in the sector will require markets with long-term stability and resultant confidence in the pricing of CO₂ by those markets.

- International collaboration and public-private partnerships must be encouraged to help speed up research, design, development and deployment of necessary new technologies.
Cement roadmap milestones

**Energy efficiency**
- R&D on fluidised bed technology
- Diffusion of BAT: phase-out of wet kilns in OECD
- Diffusion of BAT: phase-out of wet kilns in non-OECD
- R&D into new grinding equipment and additives
- Diffusion of BAT: international standard for new kilns

**Alternative fuel use and fuel switching**
- Ongoing identification and classification of suitable alternative fuels

**Clinker substitution**
- Assess substitution material properties and evaluate regional availability
- Implement international standards on blended cement use
- Develop international standards on blended cement use

**Carbon capture and storage**
- R&D - oxyfuelling, gas cleaning: 1st CCS pilot plant
- R&D - oxyfuelling, gas cleaning: develop oxyfuelling and chemical looping
- Demonstration 2 chemical absorption demonstration plants
- Mitigation costs USD/CO₂ cement (post combustion/ oxyfuelling): 125/na
- Demonstration 3 oxyfuel demos, 3 chemical looping demos
- R&D - oxyfuelling, gas cleaning: C.A. energy use to fall to 2.2 GJ/t
- Deployment: all large new kilns with CCS
- Mitigation costs USD/CO₂ cement (post combustion/ oxyfuelling): 100/60
- Commercial use of membrane technology

**Research and development (R&D) - Demonstration - Deployment**
Combination of storage and hybridization in a solar plant

**2030**
- **Diffusion of BAT:** global energy intensity 3.2-3.4 Gt/t clinker
- **Cement-to-clinker ratio:** 73%
- **Deployment:** 50-70 cement kilns with CCS
  - Mitigation costs USD/tCO₂ cement (post combustion/oxyfueling): 100/50
  - Gt captured: 0.11-0.16 Gt; % CO₂ captured: 10-12%

**2040**
- **Diffusion of BAT:** global energy intensity 3.1-3.2 Gt/t clinker
- **Cement-to-clinker ratio:** 71%
- **Deployment:** 100-200 cement kilns with CCS
  - Mitigation costs USD/tCO₂ cement (post combustion/oxyfueling): 75/40
  - Gt captured: 0.5-1.0 Gt; % CO₂ captured: 40-45%

**2050**
- **Deployment:** 220-430 cement kilns with CCS
  - Mitigation costs USD/tCO₂ cement (post combustion/oxyfueling): 75/40
  - Gt captured: 0.5-1.0 Gt; % CO₂ captured: 40-45%

**Commercialisation**
Concentrating solar power roadmap

Concentrating solar power (CSP) plants concentrate energy from the sun’s rays to heat a receiver to high temperatures. This heat is then transformed into electricity. CSP also holds potential for producing other energy carriers (solar fuels). CSP plants offer considerable flexibility and energy security in countries or regions with strong sunshine and clear skies. They can store solar energy cheaply and effectively in the form of heat and use it to produce electricity later and be backed up with heat generated by burning combustible fuels, whether fossil or biomass. CSP thus provides reliable electricity that can be dispatched to the grid when needed. CSP plants can also be designed to provide power after sunset to match late evening peak demand, or even round the clock if they are required to meet baseload demand.

To help the CSP industry achieve its contribution to mitigating climate change, governments need in particular to undertake the following actions:

- ensure long-term funding for additional RD&D;
- facilitate the development of measurement/modelling of global solar resources;
- establish long-term oriented, predictable solar-specific economic incentives;
- where appropriate, require state-controlled utilities to bid for CSP capacities;
- avoid establishing arbitrary limitations on plant size and hybridisation ratios;
- streamline procedures for obtaining permits for CSP plants and access lines.

CSP offers firm capacity and dispatchable energy

CSP offers firm capacity and dispatchable energy...
**Production and consumption of CSP electricity by 2050**

Repartition of the direct norma (irradiance in kWh/m²/yr) and of the production and consumption of CSP electricity (in TWh) by world region in 2050. Arrows represent transfers of CSP electricity.

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**Key findings**

- By 2050, with appropriate support, CSP could provide 11.3% of global electricity, with 9.6% from solar power and 1.7% from backup fuels (fossil fuels or biomass).

- In the sunniest countries, CSP can be expected to become a competitive source of bulk power in peak and intermediate loads by 2020, and of baseload power by 2025 to 2030.

- North America will be the largest producing and consuming region for CSP electricity, followed by Africa, India and the Middle East. Northern Africa has the potential to be a large exporter (mainly to Europe) as its high solar resource largely compensates for the additional cost and electricity losses of long direct-current transmission lines.

- CSP can also produce significant amounts of high-temperature heat for industrial processes, and in particular help meet growing demand for water desalination in arid countries.

- CSP facilities could begin providing competitive solar-only or solar-enhanced gaseous or liquid fuels by 2030. By 2050, CSP could produce enough solar hydrogen to displace 3% of global natural gas consumption, and nearly 3% of the global consumption of liquid fuels.

- Given the arid/semi-arid nature of environments that are well-suited for CSP, a key challenge is accessing the cooling water needed for CSP plants. Dry or hybrid dry/wet cooling can be used in areas with limited water resources.

- The main limitation to the expansion of CSP plants is not the availability of areas suitable for power production, but the distance between these areas and many large consumption centres. Technologies address this challenge through efficient, long-distance electricity transportation.
CSP roadmap milestones

**Governments**
- Establish incentives for CSP electricity and heat; lift restrictions on plant size and hybridisation ratios
- Adjust incentives to evolving market conditions
- Support mapping global solar resource from on-ground and satellite measures
- Establish incentives for solar fuels
- Facilitate grid access for CSP projects
- Increase support to RD&D, establish incentives for innovation

**Utilities and grid operators**
- Negotiate tariffs for exports/imports of CSP electricity
- Build HVDC lines throughout China, India and the United States
- Build HVDC lines between exporting and importing countries
- Sign power purchase agreements with independent CSP producers
- Participate in CSP project development

**Technology and RD&D**
- 1st tower plants with DSG; 1st tower plants with molten salts
- DSG in trough plants
- All new plants dry-cooled; working temperature 540°C; larger storage capacities
- 1st large-scale LFR
- Three-step thermal storage for DSG
- Desalination by co-generation in CSP plants
- 1st plant with 100s dishes
- Storage and backup for large dishes
- 1st tower plants with air receivers and gas turbines
- 1st supercritical CSP plants

DSG: direct steam generation.
LFR: linear fresnel reflectors.
HVDC: high-voltage direct current.
Eliminate incentives for power in many regions

Take advantage of CSP flexibility to manage more variable renewable electricity

Reward storage and backup capacities of CSP plants

Biogas and solar fuels substitute natural gas as backup fuel in power plants

Hydrogen from solar towers/large dishes introduced in natural gas grids

Production of solar-only hydrogen to manufacture liquid fuels

Solar production of other energy carriers (e.g. metals) for transport sector

GW capacity 337
Av. capacity factor 39%

GW capacity 715
Av. capacity factor 45%

GW capacity 1,089
Av. capacity factor 50%
Electric and plug-in hybrid vehicles roadmap

Electric and plug-in hybrid vehicles (EVs/PHEVs) are expected to play an important role in achieving a low-CO₂ transport system in BLUE Map, particularly for light-duty vehicles (LDV). A number of manufacturers have announced plans to mass-produce one or more models, and many countries have announced targets for sales by or before 2020. The IEA EV/PHEV roadmap envisions that by 2050, EVs/PHEVs will reach combined sales of about 100 million vehicles per year worldwide, accounting for over half of all new LDV sales.

During the next 5 to 10 years, governments and industry must:

- provide medium- and long-term targets and supporting policies to build confidence for investments in manufacturing capacity and deployment;
- draft national roadmaps, with EV/PHEV infrastructure roll-out strategies, infrastructure priorities and priority areas, timelines and funding, along with a supportive economic and policy context;
- co-ordinate the launch and ramp-up of sales, provision of recharging infrastructure, and electricity supply among national, municipal and regional governments;
- ensure the availability of less carbon-intensive electricity to power plug-in vehicles, and establish appropriate codes and standards for recharging, electricity supply and smart metering;
- improve data on potential markets and consumer behaviour, and increase R&D efforts to reduce costs and develop advanced batteries, including new concepts beyond the current generation of lithium-ion batteries.

EV/PHEV roadmap vision for growth to 2050

![Graph showing EV/PHEV sales growth from 2010 to 2050 for different regions and types of vehicles, including India, China, OECD Pacific, OECD Europe, and OECD North America.](image-url)
Key findings

- Roadmap vision: industry and governments should attain a combined EV/PHEV sales share of at least 50% of LDV sales worldwide by 2050.

- In addition to contributing significant greenhouse-gas emissions reductions, the roadmap’s level of EV/PHEV sales will deliver substantial benefits in terms of improved oil security, reduced urban area pollution and noise.

- Policy support is critical, especially in two areas: ensuring vehicles become cost-competitive and providing adequate recharging infrastructure.

- The consumer comes first: wider use of EVs/PHEVs will require an improved understanding of consumer needs and desires, as well as consumer willingness to change vehicle purchase and travel behaviour.

- Performance measurement will be needed: the IEA roadmap contains a set of proposed metrics and targets for key attributes like driving range and battery requirements to ensure that EVs/PHEVs achieve their potential.

- RD&D priorities: research, development and demonstration must continue to reduce battery costs and ensure adequate materials supply. More research is also needed on smart grids and the vehicle-grid interface.

- International collaboration can accelerate deployment: industry and governments need to work together on research programmes, codes and standards, and alignment of vehicle and infrastructure roll-out.
EV/PHEV roadmap milestones

**Policy framework**

- Adequate incentives for EV/PHEV purchase and production in line with targets; co-ordination of recharging infrastructure development in key areas
- EVs should become commercially viable without significant subsidies; support should continue for widespread expansion of recharging infrastructure

**Vehicles/batteries**

- Low- and medium-volume production, with design optimisations to 2015, then rapidly increase numbers of models offered and average production volumes; battery and other costs decline to target levels
- Vehicles become fully commercial, batteries reach all target specifications for cost and durability, including additional cycling tolerance in line with advanced batteries; full recycling systems in place

**Codes/standards**

- Ensure plugs and charging systems are compatible across major regions, including basic “smart metering” systems for home and public recharging stations; develop protocols for fast recharging
- Common systems for vehicle-to-grid electricity sales, fast recharge and/or battery swapping well established

**Recharging/electricity infrastructure**

- Establish home recharging and begin major investments in street/office daytime commercial recharging, including rapid charging where appropriate
- Expansion of recharging infrastructure to more areas; greater use of fast recharging; fully established vehicle-to-grid electricity systems

**RD&D**

- Ensure vehicle/battery systems are reliable and safe; achieve near-term technical and cost targets, such as USD 300/kWh battery cost; develop advanced battery concepts and prototypes
- Continue RD&D on advanced battery designs moving towards demonstration and deployment as concepts mature; incorporate lessons learned from earlier experiences
EVs achieve superiority to internal combustion engines in most respects, close the gap in driving range.

Availability of higher power/energy-dense batteries should position policy makers to encourage remaining segments of light-duty vehicle markets to "go electric", including greater use in larger, longer-distance vehicles.

Ongoing RD&D as needed; focus on improving battery performance to maximise vehicle driving range.

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Nuclear energy roadmap

Nuclear power has the capacity to provide large-scale, virtually CO₂-free electricity. 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 power generation in many countries.

The next ten years are a critical period for nuclear power development; milestones include:

- demonstrate the ability to build the latest nuclear plant designs on time and within budget;
- develop the industrial capacities and skilled human resources to support sustained growth in nuclear capacity;
- establish the required legal frameworks and institutions in countries where these do not yet exist;
- encourage the participation of private sector investors in nuclear power projects;
- make progress in implementing plans for permanent disposal of high-level radioactive wastes;
- enhance public dialogue to inform stakeholders about the role of nuclear in energy strategy;
- expand the supply of nuclear fuel in line with increased nuclear generating capacity.

Nuclear power capacity in the BLUE Map scenario and electricity generation in the BLUE Map and BLUE High Nuclear scenarios
This roadmap targets installed nuclear capacity reaching 1200 GW in 2050, with annual electricity production of nearly 10000 TWh. This would represent around 24% of electricity generated worldwide, making nuclear the single largest source of electricity.

The 2050 target for nuclear energy deployment does not require major technological breakthroughs, although further development will help maintain nuclear’s competitiveness.

Political support and public acceptance are key requirements for the implementation of nuclear energy programmes, with a clear and stable commitment to nuclear energy in national energy policy.

Financing the very large investments needed to build nuclear power plants will be a major challenge in many countries, and in some cases governments will need to take a role in addressing this.

There is an urgent need to strengthen the nuclear workforce to meet future demands, by investing in education and training.

Industrial capacities for constructing nuclear power plants will need to increase substantially. Uranium production and fuel cycle capacities will also need to grow.

The management and disposal of radioactive wastes is an essential component of all nuclear programmes. Progress needs to be made in building and operating facilities for the disposal of high-level wastes.

The international system of safeguards on sensitive nuclear materials and technologies must be maintained and strengthened where necessary.

Advanced nuclear technologies, now under development, potentially offer advantages over current technologies. The first of these could be ready for commercial deployment after 2030, although they are not expected to form a large part of nuclear capacity in 2050.
Nuclear roadmap milestones

**Policy support**
- Provide a clear and stable commitment to nuclear power in energy and environmental policy
- Harmonise regulatory requirements to facilitate the use of standardised designs
- Ensure that the relevant legal and regulatory systems work effectively
- Strengthen international non-proliferation regimes, while providing security of fuel supply
- Ensure that institutions and funding are in place for waste disposal and decommissioning

**Technology development and deployment**
- Fully establish Generation III+ designs, bringing first-of-a-kind plants on line
- Demonstrate on-time and on-budget completion of further Generation III+ plants
- Implement plans to build and operate geological repositories for waste disposal
- Complete demonstration projects for the most promising Generation IV nuclear plants
- Strengthen RD&D in advanced fuel cycles

**Capacity building and industry**
- Increase industrial capacities to supply nuclear plant components and systems
- Achieve nuclear construction rates from 2020 around double present levels
- Develop the qualified and skilled human resources needed
- Provide a clear and stable commitment to nuclear power in energy and environmental policy

**Financing**
- Establish electricity and carbon markets that support large, long-term investments
- Consider direct government support or guarantees for nuclear investments
- Increase the availability of private sector finance for nuclear plants
- Develop nuclear energy expertise in private sector financial institutions
The timescales shown are approximate and will vary from country to country. In particular, countries without an existing nuclear programme will need to take additional capacity and institution building steps that may require more time.

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Solar photovoltaic power roadmap

Solar photovoltaic (PV) power is a commercially available and reliable technology directly converting solar energy into electricity. Global PV capacity has been increasing at an average annual rate of more than 40% since 2000 and it has significant potential for long-term growth in nearly all world regions.

This roadmap identifies the critical window of the coming decade for policy action to help bridge the gap to PV competitiveness. During the next 5 to 10 years, governments and industry should:

- provide long-term targets and supporting policies to build confidence for investments in manufacturing capacity and deployment of PV systems;
- implement effective and cost-efficient PV incentive schemes that are transitional and decrease over time so as to foster innovation and technological improvement;
- develop and implement appropriate financing schemes, in particular for rural electrification and other applications in developing countries;
- increase R&D efforts to reduce costs and ensure PV readiness for rapid deployment, while also supporting longer-term innovations; exchange best practice with developing countries.

Solar PV: installed capacities in leading countries, 2009

<table>
<thead>
<tr>
<th>Year 2000</th>
<th>Year 2004</th>
<th>Year 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>800 MW</td>
<td>3 000 MW</td>
<td>more than 14 500 MW</td>
</tr>
</tbody>
</table>

Rest of the world 23%
United States 18%
Japan 44%
Germany 15%
United States 13%
Japan 38%
Germany 35%
Rest of the world 14%
**Key findings**

- By 2050, PV global cumulative installed capacity could reach 3 000 gigawatts, providing 4 500 TWh per year, i.e. around 11% of global electricity production. In addition to avoiding 2.3 gigatonnes (Gt) of CO₂ per year, this level of PV would deliver substantial benefits in terms of the security of energy supply and socio-economic development.

- In the first decade, PV is expected to reduce system and generation costs by more than 50%. PV residential and commercial systems will achieve the first level of grid parity – i.e. parity with electricity retail prices – by 2020 in many regions. As grid parity is achieved, the policy framework should evolve towards fostering self-sustained markets, with the progressive phase-out of economic incentives, but maintaining grid access guarantees and sustained R&D support.

- Towards 2030, typical large-scale utility PV system generation costs are expected to decrease to USD 7 to USD 13 cents/kWh. As PV matures into a mainstream technology, grid integration and management and energy storage become key issues.

- The PV industry, grid operators and utilities will need to develop new technologies and strategies to integrate large amounts of PV into flexible, efficient and smart grids.

- Governments and industry must increase R&D efforts to reduce costs and ensure PV readiness for rapid deployment, while supporting longer-term technology innovations.

- There is a need to expand international collaboration in PV research, development, capacity building and financing to accelerate learning and avoid duplicating efforts.

- Emerging major economies are already investing substantially in PV research, development and deployment; however, more needs to be done to foster rural electrification and capacity building. Multilateral and bilateral aid organisations should expand their efforts to express the value of PV energy in low-carbon economic development.
Solar PV roadmap milestones

**Regulatory framework and support schemes**
- Market support schemes to achieve grid competitiveness – to be phased out over time
- Market enabling framework with net metering and priority access to the grid
- Regulatory framework preparing large-scale integration of PV into the grid
- Internalisation of external costs for level playing field

**Market facilitation and transformation**
- Building codes and standards for PV products and interconnection rules
- Energy standards taking into account solar PV building regulations and obligations
- Business models for end users and rural electrification
- Implementation mechanisms for grid investments and storage solutions for full scale integration of PV
- Training and education for skilled workforce along the PV value chain; technology outreach to target audiences/stakeholders

**Technology development and R&D**
- Increased R&D funding to accelerate cost reductions and transfer to industry
- Continuous R&D funding on medium-term PV cell and system technologies
- Technical improvements, industrial processes, standardisation and scaling-up of manufacturing
- Enhanced system applicability of PV and related technologies and products
- Increased performance for PV cell/module technologies and balance-of-system components
- Basic and applied research on emerging PV technologies and applications
- Smart grid and grid management tools
- Enhanced storage technologies

GW capacity 200
Market 34 GW/yr

GW capacity 900
Market 105 GW/yr
Key actions and respective leading roles for:

- **Government stakeholders**
- **Market stakeholders (demand side)**
- **R&D and PV industry stakeholders (supply side)**

Framework for full market competition with priority access to the grid

- **2030**
  - GW capacity: 900 GW/year
  - Market: 105 GW/year

- **2040**
  - GW capacity: 2,000 GW/year
  - Market: 127 GW/year

- **2050**
  - GW capacity: 3,000 GW/year
  - Market: 141 GW/year

Continuous R&D funding on novel concepts and applicability

Research into concepts for ultra high performance/low-cost approaches
Wind resources are available in nearly every country, and significant cost reductions have made wind energy the fastest growing electricity source worldwide. Wind energy is a sound investment as it reduces energy import dependence with no fuel constraint or price risk, is emissions-free, and has a low environmental impact. The IEA wind energy roadmap contains milestones for continued cost reductions, flexible, targeted incentives, transmission planning, evolved power system operation for reliable integration of wind energy, and social acceptance of infrastructure.

Government and industry over the next ten years should:
- set long-term targets, supported by predictable market-based mechanisms; pursue cost reductions;
- plan new plants to attract investment, taking into account other power system needs and land/sea usage;
- appoint lead agencies to co-ordinate planning of transmission to resource-rich areas and interconnect power systems; set incentives to build transmission; assess power system flexibility;
- raise public awareness of the benefits of wind power and of the accompanying need for additional transmission infrastructure;
- exchange best practices with developing countries; target development finance bottlenecks; further develop carbon finance options in developing regions.

Wind power has grown rapidly over the last 20 years; several countries have major wind markets today.
Key findings

- This roadmap targets 12% of global electricity from wind energy by 2050. 2,000 GW of capacity will annually avoid the emission of 2.8 gigatonnes of CO₂-equivalent.

- Achieving these targets requires investment of some USD 3.2 trillion. 47 GW would need to be installed on average every year for the next 40 years – a 75% increase – amounting to USD 81 billion/yr.

- In 2030, non-OECD economies will produce some 17% of global wind energy, rising to 57% in 2050.

- Wind power can be competitive today where the resource is strong and when the cost of carbon is reflected in markets. Costs per MWh range from USD 70 to USD 130.

- Costs are expected to decrease further as a result of technology development, deployment and economies of scale – by 23% by 2050. Transitional support is needed to encourage deployment until full competition is achieved.

- Offshore costs are at present twice those on land, although the quality of the resource can be 50% higher. This roadmap projects cost reductions of 38% by 2050.

- To reliably achieve high penetrations of wind power, the flexibility of power systems and markets must be enhanced and, eventually, increased. Flexibility is a function of access to flexible generation, storage and demand response, and is enhanced by interconnection, larger and faster power markets, smart grids and forecasting.

- Intensified R&D is particularly needed in the offshore sector to develop a new generation of turbines and sub-surface structures fundamentally designed for the marine environment with minimum operating and maintenance requirement.
Wind roadmap milestones

**Policy framework**
- Transitional market support mechanisms; long-term deployment targets
- Integrated deployment plans; accelerated permitting processes
- Best-practice exchange with developing countries; targeted development financing and CO₂-based mechanisms
- Internalised external energy costs

**Public engagement and environment**
- Raised public awareness of value of wind energy and of the need for stronger transmission systems
- Improved assessment and mitigation methods for socio-environmental impacts

**Technology and industry**
- Improved resource assessment
- Industry databases of resource, conditions and operating experiences
- Advanced rotors, lighter and stronger materials
- Offshore: cheaper foundations <40m; improved supply chains and installation strategies
- Next generation of dedicated offshore turbines; foundations <200m
- Education and training programmes in OECD and developing countries
- Intensified R&D funding and international collaboration
- Stronger focus on deep offshore

**Power system**
- Improved forecasting models taken up in system operation
- Integrated transmission planning, incentives to build, equitable grid access
- Continental scale and offshore grid deployment
- Assessment of additional system flexibility needs
- Optimised markets; responsive demand; smarter grids

GW capacity: 671 (incl. offshore: 109)
GW capacity: 1 024 (incl. offshore: 194)

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Key actions and respective leading roles for:
- Government
- Wind industry
- Power system and regulators

GW capacity: 1,024 (incl. offshore: 194)
GW capacity: 1,572 (incl. offshore: 366)
GW capacity: 2,016 (incl. offshore: 652)
Key findings

- The BLUE Map scenario requires the investment of USD 46 trillion additional to the investment required in the Baseline scenario from 2010 to 2050. Almost half of these additional investments are needed in the transport sector for advanced vehicle technologies.

- The transition to a low-carbon energy system will yield significant fuel cost savings. Undiscounted savings are estimated at USD 112 trillion from 2010 to 2050. Subtracting these fuel savings from the additional investment costs yield total undiscounted net savings of USD 66 trillion. Even at a 10% discount rate, fuel savings in the BLUE Map scenario outweigh the additional incremental investment needed.

- There is an urgent need to scale up investment in low-carbon energy technologies. Current investment levels are insufficient to make the necessary transition to a low-carbon energy system. Investment in traditional fossil-based technologies needs to be shifted towards low-carbon energy technologies.

- Annual investments in low-carbon energy technologies averaged approximately USD 165 billion over the last three years. To implement the BLUE Map scenario investments in clean technologies will need to reach approximately USD 750 billion per year by 2030, rising to over USD 1.6 trillion per year from 2030 to 2050.

- The transition to a low-carbon energy system will offer significant new opportunities for business as a large range of new breakthrough and emerging technologies will need to be developed and widely deployed over the next few decades.

- International carbon reduction mechanisms are needed to support the deployment of low-carbon energy technologies in developing countries. These market-based mechanisms should be designed to encourage investments where they are least expensive.

- During the demonstration and early deployment of new energy technologies, direct support from governments is likely to be required to reduce the risks of technology development. As new technology gains acceptability, the need for government support should decline.

- The involvement of large corporations in technology development will help to facilitate financing as these companies have access to much lower costs of debt and a wider range of investors.

- Policy predictability at national and international levels will be important to enable investors to evaluate the risk of policy changes on potential investments, thereby allowing them to consider longer payback periods and allowing lenders to finance a higher portion of the needed investments.

- Capital is limited and returns must be sufficient to warrant the risks associated with these investments. Investment in new technologies will require higher returns than investment in traditional technologies. Institutional investors, who hold the largest share of private-sector funding are risk-adverse and will require predictable income streams before they will invest.
Governments and industry should increase public education, raise the awareness of climate change issues among the financial community and promote investment opportunities to new investors.

Greater collaboration with the finance community, and particularly venture capital and private equity investors could help governments more effectively distribute their innovation funding.

Investment needs

Baseline scenario

In the Baseline scenario, total final energy consumption almost doubles between 2007 and 2050 as the demand for energy-dependent goods, services and leisure activities increases. This implies very high levels of investment on the demand side in energy-consuming devices and processes. It also implies high levels of investment on the supply side in the energy production and supply infrastructure that will be needed to service them.

In the Baseline scenario, total investment1 is estimated to be USD 270 trillion between 2010 and 2050. Most of this (USD 240 trillion) is accounted for by investments that consumers will make in capital equipment that uses energy, including vehicles, and plants in heavy industry.

In the Baseline scenario, investment needs between 2030 and 2050 are almost double those in the period up to 2030 as the global economy develops and as the demand for cars and other consumer durables rises alongside incomes in emerging and developing countries (Table 14.1). In the BLUE Map scenario, even higher levels of investment are needed between 2030 and 2050 as demand increases for the wider diffusion of low-carbon technologies.

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

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Power generation</td>
<td>210</td>
<td>360</td>
<td>430</td>
<td>270</td>
<td>470</td>
<td>640</td>
<td></td>
</tr>
<tr>
<td>Transmission and distribution</td>
<td>170</td>
<td>220</td>
<td>210</td>
<td>270</td>
<td>260</td>
<td>350</td>
<td></td>
</tr>
<tr>
<td>Industry</td>
<td>130</td>
<td>150</td>
<td>290</td>
<td>150</td>
<td>170</td>
<td>340</td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td>3 800</td>
<td>4 490</td>
<td>7 220</td>
<td>4 028</td>
<td>4 760</td>
<td>8 080</td>
<td></td>
</tr>
<tr>
<td>Total investment (excluding buildings)</td>
<td>4 310</td>
<td>5 210</td>
<td>8 150</td>
<td>4 720</td>
<td>5 660</td>
<td>9 400</td>
<td></td>
</tr>
</tbody>
</table>

Note: Total investments in the buildings sector are not available. Numbers may not add due to rounding. Investments in industry include only cement, aluminium, iron and steel, pulp and paper and chemical and petrochemical sectors.

1. Excluding upstream investments in the production and transportation of coal, oil and gas.
The investment needs in the BLUE Map scenario are 8.6% higher between 2015 and 2030 and 16% higher between 2030 and 2050 than in the Baseline scenario. Transport investment costs rise over time in the Baseline scenario as the sales of vehicles of all types increase, particularly in the developing world.

**BLUE Map scenario**

The BLUE Map scenario envisages a need for investment USD 46 trillion higher than the Baseline scenario to 2050. Consumers invest in more energy-efficient equipment, buildings, vehicles and industrial plants with carbon capture and storage (CCS), and electricity generators invest in more capital-intensive renewables, nuclear and CCS-equipped plant. Some of these investments are economic even without a carbon dioxide (CO₂) reduction incentive as they yield lifetime fuel cost savings that more than justify the additional investment. But many firms require payback periods of less than 5 years and this creates a major financial barrier to the adoption of energy-efficient technologies with high initial costs and longer payback periods. Additional investment needs are dominated by the transport sector, accounting for 50% of total additional investments, as consumers invest in more expensive advanced vehicle technologies. The buildings sector accounts for 27% of the total investment, power 20%, and industry 4%.

Additional investment needs from 2010 to 2030 are estimated at USD 13 trillion (Figure 14.1), with investments in transport and buildings accounting for the largest shares. USD 33 trillion is required after 2030 for the much more rapid penetration of more advanced vehicle technologies, and for CCS and renewable and nuclear power.

**Figure 14.1** Additional investments by sector in the BLUE Map scenario

![Figure 14.1](image)

*Note: Additional investments in residential and commercial sectors include cooking, lighting, appliances, space and water heating systems, cooling systems and building shell improvements.*

*Key point*

*Most of the additional investment in low-carbon technologies will be required after 2030.*
In the power sector, the benefits of greater energy efficiency in the BLUE Map scenario mean that additional investment needs are more modest, while after 2030 the larger share of renewable power generation and increased demand from greater electrification in transport and industry sharply increase the additional investment needed in the power sector in the BLUE Map scenario compared to the Baseline scenario.

Transport

In the Baseline scenario, investment in planes, trucks, buses and passenger light-duty vehicles (LDVs) dominates total transport investments, amounting to 93% of the total USD 230 trillion investment in the transport sector between 2010 and 2050. LDVs alone account for around 60% (USD 139 trillion) of total transport investments (Table 14.2). The scenario envisages about 5 billion LDVs will be sold between 2010 and 2050, rising from 70 million in 2010 to 160 million in 2050, with average annual sales of 120 million LDVs per year. Hybrid vehicles reach about 25% of all sales by 2050. In the Baseline scenario, advanced technology vehicles, including plug-in hybrid electric vehicles (PHEVs), electric vehicles (EVs) and fuel cell vehicles (FCVs), account for only a small share of sales worldwide in 2050.

In the BLUE Map scenario, the incremental investment cost across all transport modes through 2050 amounts to USD 23 trillion, 10% higher than the Baseline. This includes USD 13 trillion for LDVs and USD 5 trillion for trucks and buses, with the balance mainly for aircraft and ships. The additional investments are needed for improvements to engines, better aerodynamics, and light weighting of all types of vehicles. The additional cost per vehicle for such improvements, especially in respect to batteries and fuel cell components, is expected to decline over time and with cumulative production.

<table>
<thead>
<tr>
<th>Table 14.2</th>
<th>Total investment needs for LDVs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010-30</td>
</tr>
<tr>
<td>USD billion</td>
<td>Baseline</td>
</tr>
<tr>
<td>Conventional vehicles</td>
<td>49 560</td>
</tr>
<tr>
<td>Hybrids</td>
<td>1 960</td>
</tr>
<tr>
<td>Plug-ins/EVs</td>
<td>2</td>
</tr>
<tr>
<td>FCVs</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>51 520</td>
</tr>
</tbody>
</table>

Power sector

In the Baseline scenario, investments in the power sector are estimated to be USD 23.5 trillion between 2010 and 2050. More than half of these investments (USD 15 trillion) will be needed for new power generation capacity, USD 5.8 trillion for maintaining and expanding the electricity distribution network and USD 2.5 trillion for the electricity transmission network. Investments in the conventional technologies of gas, coal, biomass, hydro and nuclear dominate investments in power generation.
In the BLUE Map scenario, energy efficiency reduces electricity demand growth. There is a switch to more capital-intensive renewable, nuclear and CCS-equipped thermal technologies. Additional investment needs in the BLUE Map scenario are estimated at USD 6.0 trillion for power generation, 33% of which is needed from 2010 to 2030 and 67% from 2030 to 2050 (Figure 14.2). Additional investment in the distribution network is estimated at USD 1.6 trillion, while USD 1.7 trillion is needed for transmission systems to connect more remote renewables to the grid. The connection of variable renewables will also require some reinforcing of grids.

**Figure 14.2** Additional investment needs in the power sector for the BLUE Map scenario compared to the Baseline scenario, 2010-50

![Graph showing additional investment needs in the power sector for the BLUE Map scenario compared to the Baseline scenario, 2010-50.](image)

**Key point** Additional investment costs needed to decarbonise the power sector are estimated at USD 9.3 trillion.

**Buildings**

The transition to a more sustainable energy future for the buildings sector will require significant additional investment. Residential, service-sector and public buildings use a wide range 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. The additional initial costs of higher performance building shells, windows, heating and cooling systems, lighting and appliances are often significant, but will come down with deployment, thereby helping to reduce the overall cost of meeting the goals in the BLUE Map scenario.

The buildings sector has a significant number of very attractive energy-efficient and low-carbon technologies that, although they have higher initial costs, are often cheaper on a least life-cycle cost basis than the technologies they replace. Such options can be found in new building shells, lighting, appliances and heating and cooling systems. The modelling takes up these cost-effective options first. Achieving
the deeper levels of cut in the BLUE Map scenario requires some much more expensive measures to be taken up, most notably to address the low performance of the existing residential building stock in OECD countries.

The investment is required to ensure that new buildings meet more stringent building codes, to refurbish to a low-energy standard around three-quarters of the existing building stock still standing in 2050 in OECD countries, and for additional investments in heat pumps, solar thermal systems, combined heat and power (CHP) systems, lighting systems and appliances.

The total additional investment in the BLUE Map scenario for the residential and service sectors is estimated to be USD 12.3 trillion, of which USD 7.9 trillion is needed in the residential sector and USD 4.4 trillion in the service sector (Table 14.3).

<table>
<thead>
<tr>
<th>Incremental investment</th>
<th>Share of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>(USD billion)</td>
<td></td>
</tr>
<tr>
<td>Water heating</td>
<td>935</td>
</tr>
<tr>
<td>Space heating</td>
<td>566</td>
</tr>
<tr>
<td>Cooling and ventilation</td>
<td>2 318</td>
</tr>
<tr>
<td>Lighting</td>
<td>231</td>
</tr>
<tr>
<td>Appliances and miscellaneous end-uses</td>
<td>2 877</td>
</tr>
<tr>
<td>Demolition/early retirement</td>
<td>680</td>
</tr>
<tr>
<td>New building shell measures</td>
<td>1 768</td>
</tr>
<tr>
<td>Refurbishment of building shell in OECD</td>
<td>2 944</td>
</tr>
<tr>
<td>Total</td>
<td>12 289</td>
</tr>
</tbody>
</table>

The additional investment required in building shells dominates the total additional investment needs in the BLUE Map scenario over and above the Baseline by 2050. Around 60% of this additional investment is needed to refurbish the existing building stock in OECD countries. This additional investment helps to reduce the incremental investment needs for space heating and helps offset some of the cost of shifting to more capital-intensive technology 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.

**Industry**

In the BLUE Map scenario, investment needs by 2050 are estimated to be between USD 2 trillion and USD 2.5 trillion higher than in the Baseline scenario, with most investment being needed in the cement, iron and steel and chemical sectors (Table 14.4). Total additional investments in industry represent 4% of the total investment costs needed across all sectors to halve global CO₂ emissions in the BLUE Map scenario. With the exception of cement, where investment needs in the BLUE Map scenario are more than 50% higher than in the Baseline scenario, investments in the other sectors are estimated to be 10% to 15% higher than in the Baseline scenario.
Table 14.4  
**Investment needs in industry in the Baseline and BLUE Map scenarios**

<table>
<thead>
<tr>
<th>In USD billion</th>
<th>Total investment needs</th>
<th>Total investment needs</th>
<th>Additional investments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010-50 Baseline</td>
<td>2010-50 BLUE Map</td>
<td></td>
</tr>
<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>

**Fuel savings**

The additional investment needs in the BLUE Map scenario will yield significant savings in fossil-fuel consumption, offset by increased bioenergy fuel costs. The total fuel savings in the BLUE scenario compared to the Baseline scenario are around 180 000 Mtoe over the period 2010 to 2050. Calculated using Baseline prices for the Baseline scenario and BLUE prices for the BLUE scenario, the undiscounted value of these fuel savings from 2010-2050 is USD 112 trillion. 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 these investments generate at a 3% discount rate yields net discounted savings of USD 32 trillion. At a 10% discount rate, net savings are USD 8 trillion (Figure 14.3).

**Figure 14.3**  
Additional investment and fuel savings in the BLUE Map scenario compared to Baseline, 2010-50

**Key point**

Even using a 10% discount rate, fuel savings in the BLUE Map scenario more than offset additional investment needs.

---

2. If the fuel savings calculation were based on Baseline fuel prices in both scenarios, which removes the effect of the lower fuel prices under the BLUE scenario, the total fuel savings would decline to USD 78 trillion. The net savings would fall to USD 32 trillion undiscounted, USD 16 trillion based on a 3% discount rate and USD 4 trillion based on a 10% discount rate.
Current trends in financing of low-carbon technologies and global energy asset finance

Investments in low-carbon technologies, particularly in the power sector, have increased very significantly since 2001 reaching over USD 173 billion in 2008 from less than USD 11.6 billion in 2001 (Bloomberg New Energy Finance). In 2009, the impacts of the financial crisis and slow-down in economic growth resulted in a 6.6% drop in low-carbon investments (Figure 14.4). The economic stimulus packages and CO₂ targets set by many major economies can be expected in time to result in a rebound in investment flows into low-carbon technologies.

Asset finance remains the most important source of funding for low-carbon technologies accounting for USD 99 billion (60%) of the total funds invested in 2009. Funding from asset finance can be raised either through project finance, on-balance sheet funding in the form of corporate debt or direct equity investment, or through the bond market. Project finance offers an attractive way for companies to fund investments in new generation capacity as the projected cash flow from the project is used to justify the investment rather than the cost being carried on the balance sheet of the project owners.

The drop in liquidity caused by the global financial crisis has significantly constrained the ability of project developers to raise funding through project finance. As a result, a much larger share of asset finance has been in the form of on-balance sheet funding. Large corporations with solid balance sheets and strong banking relationships have benefitted from the drop in liquidity driving out many smaller players in the low-carbon energy market. Wind project developers have seen the cost of borrowing rise significantly. This has made many projects unfinanceable. Projects have only been financed on the strength of their developers’ corporate balance sheets.

Funding from public markets, which represented an important share of finance in 2006 (12%) and 2007 (16%) saw a significant decline in activity in 2008 as the global financial crisis reduced market appetite for the listing of new companies. Some renewed activity on the public markets was seen during the second half of 2009 with 10 new companies raising USD 3.5 billion via initial public offerings (IPOs) on the market. As confidence returns, a growing share of the funding needs for low-carbon technologies will come from the stock markets through the issuing of new equity.

---

3. Investments in low-carbon technologies are based on Bloomberg New Energy Finance data which include investments in renewables (including biofuels and small hydropower) and energy efficiency. IEA analysis on additional investment needs in low-carbon technologies also includes investment in transport, electricity networks, nuclear and CCS. Including investments in these other technologies, the current investments in low-carbon technologies are estimated to be approximately USD 200 billion per year.

Figure 14.4  Investments in low-carbon energy technologies

![Graph showing investments in low-carbon energy technologies from 2001 to 2009.](image)

Note: Asset finance excludes amount reinvested in equity. Estimates for corporate research, development and demonstration (RD&D), and investments in small scale projects are not available for 2001, 2002 and 2003.
Source: Bloomberg New Energy Finance.

Key point

Investment in low-carbon technologies has risen steadily over the last decade, but has dropped back since the start of the financial crisis.

In 2009, low-carbon investment flows from venture capital and private equity amounted to USD 7 billion, a 41% decrease compared to 2008 levels. These funds are particularly important for technology companies in their early stage of development and for manufacturers looking for expansion capital to fund new projects or facilities. Investments in corporate and government RD&D amounted to USD 24 billion in 2008 and 2009.

Investments in wind have accounted for the largest share of total investments in low-carbon technologies, with a share of between 40% and 60% since 2001 (Figure 14.5). Investment in solar energy technologies, which accounted for the second-largest share of total investments (21%) in 2009, has shown the largest increase, rising eightfold from USD 3.2 billion in 2005 to USD 25 billion in 2009. Investment in biomass technologies which accounted for the second-largest share (32%) in 2001 has shown a relatively modest increase compared to wind and solar technologies. The biomass share of total investments in low-carbon technologies has fallen to 10% in 2009. Biofuels, which saw significant growth in activity between 2005 and 2007, showed a decline of 11% in 2008 and 21% in 2009 as lower oil prices and concerns over sustainability of biofuels made investments in biofuels less attractive.

In 2008, an estimated 65 gigawatts (GW) of new renewable power generation, including large hydro, was added globally. This represented a total investment of approximately USD 140 billion. New renewable power generation represented about 40% of the approximately 160 GW of new capacity added in 2008. Investments in renewable power over the next decade will continue to show strong growth, driven by the ambitious renewable energy targets being set by most major economies.
Regionally, Europe remains the leader in low-carbon energy finance, accounting for 36% of total investments in 2009 (Figure 14.6). North America has steadily seen its share of worldwide low-carbon energy investments decline, falling to 18% in 2009 as other regions have invested more heavily. Investment in Asia, driven primarily by strong growth in China, has seen the largest rise, investing approximately USD 40 billion in 2009, 34% of global low-carbon energy investments. In South America, investments have continued to rise steadily since 2001, reaching USD 12 billion in 2009. The bulk of these investments are attributable to biofuel investments in Brazil.

Current annual investments in the energy sector are estimated at between USD 650 billion and USD 750 billion. The largest share of these investments are in the oil and gas sector, where a survey of the largest 50 oil and gas companies showed investments in 2008 of USD 525 billion (IEA, 2009e). Investments by the largest 25 companies in the electricity and coal mining sectors in 2008 reached USD 143 billion and USD 13 billion, respectively (Table 14.5). In the same year, investments in low-carbon technologies reached just under USD 162 billion.5

---

5. This excludes investments in the transport sector, electricity networks, nuclear and CCS.
Figure 14.6  Low-carbon energy investments by region (USD billions)

North America

Europe

Asia and Oceania

South America

Africa and Middle East

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: New investment volume adjusted for reinvested equity. Total values include estimates for undisclosed deals.

Sources: Bloomberg New Energy Finance; UNEP SEFI (2009).

Key point

Europe invests most in low-carbon technologies, although growth has been strongest in Asia.
Table 14.5  Investments by the 25 largest companies in oil and gas, power and coal mining sectors, 2008 (USD billions)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PetroChina</td>
<td>China</td>
<td>34.0</td>
<td>E.ON</td>
<td>Germany</td>
<td>23.9</td>
<td>Shenhua Group</td>
<td>China</td>
</tr>
<tr>
<td>Shell</td>
<td>United Kingdom-Netherlands</td>
<td>32.0</td>
<td>GDF Suez</td>
<td>France-Belgium</td>
<td>14.9</td>
<td>Xstrata</td>
<td>United Kingdom-Switzerland</td>
</tr>
<tr>
<td>Petrobras</td>
<td>Brasil</td>
<td>29.1</td>
<td>EDF</td>
<td>France</td>
<td>14.5</td>
<td>China National Coal</td>
<td>China</td>
</tr>
<tr>
<td>Gazprom</td>
<td>Russia</td>
<td>25.6</td>
<td>ENEL</td>
<td>Italy</td>
<td>9.7</td>
<td>BHP Billiton</td>
<td>United Kingdom-Australia</td>
</tr>
<tr>
<td>ExxonMobil</td>
<td>United States</td>
<td>23.9</td>
<td>Iberdrola</td>
<td>Spain</td>
<td>9.7</td>
<td>Anglo American</td>
<td>United Kingdom-South Africa</td>
</tr>
<tr>
<td>Chevron</td>
<td>United States</td>
<td>22.8</td>
<td>TEPCO</td>
<td>Japan</td>
<td>7.5</td>
<td>Teck Cominco</td>
<td>Canada</td>
</tr>
<tr>
<td>BP</td>
<td>United Kingdom</td>
<td>22.0</td>
<td>Kansai Electric</td>
<td>Japan</td>
<td>6.9</td>
<td>Coal India</td>
<td>India</td>
</tr>
<tr>
<td>ENI</td>
<td>Italy</td>
<td>21.4</td>
<td>Florida Power &amp; Light</td>
<td>United States</td>
<td>5.2</td>
<td>Massey Energy</td>
<td>United States</td>
</tr>
<tr>
<td>Total</td>
<td>France</td>
<td>20.5</td>
<td>KEPCO</td>
<td>Korea</td>
<td>5.2</td>
<td>Rio Tinto</td>
<td>United Kingdom-Australia</td>
</tr>
<tr>
<td>ConocoPhilips</td>
<td>United States</td>
<td>19.9</td>
<td>Endesa</td>
<td>Spain</td>
<td>5.1</td>
<td>PT Bumi Resources</td>
<td>Indonesia</td>
</tr>
<tr>
<td>PEMEX</td>
<td>Mexico</td>
<td>18.0</td>
<td>EDP</td>
<td>Portugal</td>
<td>4.5</td>
<td>SUEK</td>
<td>Russia</td>
</tr>
<tr>
<td>StatoilHydro</td>
<td>Norway</td>
<td>16.9</td>
<td>RWE</td>
<td>Germany</td>
<td>4.3</td>
<td>Consol Energy</td>
<td>United States</td>
</tr>
<tr>
<td>Sinopec</td>
<td>China</td>
<td>15.8</td>
<td>National Grid</td>
<td>United Kingdom</td>
<td>4.3</td>
<td>Kompania Weglowa</td>
<td>Poland</td>
</tr>
<tr>
<td>Lukoil</td>
<td>Russia</td>
<td>11.1</td>
<td>Dominion Resources</td>
<td>United States</td>
<td>3.5</td>
<td>RWE Power</td>
<td>Germany</td>
</tr>
<tr>
<td>Devon Energy Corp</td>
<td>United States</td>
<td>9.4</td>
<td>Chubu Electric</td>
<td>Japan</td>
<td>3.4</td>
<td>Peabody Energy</td>
<td>United States</td>
</tr>
<tr>
<td>Repsol YPF</td>
<td>Spain-Argentina</td>
<td>9.3</td>
<td>Peabody Energy</td>
<td>United States</td>
<td>3.4</td>
<td>Peabody Energy</td>
<td>United States</td>
</tr>
<tr>
<td>Rosneft</td>
<td>Russia</td>
<td>9.1</td>
<td>Exelon</td>
<td>United States</td>
<td>3.0</td>
<td>Sasol</td>
<td>South Africa</td>
</tr>
<tr>
<td>Marathon</td>
<td>United States</td>
<td>7.4</td>
<td>CEZ</td>
<td>Czech</td>
<td>2.5</td>
<td>Banpu</td>
<td>Thailand</td>
</tr>
<tr>
<td>EnCana</td>
<td>Canada</td>
<td>7.4</td>
<td>Eletrobras</td>
<td>Brasil</td>
<td>2.1</td>
<td>Drummond</td>
<td>United States</td>
</tr>
<tr>
<td>Occidental</td>
<td>United States</td>
<td>6.8</td>
<td>Scottish Southern</td>
<td>United Kingdom</td>
<td>1.7</td>
<td>Kuzbassrazrezugol</td>
<td>Russia</td>
</tr>
<tr>
<td>Canadian Natural Resources</td>
<td>Canada</td>
<td>6.4</td>
<td>Fortum Oy</td>
<td>Finland</td>
<td>1.6</td>
<td>Shenhua Group</td>
<td>China</td>
</tr>
<tr>
<td>Apache</td>
<td>United States</td>
<td>5.9</td>
<td>CLP Holdings</td>
<td>Hong Kong</td>
<td>0.8</td>
<td>Mitsubishi Development</td>
<td>Japan</td>
</tr>
<tr>
<td>Anadarko</td>
<td>United States</td>
<td>5.5</td>
<td>China National Coal</td>
<td>China</td>
<td>1.4</td>
<td>Shenhua Group</td>
<td>China</td>
</tr>
<tr>
<td>Talisman</td>
<td>Canada</td>
<td>5.2</td>
<td>Pacific Corp</td>
<td>United States</td>
<td>5.1</td>
<td>PT Kideco Jaya Agur</td>
<td>Indonesia</td>
</tr>
<tr>
<td>CNOOC</td>
<td>China</td>
<td>5.1</td>
<td>Pacific Corp</td>
<td>United States</td>
<td>5.1</td>
<td>PT Kideco Jaya Agur</td>
<td>Indonesia</td>
</tr>
</tbody>
</table>

Sources: Thomson Reuters database and IEA (2009e).
Between 2010 and 2020, an estimated USD 300 billion to USD 400 billion per year of additional investments will be required to deliver the BLUE Map scenario outcomes compared to the Baseline scenario. Much of this will be funding through asset finance. The scaling up of investments in low-carbon technologies from 2004 to 2007 will need to continue at a similar rate over the next decade to achieve this. A growing share of the investment currently seen in the energy sector will need to flow into low-carbon technologies. In the power sector, investment flows into renewable power generation is showing an encouraging trend, with investment in renewable power generation surpassing flows into fossil-fueled generation for the first time in 2008.

A growing share of the funding for low-carbon energy technologies will need to be financed by the private sector. Smaller, more innovative companies backed by venture capital and private equity markets are likely to continue to play an important role in the development of low-carbon technologies. Scaling up and deploying these technologies will require large investment flows which will need to be funded by large corporations. Large corporations will finance these investments through a mix of internally generated cash flow and project finance and by issuing debt and equity on international financial markets. In March 2009, USD 95.4 billion was deployed in clean energy investment (Bloomberg New Energy Finance). Of this, USD 51.1 billion was managed in core clean energy funds which had more than 50% of their investments in low-carbon energy companies or projects. An additional USD 10.3 billion was held by energy and infrastructure funds with at least 10% of assets held in renewable energy. Another USD 33.9 billion was managed by environmental and climate change funds in which investments in low-carbon energy represented an important share of the total holdings.

Current trends in low-carbon energy investment are encouraging, but investments over the next 20 years will need to be scaled up by a factor of almost five to reach USD 750 billion per year if the investment needs in the BLUE Map scenario are to be met. Incentives for green growth in economic stimulus packages should help to support investments in the short term. A transition to a low-carbon economy over the medium and long term will be dependent on establishing a clear policy framework which will provide the necessary incentives for investment in these technologies.

International financing mechanisms

Financing technology deployment in non-OECD countries

Many of the least-cost opportunities for deploying some of the leading low-carbon energy technologies, particularly renewable energies, are in non-OECD countries. Much of the additional investment needed to achieve the transition to low-carbon technologies will need to be deployed in countries where only very limited carbon policies currently exist. Funds will need to be transferred from developed to developing countries to overcome financial barriers related to technology diffusion. Current financing flows to developing countries need to be scaled up sharply.
International carbon reduction mechanisms such as the Clean Development Mechanism (CDM) will need to play an important role. In general, CDM is best suited for financing large investments in the power and industry sectors. Investments in the transport and the buildings sectors which will need to be made by billions of small households are not well suited to CDM given the high transaction costs and much smaller individual investment requirements for these sectors.

The most appropriate sources of funding for a given country will depend on its stage of economic development. Market-based mechanisms such as the CDM combined with in-country finance should be the main funding mechanisms for a group of the richest non-OECD countries (other major economies), such as China and Russia (Table 14.6). At the 15th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in December 2009 (COP-15), China stated that it would not seek direct financial assistance. In emerging countries, where development aid is needed to improve access to energy, market-based mechanisms and in-country finance may need to be supplemented by additional funding from developed countries. Investment in least developed countries will most probably need to be directly funded by developed countries as these countries are unable to secure financing because of their low credit ratings.

<table>
<thead>
<tr>
<th>Possible funding mechanisms for meeting the additional cost of energy technology transition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gross domestic product per capita USD (purchasing power parity)</strong></td>
</tr>
<tr>
<td>OECD</td>
</tr>
<tr>
<td>Other major economies</td>
</tr>
<tr>
<td>Emerging economies</td>
</tr>
<tr>
<td>Least developed countries</td>
</tr>
</tbody>
</table>

The largest share of the additional investment between the Baseline and the BLUE Map scenarios to 2030 is in OECD countries, with an average annual incremental investment from 2010 to 2030 of USD 291 billion (Figure 14.7). Incremental investment needs from other major economies between 2030 and 2050 is the largest of the four groupings. Investment levels in emerging economies from 2030 to 2050 is over half those of the OECD countries. Emerging economies will require additional support to reach these levels. Investment needs for least developed countries account for the smallest share at 3% from 2010 to 2050. Other major economies account for the largest share of investment needs over the 2010 to 2050 period, with incremental investment needs of USD 480 billion per year. In comparison, additional investments in OECD countries are USD 425 billion per year from 2010 to 2050.
Figure 14.7 ▶ Additional investment needs in the BLUE Map scenario compared to the Baseline scenario by region and sector

Key point

Although OECD countries will account for the largest share of investments from 2010 to 2030, most of the additional investment from 2030 to 2050 will need to occur in non-OECD countries.

Bilateral and multilateral climate funds

Bilateral and multilateral climate funds offer an important source of finance for low-carbon technologies in developing countries (Table 14.7). These funds cover both mitigation and adaptation costs. Much of the multilateral funding is under the management of the World Bank, which has approximately USD 9.5 billion of funds to distribute for climate change mitigation and adaptation from 2008 to 2012. A number of countries have also committed funds to support investments in developing countries. Japan has made the largest commitment with USD 15 billion being available under the Hatoyama Initiative.

International funds could play a variety of roles as part of a post-2012 agreement. A number of options are under consideration. Future international institutional funding for climate purposes is likely to be significantly larger than it is currently. Existing institutions will need to adapt to handle the larger flow of funds and the different purposes to which they may be put. The extent to which international funding will continue to be delivered by the existing institutions in the future, or whether there may be additional bodies, is the subject of ongoing negotiations.
Table 14.7  Multilateral and bilateral funding for low-carbon technologies

<table>
<thead>
<tr>
<th>Fund</th>
<th>Total amount USD millions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Multilateral initiatives</strong></td>
<td></td>
</tr>
<tr>
<td>Climate Investment Funds</td>
<td>6 100 (A+M*)</td>
</tr>
<tr>
<td>Clean Technology Fund</td>
<td>4 700</td>
</tr>
<tr>
<td>Strategic Climate Fund</td>
<td>1 400</td>
</tr>
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<td>International Finance Corporation</td>
<td></td>
</tr>
<tr>
<td>Sustainable Energy and Water</td>
<td>2 000</td>
</tr>
<tr>
<td>GEF 4 (including land-use change and forestry)</td>
<td></td>
</tr>
<tr>
<td>1 400</td>
<td></td>
</tr>
<tr>
<td>Asian Development Bank</td>
<td></td>
</tr>
<tr>
<td>Climate Change Fund</td>
<td>40</td>
</tr>
<tr>
<td>Clean Energy Financing Partnership Facility</td>
<td>90</td>
</tr>
<tr>
<td>Poverty and Environment Fund</td>
<td>3.6</td>
</tr>
<tr>
<td>European Investment Bank</td>
<td></td>
</tr>
<tr>
<td>Multilateral Carbon Credit Fund (with EBRD)</td>
<td>275.5</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>9 910</td>
</tr>
<tr>
<td><strong>Bilateral initiatives</strong></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>Hatoyama Initiative</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Development Co-operation</td>
</tr>
<tr>
<td>Australia</td>
<td>International Forest Carbon Initiative</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Environmental Transformation Fund - International Window</td>
</tr>
<tr>
<td>Norway</td>
<td>Climate Forest Initiative</td>
</tr>
<tr>
<td>Germany</td>
<td>International Climate Initiative</td>
</tr>
<tr>
<td>European Commission</td>
<td>Global Climate Change Alliance</td>
</tr>
<tr>
<td>Spain</td>
<td>Millennium Development Goals Achievement Fund</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>20 220</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>30 130</strong></td>
</tr>
</tbody>
</table>

Note: List of funds is not exhaustive and focuses on funding for mitigation. The funds are multi-year commitments.

*A+M = adaptation and mitigation; A = adaptation; M = mitigation.
Sources: World Bank (2009a) and UNFCCC (2008).

Box 14.1  New funding commitments in the Copenhagen Accord

As part of the Copenhagen Accord agreed at COP-15, developed countries agreed collectively to commit around USD 30 billion over the period 2010 to 2012 “to enable and support enhanced action on mitigation, including substantial finance to reduce emissions from deforestation and forest degradation (REDD-plus), adaptation, technology development and transfer and capacity-building” (UNFCCC, 2009).

Developed countries have agreed to increase this support to USD 100 billion per year by 2020. As this figure includes financial support for adaptation and REDD-plus, the values are in line with estimates for the additional investment needed in emerging economies and least developed countries for mitigation shown in Figure 14.7. The Accord also outlines the creation of a Copenhagen Green Climate Fund to be the operating entity of the financial mechanisms of the Convention and calls for the establishment of a Technology Mechanism to accelerate technology development and transfer in support of action on adaptation and mitigation. The terms for the creation of these two new mechanisms are currently unclear and will depend on continued negotiations. It is also unclear whether or not these new bodies are intended as a replacement of, or supplement to the Global Environment Fund.
Carbon markets and finance

The Kyoto Protocol established a series of flexibility measures which enable countries to meet their targets by co-operating on emissions reductions across national borders. It also established the principle of the use of carbon sinks, such as certain forestry and land-use activities, to soak up emissions.

Three emissions market mechanisms were introduced to assist countries in meeting their emission targets in a flexible, cost-effective way:

- International emissions trading which allows country-to-country market transactions.
- The Joint Implementation (JI) of greenhouse-gas mitigation projects between developed countries.
- The CDM for joint projects by developed countries in developing countries.

The Kyoto Protocol also created the infrastructure needed for these international market mechanisms, such as registries and an international transaction log. Subsequently, countries and regions started building their own emissions trading systems. Among the early movers were Denmark and the United Kingdom. The most important milestone was the launch of the European Union Emissions Trading System (EU-ETS) in 2005, still the world’s largest system for trading greenhouse gases, which stimulated the development of further trading programmes. In addition, voluntary markets emerged, driven by retail or consumer considerations.

The global carbon market has steadily expanded since 2004. Between 2005 and 2008, the volume of trading increased by a factor of almost 7 and the financial value transacted by a factor of more than 11. Despite turmoil in the financial markets, the financial value of the global carbon market doubled to USD 126 billion in 2008, with a 61% increase in the volume of trading compared to 2007 (World Bank, 2009b) (Figure 14.8 and Table 14.8).

**Figure 14.8** The development of the carbon market


**Key point**

The EU-ETS accounts for the largest share of trade in the carbon markets.
Table 14.8 The carbon market (USD billions)

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
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</thead>
<tbody>
<tr>
<td>EU Emissions Trading Scheme</td>
<td>7.9</td>
<td>24.4</td>
<td>49.1</td>
<td>91.9</td>
</tr>
<tr>
<td>CDM: primary transactions</td>
<td>2.4</td>
<td>5.8</td>
<td>7.4</td>
<td>6.5</td>
</tr>
<tr>
<td>CDM: secondary market</td>
<td>0.2</td>
<td>0.4</td>
<td>5.5</td>
<td>26.3</td>
</tr>
<tr>
<td>Joint implementation</td>
<td>0.1</td>
<td>0.1</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Other</td>
<td>0.3</td>
<td>0.4</td>
<td>0.6</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Total transactions</strong></td>
<td>10.9</td>
<td>31.2</td>
<td>63.0</td>
<td>126.3</td>
</tr>
</tbody>
</table>

Note: “Other” includes transactions on the voluntary market, the Chicago Climate Exchange, in the New South Wales and US Regional Greenhouse Gas Initiative (RGGI) systems, and (as of 2008) also of assigned amount units (AAUs).

The EU-ETS accounts for approximately USD 92 billion of trading through the transaction of allowances and derivatives for compliance, risk management, arbitrage, raising cash and profit-taking purposes. The second-largest segment of the carbon market is the CDM secondary market for Certified Emission Reductions (CERs). This is a financial market with spot, futures and options transactions in excess of USD 26 billion. This secondary CDM market has grown fastest in recent years, with an almost fivefold increase in both value and volume in 2008 compared to 2007.

For the first time since the start of the international carbon market, transactions financing CDM projects fell by 30% by volume and 12% by value in 2008. JI projects also experienced a severe drop. This was the result of difficulties in obtaining financing for climate-friendly projects during the financial crisis, regulatory delays and of uncertainty surrounding the future of the market under the new global climate change agreement that had been expected to be agreed in Copenhagen in December 2009.

The emergence of these markets at multiple levels, each with their own drivers and prices, demonstrates that carbon markets are likely to have an important role to play in achieving significant greenhouse-gas emissions reductions. Two types of carbon market have emerged:

- Markets induced by cap-and-trade regimes, such as the Kyoto Protocol or the EU ETS. In these markets, transactions are allowance-based.
- Markets induced by the projects implemented under the JI and CDM. In these markets, transactions are project-based.

**Allowance-based markets**

New emissions trading systems are developing or being proposed in several regions and countries. While some have already defined rules, others have not yet finalised their detailed approach. Lessons are being learned from the early years of existing schemes.

The EU-ETS currently covers the 27 EU member states and about 40% of the total EU greenhouse-gas emissions. In December 2008, the European Council and the European Parliament endorsed an agreement on climate change and energy, which implements a political commitment by the European Union to reduce its
greenhouse-gas emissions by 20% by 2020 compared to 1990 levels. The EU-ETS will play a pivotal role in achieving this target as the 2020 cap for ETS installations is 21% below the actual level of 2005 emissions.

Several other trading systems are being developed, including in countries that are not Parties to the Kyoto Protocol. In the United States, the first regional scheme, the RGGI in the north-eastern states, began on 1 January 2009. Others are in discussion, such as the Western States Climate Action Initiative. On 26 June 2009, the House of Representatives passed an American Clean Energy and Security Act. If passed by the Senate, this would create a cap-and-trade programme covering 85% of US greenhouse-gas emissions, including in the power, industry, transport, commercial and residential sectors. The targets are set against 2005 emission levels at a 3% reduction by 2012, 17% by 2020, 42% by 2030 and 83% by 2050.

In New Zealand, the government announced an emissions trading system (the NZ ETS) in September 2007 which aimed to have all the major greenhouse-gas emitting sectors included in the scheme by 2013. The scheme envisaged the unlimited use of Kyoto Protocol project credits. The NZ ETS, which currently only covers the forestry sector, started on 1 January 2008. The new government that came into place in 2008 established a committee to review the NZ ETS. A revised law was passed in November 2009.

Since 2008 the Australian government has been working on plans to establish an emissions trading scheme (the so-called “Carbon Pollution Reduction Scheme [CPRS]”) as a key mechanism to transition Australia to a low greenhouse-gas emission future. The proposal includes broad coverage of greenhouse-gas emissions and sectors, covering around 75% of Australian greenhouse-gas emissions, a mix of direct and upstream point of obligation and assistance to help households and business adjust. The emission threshold for direct obligations under the scheme would apply to entities with facilities which have direct emissions of 25 000 tCO₂ equivalent per year or more. If enacted, existing trading systems like the New South Wales Greenhouse Gas Reduction Scheme would be replaced by this more comprehensive system. The House of Representatives passed the CPRS Bill 2010 (and associated Bills) in February 2010, however further consideration of the legislation has been deferred and the scheme will not now be implemented until at least 2013.

The government of Canada is committed to reducing Canada’s total greenhouse-gas emissions by 17% from 2006 levels by 2020 and by 60% to 70% by 2050. The creation of a carbon market is part of the government’s commitment to reduce emissions. In June 2009, the Canadian government published new guidelines for Canada’s Offset System for Greenhouse Gases. The domestic offset system is an important step in the creation of a carbon market in Canada, establishing tradable credits for greenhouse-gas reductions and encouraging cost-effective domestic emissions reductions in areas such as forestry and agriculture that will not be covered by planned federal regulations. Under the proposed regulations, firms will have several options to meet their compliance obligations. These include domestic offset credits and emissions trading as an important component of the

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6. A 30% reduction target is proposed if others adopt equally ambitious mitigation objectives.
7. For a detailed description and analysis of the EU-ETS first phase, see Ellerman, Convery and de Perthuis (2010).
government’s market-driven approach to reducing greenhouse-gas emissions. The Canadian government has indicated that it will continue to monitor United States developments to ensure harmonised rules.

In September 2008, Japan unveiled an outline of a greenhouse-gas ETS, which was launched on a trial basis in October 2008. Initially, the system is voluntary and Japanese companies are allowed to set their own emissions reduction targets. In addition to allowance trading, companies will be able to use CDM credits, national offset credits and credits from Japan’s voluntary emissions trading scheme. In September 2009, the Japanese Prime Minister committed to mobilise all available policy tools including a domestic emissions trading mechanism.

Project-based markets

The Kyoto Protocol established two project-based mechanisms, the CDM and JI. JI had a much slower start than the CDM as the CDM allowed CERs to accrue from projects from 2000 onwards. This created a good deal of interest, particularly after the entry into force of the Kyoto Protocol in 2005.

The CDM has successfully used market mechanisms to identify cost-effective emissions reductions. It has also raised awareness in developing countries. Between 2004 and 2007, CDM projects grew by a factor of more than 8 in terms of volume, and almost 27 times in terms of financial value. In 2008, the World Bank reported that the CDM had initiated transactions for 389 Mt CO₂ equivalent. The secondary CDM markets covered transactions worth an additional 1 072 Mt CO₂. Together these transactions were worth a total of USD 32.8 billion. In February 2010, the United Nations Environment Programme Risø CDM/JI Pipeline indicated that a total of 4 926 CDM projects were under consideration, covering a wide range of categories and industries. Only 41% of these projects had been registered by the CDM Executive Board; most (55%) were still at the validation stage. Of the registered projects only 26% had been issued with CERs. The very large increase in CDM projects over recent years appears to have intensified problems in the registration of projects and the issuing of CERs.

Of all the projects currently submitted,8 more than 79% are in the field of renewable energy. These are expected to receive over a third of the CERs up to 2012. Projects to reduce hydrofluorocarbons, perfluorocarbons and nitrous oxides are expected to secure almost 29% of the cumulative 2012 CERs, although they account for only 2.3% of the projects. Categories like fuel switching, afforestation and reforestation or transport are only marginally involved. Most projects (76%) are located in Asia and the Pacific region. These are expected to receive 80% of the cumulative CERs up to 2012, delivering emissions savings of 2.1 Gt CO₂-eq. China and India have the largest number of projects. China would host 36% of the currently submitted projects, equivalent to 54% of the expected CERs up to 2012, accounting for emissions savings of 1.4 Gt CO₂-eq. India also has a large share of the submitted projects (28%), but these projects are expected to attract only about 15% of the expected CERs up to 2012, achieving emissions reductions of 0.4 Gt CO₂-eq. Least developed countries only have 1% of the submitted projects.

8.Withdrawn or rejected projects are not counted.
accounting for 1% of the expected cumulative CERs up to 2012, and emissions savings of 0.03 Gt CO$_2$-eq.

The outlook for carbon finance

The economic downturn and the consequent drop in CO$_2$ emissions have lowered carbon price expectations in the short term. The uncertain outcome of COP-15 has also reduced confidence in the longer-term prospects for carbon trading. Uncertainties around the timing of any potential cap-and-trade legislation in the United States are an additional negative factor. Even so, global carbon markets have continued to expand. This suggests that carbon finance has gained a momentum of its own, with strong incentives for interested stakeholders.

Carbon markets have shown that they can drive significant emissions reductions worldwide. The development of domestic and regional trading systems has created carbon prices that have already played an important role in supporting investment in abatement measures. But the levels of investment driven by the carbon market to date are insufficient to meet ambitious climate policy goals. To pave the way for an expansion of the carbon market, scaled-up market mechanisms are needed that can cost-effectively support larger-scale emissions reductions in developing countries.$^9$

The Copenhagen Accord provides little guidance on the likely use of market mechanisms after 2012. The Accord only states that various approaches will be pursued to enhance cost-effectiveness and promote mitigation action, including the use of markets. This statement keeps the door open both for existing market mechanisms such as the CDM as well as for new market mechanisms. The lack of a clear signal to the carbon market may, at least in the short term, have a negative impact on the role of carbon finance in incentivising lower-greenhouse gas developments. The outcome of COP-15 has also created uncertainty around the precise role of the UNFCCC in delivering any new climate change architecture, adding to uncertainty over the continuation of the CDM and JI mechanisms beyond 2012 at least in their current forms.

Even so, one of the most concrete outcomes of the Copenhagen negotiations was a decision achieved at the meeting of the Parties to the Kyoto Protocol on its fifth session (CMP5) on the enhancement of CDM processes, aimed at improving the future functioning of the CDM. This decision includes requirements to strengthen transparency, to improve the timeliness of the registration and issuance processes, to develop modalities and procedures for standardised baselines and guidance on how to account for national environmental policies, and to tackle issues related to the regional distribution of projects.

From an economic perspective, progressive evolution in the carbon market is welcome insofar as it meets expectations on the demand and supply sides, and reflects the environmental imperatives and political realities of global mitigation. Preliminary estimates show that the potential supply of emissions reduction credits could be much larger than demand, depending on how quickly sectors and countries establish sectoral objectives and achieve mitigation.$^{10}$ Discussions in several

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9. For an overview of these proposed mechanisms see IEA (2009c), www.oecd.org/env/cc/sectoral.
countries suggest that there may be hard limits on the demand side. If so, scaled-up mechanisms will need to be designed carefully in order to avoid a low-carbon price and possible carbon lock-ins that would make it more difficult or expensive to achieve deep reductions in later years. Introduction of price floors in carbon markets could be a possible solution to ensuring that carbon prices are sufficiently high to attract investments in low-carbon technologies. To make best use of carbon finance in any post-2012 climate architecture, market-based instruments should be combined with targeted policy measures that are able to ensure that the support for mitigation in developing countries helps them meet their development goals.\textsuperscript{11}

## Financing options for an energy technology revolution

A number of other approaches can be adopted to fund low-carbon energy technologies including direct government finance and private-sector finance. As the largest share of funding will come from the private sector, governments need a better understanding of how these markets operate so that they can design appropriate regulation and policy measures to attract that funding.

Different funding approaches will work best at different stages of technology development (Figure 14.9). Government funding is most relevant for early-stage technology development, while private finance tends to focus on later-stage technology deployment and commercialisation. The size of the different investment requirements for the different stages of technology development is roughly captured by area represented in the pyramid.\textsuperscript{12}

### Private-sector finance

Private-sector finance can come through company cash flow generation, equity finance and debt finance. Debt finance includes a wide range of options including bank loans, bonds, project finance and supplier credits. Project finance is particularly attractive as a means of financing new power generation as debt investors lend to a single-purpose entity whose only asset is the new plant. Developers can thereby raise larger quantities of debt without impacting on the company’s debt to equity ratios. And lenders get their loans repaid once the project is operational. Equity finance raises money for company activities in exchange for ownership interest in the company. Equity financing is more expensive than debt financing for corporations as the associated risks, and therefore the required returns, are higher for equity than for debt.

An important share of the investment in low-carbon energy technologies will come from large corporations. They will fund these investments from the internal cash flow from their operations and from debt and equity raised in the capital markets.

\textsuperscript{11} For a discussion of this approach see Baron and Buchner (2009). For an application of the approach in the energy sector see IEA (2009b).

\textsuperscript{12} The actual share of investments needed at each stage of technology development differs significantly from one technology to another, but in general investment needs rise as technology moves from R&D to demonstration, to deployment, to commercialisation.
**Figure 14.9** Funding options for different stages of technology development

- Research and development: Governments, Corporations
- Demonstration: Governments, Corporations, Venture capital, Angel investors
- Deployment: Governments, Corporations, Private equity, International financial institutions
- Commercialisation: Corporations, Commercial banks, Pension funds, Mutual funds, Sovereign wealth funds, Carbon funds

**Key point**

Investment needs rise significantly as technologies move along the innovation chain.

**Box 14.2** Debt financing options

Companies can raise money from a variety of debt (loan) instruments to finance their operations. Financial institutions agree to lending money to a company in exchange for a promise to repay the capital plus interest. The cost of the debt to the company is the interest charged on the loan, the level of which will in part reflect the level of risk that the debt will not be repaid.

**Senior debt**: is debt which has priority for repayment over unsecured or subordinated debt. Banks provide finance to companies to fund operations.

**Mezzanine or subordinate debt**: is debt which will be repaid after senior debt has been repaid if a company is unable to fully service its liabilities. Subordinated debt is more expensive than senior debt because the risk of default is higher. It is used when the level of senior debt available has been surpassed. The cost of a mezzanine loan is less than issuing equity to finance investments and therefore offers higher rate of returns for a project.

**Project finance**: money is borrowed to fund a specific project with repayment due from project revenues only once the project is operational. The amount of debt available is linked to the projected future revenues of the project.
Smaller corporations often have a leading role to play in developing and bringing new technologies to market, but lack the financial muscle to deploy and commercialise their developments. For this they need the support of larger corporations which have greater access to affordable financing for the scale of investments needed. Smaller firms may seek to form partnerships with large established energy companies to help them deploy their new technologies. Governments should also design and implement policies aimed at helping small- and mid-size companies gain access to affordable financing.

The borrowing capacity of the energy market is potentially very large. For example, the current market capitalisation of the global electricity generation market is estimated at USD 1.5 trillion to USD 2 trillion. If this is leveraged by a factor of two or three, a not unreasonable assumption given the relative financial stability of utilities, a total of USD 3 trillion to USD 6 trillion could potentially be raised by utilities to fund investments. Companies will only support investments in low-carbon technologies if sufficient returns from these investments seem likely to be realised.

Global fund management industry

In 2008, the global fund management industry had approximately USD 90 trillion of assets under management (Figure 14.10). The largest share of these funds comes from the United States (approximately USD 30 trillion), followed by the United Kingdom (USD 8 trillion). Conventional funds, including pension, mutual and insurance funds, accounted for about two-thirds of the assets under management. Alternative funds, dominated by private wealth assets, sovereign wealth funds (SWFs), private equity funds and hedge funds, make up the remaining USD 30 trillion. A further USD 33 trillion of private wealth is available, about one-third of which is incorporated in conventional investment management. Different types of investors have different risk and return profiles (Box 14.3).

**Figure 14.10** Global assets, 2008

Private debt securities

Stock market capitalisation

Public debt securities

Pension funds

Mutual funds

Insurance funds

Sovereign wealth funds

Hedge funds

Private equity

Private wealth*

Conventional investment management assets

Alternative investment management assets

USD trillion

0 5 10 15 20 25 30 35 40 45 50 55

Note: Approximately one-third of private wealth is invested in pension and mutual funds.

Source: IFSL (2009).

**Key point**

Conventional funds account for about two-thirds of the assets under management.
Box 14.3 Investment profiles for different classes of equity investor

Equity investments are direct investments made by investors in exchange for a share of the ownership in a company or project. Different types of equity investors can be classified according to the level of risk they are willing to take and the types of investments in companies they finance. Investments in early-stage companies are inherently more risky with most failing to reach deployment. In these circumstances, extremely high returns are required. In contrast, investments in mature companies are less risky, but also offer significantly lower returns.

Classifying investors by reference to their appetite for risk, from the highest risk takers to the most risk-adverse, investors can be seen to fall into 8 main types:

**Angel investors** are individuals who provide capital for business start-ups, usually in exchange for a stake in the company. Their investment horizon is usually 5 to 7 years. They seek very high returns of at least 10 times their initial investment over its lifetime. Angel investors invest their own capital.

**Venture capital funds** are raised from a wide range of sources with high risk appetite, and are generally used to finance new technology development. Their focus is on early-stage company development and funds are provided in exchange for equity in the company. The investment horizon ranges from 4 to 7 years. There is a high risk of failure, so venture capital funds seek internal rates of return (IRR) of 50% to 500%.

**Private equity funds** are raised from a wide range of sources with medium risk appetite. They are used to finance more mature technology, demonstrator companies or under-performing companies. Their investment horizon is shorter, typically 3 to 5 years. They seek a relatively high IRR of 25 to 50%.

**Mutual funds** are professionally managed collective investment schemes that pool money from different shareholders for investments in a variety of instruments similar to those of pension funds. They have a medium to low risk appetite and seek IRRs of around 15%.

**Sovereign wealth funds** are state-owned investment funds from countries with large foreign reserve surpluses. These funds invest in a wide range of financial assets aimed at increasing the return on their excess foreign reserves. Investment horizons are medium to long term. Their risk appetite is medium to low. They seek IRRs of around 15%.

**Infrastructure funds** are raised from institutional investors and pension funds to invest in essential assets with long life spans such as electricity networks, power plants, highways and rail systems. These investments generally provide low-risk, stable cash flows. Investment horizons are medium term from 7 to 10 years. Such funds seek IRRs of 10% to 15%.

**Insurance funds** represent insurance premiums paid and are invested by insurance institutions in order to meet the liability at maturity. The majority of these funds are from long-term insurance policies. They have a low risk appetite and seek IRRs of approximately 10%.

**Pension funds** are pooled assets from contributions to pension plans. Investments are made in a wide range of instruments including public equity via stock markets, corporate and government bonds, real estate, and other assets such as infrastructure and commodities which can generate a stable income stream. They have a low risk appetite and seek IRRs of approximately 10%.
The transition to a low-carbon economy will depend on significant funding being made available by the private sector. The global fund management industry will need to contribute a significant share of this funding. Investments by the industry into low-carbon technologies were USD 162 billion in 2009, about 20% of the total investment of USD 650 billion to USD 750 billion in the energy sector. Current financial flows from the global fund management industry into low-carbon technologies are relatively small, but there is growing interest among institutional investors to move a larger share of their portfolios into this area. This could be achieved either by investing directly in clean technology companies or through investments in large companies which have significant investments in these companies.

Pension funds account for the largest share (39%) of conventional investment management assets (Table 14.9). These are pooled assets from contributions to pension plans that are used to finance pension plan benefits. Mutual funds are professionally managed collective investment schemes that pool money from different shareholders for investment in a variety of financial instruments. Insurance assets represent insurance premiums paid to insurance companies.

Given the large sums managed by insurance companies, pension and mutual funds, a growing share of future investments in low-carbon technologies will need to be funded by these institutional investors if the funding needed to transition to a low-carbon energy sector is to be secured.

Table 14.9 Conventional investment assets, 2007

<table>
<thead>
<tr>
<th>USD bn</th>
<th>Pension funds*</th>
<th>Insurance assets</th>
<th>Mutual funds</th>
<th>Total conventional</th>
<th>% share</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>15 255</td>
<td>6 120</td>
<td>9 601</td>
<td>30 976</td>
<td>50</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>2 658</td>
<td>2 576</td>
<td>505</td>
<td>5 739</td>
<td>9</td>
</tr>
<tr>
<td>Japan</td>
<td>787</td>
<td>2 555</td>
<td>575</td>
<td>3 917</td>
<td>6</td>
</tr>
<tr>
<td>France</td>
<td>144</td>
<td>2 007</td>
<td>1 591</td>
<td>3 742</td>
<td>6</td>
</tr>
<tr>
<td>Germany</td>
<td>109</td>
<td>1 692</td>
<td>238</td>
<td>2 039</td>
<td>3</td>
</tr>
<tr>
<td>Netherlands</td>
<td>810</td>
<td>444</td>
<td>77</td>
<td>1 331</td>
<td>2</td>
</tr>
<tr>
<td>Switzerland</td>
<td>404</td>
<td>356</td>
<td>135</td>
<td>895</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>3 833</td>
<td>2 960</td>
<td>6 195</td>
<td>12 988</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>24 000</td>
<td>18 709</td>
<td>18 917</td>
<td>61 626</td>
<td>100</td>
</tr>
</tbody>
</table>

Note: Figures are for domestically sourced funds regardless of where they are managed.
* IFSL estimates based on OECD and Watson Wyatt data.
Source: IFSL (2009).

Conventional funds are best suited to finance projects which are mature and can show a stable income stream. Funds which look for higher returns are better suited to the earlier-stage financing of technology companies. Many funds are not currently set up to invest in alternative energy assets. More education is needed to promote the advantages of clean energy investments to fund trustees both from an investment viewpoint as well as from sustainability. Pension and mutual funds can influence the direction of investments made by companies they own. They should also therefore be encouraged to commit more of their funds to sustainable investment.

Private wealth

In 2007, there were just over 10 million high net-worth individuals (defined as those with over USD 1 million of assets) and over 100 000 ultra high net-worth...
individuals (defined as those with over USD 30 million of assets). Together, these individuals had total assets under management of USD 15 trillion (Merrill Lynch Capgemini, 2008). These investors make up approximately 17% of the fund management industry. In a 2008 survey by Merrill Lynch Cap Gemini, 12% of high net-worth investors and 14% of ultra high net-worth investors said they allocated part of their portfolio to green technologies and alternative energy sources.

A number of the wealthiest, including Bill Gates and George Soros, have already committed to helping support investments in low-carbon technologies. Some have set up special foundations to support a wide range of philanthropic activities including support for mitigating climate change. The Energy Foundation, a partnership of major donors including some of the largest foundations, provides support to institutions for advancing new energy technologies. Greater collaboration with, and directed promotion of low-carbon technologies to ultra high net-worth individuals could help to spur additional funding. These investors also have significant influence over pension fund managers and trustees.

Sovereign wealth funds

Countries with large foreign reserve surpluses, particularly those in Asian and oil-producing countries, aim to increase the return on their excess reserves by managing their foreign reserves more actively under special SWFs. More than 60% of the funding of SWFs comes from the export of oil and gas. Funding from the export of non-commodity goods, especially in China, Singapore and Hong Kong also makes up a large portion of SWFs.

Current assets under management by SWFs are estimated at USD 3.8 trillion. As funds under management grow, SWFs are looking at new areas for investment. Low-carbon energy technologies can offer these funds an attractive natural hedge to their oil and gas assets. The medium- to long-term investment horizon of SWFs fits well with the investment characteristics of most low-carbon technologies.

<table>
<thead>
<tr>
<th>Country</th>
<th>Fund name</th>
<th>Assets USD billion</th>
<th>Origin of funds</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAE - Abu Dhabi</td>
<td>Abu Dhabi Investment Authority</td>
<td>627</td>
<td>Oil</td>
</tr>
<tr>
<td>Norway</td>
<td>Government Pension Fund – Global</td>
<td>445</td>
<td>Oil</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>SAMA Foreign Holdings</td>
<td>431</td>
<td>Oil</td>
</tr>
<tr>
<td>China</td>
<td>SAFE Investment Co.</td>
<td>347</td>
<td>Non-commodity</td>
</tr>
<tr>
<td>China</td>
<td>China Investment Corp.</td>
<td>289</td>
<td>Non-commodity</td>
</tr>
<tr>
<td>Singapore</td>
<td>Government of Singapore Investment Corp.</td>
<td>248</td>
<td>Non-commodity</td>
</tr>
<tr>
<td>Kuwait</td>
<td>Kuwait Investment Authority</td>
<td>203</td>
<td>Oil</td>
</tr>
<tr>
<td>Russia</td>
<td>National Welfare Fund</td>
<td>179</td>
<td>Oil</td>
</tr>
<tr>
<td>China</td>
<td>National Social Security Fund</td>
<td>147</td>
<td>Non-commodity</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>Hong Kong Monetary Authority Inv. Portfolio</td>
<td>140</td>
<td>Non-commodity</td>
</tr>
<tr>
<td><strong>Total oil and gas related</strong></td>
<td></td>
<td>2,246</td>
<td></td>
</tr>
<tr>
<td><strong>Total other</strong></td>
<td></td>
<td>1,566</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>3,812</td>
<td></td>
</tr>
</tbody>
</table>

Source: WFI (2010).
Public finance mechanisms

Public finance mechanisms of various kinds have been used to successfully promote investments in the development and deployment of energy efficiency and renewable energy technologies (Table 14.11). These mechanisms help to overcome market barriers by enabling governments to share risks with the private sector and can help bridge funding gaps which occur along the technology innovation chain. Public financing mechanisms can help to leverage commercial financing by a factor of 5 to 15 (UNEP SEFI, 2008).

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

<table>
<thead>
<tr>
<th>Mechanisms</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Credit lines</td>
<td>to local commercial financial institutions (CFI) for proving both senior and</td>
</tr>
<tr>
<td></td>
<td>mezzanine debt to projects</td>
</tr>
<tr>
<td>Guarantees</td>
<td>to share with local CFIs the commercial credit risks of lending to projects</td>
</tr>
<tr>
<td></td>
<td>and companies</td>
</tr>
<tr>
<td>Debt financing</td>
<td>of projects by entities other than CFIs</td>
</tr>
<tr>
<td>Private equity (PE) funds</td>
<td>investing risk capital in companies and projects</td>
</tr>
<tr>
<td>Venture capital (VC) funds</td>
<td>investing risk capital in technology innovations</td>
</tr>
<tr>
<td>Carbon finance</td>
<td>facilities that monetise the advanced sale of emissions reductions to finance</td>
</tr>
<tr>
<td></td>
<td>project investment costs</td>
</tr>
<tr>
<td>Grants and contingent grants</td>
<td>to share project development costs</td>
</tr>
<tr>
<td>Loan softening programmes</td>
<td>to mobilise domestic sources of capital</td>
</tr>
<tr>
<td>Inducement prices</td>
<td>to mobilise domestic sources of capital</td>
</tr>
<tr>
<td>Technical assistance</td>
<td>to build the capacity of all actors along the financing chain</td>
</tr>
</tbody>
</table>


Public or government funding will be particularly important to support early technology development and demonstration where high technology risks limit the availability of investment capital from the private sector. Direct investments by governments in venture capital and private equity funds could help to more efficiently distribute innovation funding. Venture capital investments are usually around USD 5 million to USD 10 million in size. Private equity transactions are usually larger than USD 50 million to USD 100 million. Government funding may also be warranted for project development where the investment is too small to attract private investors owing to the high transaction costs linked to each individual investment.

The development of “green banks” or specialty banks for the financing of low-carbon energy technologies is an option that is being discussed in a number of countries. These special-purpose financing institutions would provide loans to support the early-stage development of clean energy companies. Initial capitalisation for these banks would come from government funds.
Export credit agencies (ECAs)

Since 2000, ECAs have supported annually on average more than USD 80 billion of investment, either through loans or loan guarantees. Within this total, support for medium- and long-term projects with repayment terms of 5 years or more amounted to USD 30 billion per year. Projects in the energy generation and distribution sectors represented on average 10% of these medium- and long-term projects. Financing from ECAs could play an important role in the future funding of low-carbon technologies, particularly in countries where credit is tight or where domestic banks are unwilling to finance new technologies.

ECAs offer credit insurance or guarantees or act as direct lenders to importers on behalf of governments. In doing so, they facilitate the export of capital goods and related services, in particular in sectors such as infrastructure, transport, manufacturing, energy production or distribution facilities. Since 2008, they have been helping to fill an important funding gap created by the current credit crisis which has sharply reduced the funding available for investments in low-carbon technologies.

Almost all exporting countries have at least one ECA, which plays a counter-cyclical role especially during moments of financial crisis when private market export financing becomes a scarce resource. ECAs have the capacity to extend medium- and long-term insurance or financing. Financial terms and conditions are regulated internationally, primarily through the Arrangement on Officially Supported Export Credits (AOSEC) (OECD, 2009).

The OECD has also offered a forum in which environmental guidelines relating to ECAs underwriting projects in sensitive sectors or sensitive areas have been agreed and implemented. Specific financial terms and conditions have been agreed for the involvement of ECAs in the support of projects in nuclear (Sector Understanding on Export Credits for Nuclear Projects [NSU]) and renewable energies and the water sector (Sector Understanding on Export Credits for Renewable Energies and Water Projects [RSU]). The RSU and NSU include repayment terms of up to 18 years and more flexible repayment schedules, together with a revised fixed interest rate regime for longer-term loans.

The RSU is designed to support renewable energy sources such as solar, wind, biomass and hydropower in preference to traditional energy projects using fossil fuels, for which stricter financial terms and conditions apply. The OECD is reviewing the RSU to broaden its scope to include climate change mitigation projects including those involving improvements in energy efficiency.

Individual underwriting decisions as well as portfolio management strategies remain in the hands of each ECA or its guardian authorities. With their financial capacity to support large capital-intensive transactions, ECAs can influence other credit providers. Within the limits of internationally agreed disciplines, any government or ECA can decide to facilitate the export of certain goods or services deemed to be more environmentally-friendly, or be more generous to low-carbon projects by offering more favourable terms.
Risk and returns

Of the USD 46 trillion in total additional investments needed to transform the energy sector, an estimated USD 20 trillion will need to be financed by large corporations and the international financial markets. Projects seeking to secure this investment capital will need to compete in the market place with other private and public competitors for capital. Similarly, within corporations, projects will need to compete with each other for limited corporate capital.

Cost of debt and equity

A company’s cost of debt is its cost of borrowing money to fund investments. This reflects a risk premium based on an assessment of the likelihood that the company will default on its loan. This assessment will depend on a number of factors including the company’s current debt level, its projected income stream and cash flow, and its relationship and reputation with the commercial banks. New lenders who do not have established banking relationships generally find it more difficult to raise finance than established lenders with good long-term repayment records. In times of low liquidity such as those that have existed since late 2008, large corporations often benefit from greater access to capital.

A firm’s cost of equity is the minimum return on investments which shareholders require. In general, it is more expensive for a firm to raise equity finance than debt finance as the risk associated with holding shares in a company is greater than that of holding debt in a company. 13

Risk versus return

When evaluating the future returns of a given project, investors and corporations judge the value of future income streams from the project by estimating its future revenues and cost streams. A discount rate is applied to the projected income based on the perceived risk of the project or the probability that the estimated income streams will fail to materialise. The higher the perceived risk of a project, the higher the discount rate applied. A risky project needs to be able to project higher profitability if it is to be competitive with lower-risk projects against which it may be competing for capital.

Governments generally apply a lower discount rate than private companies since governments can borrow more cheaply than companies. In addition, investments in the private sector generally require a much higher return than investments made by governments. Relatively low societal discount rates of around 3% are often used to analyse investment choices by governments. In the private sector, discount rates closer to 10% to 15% (or higher for particularly risky investments) are often applied to reflect private-sector costs and required returns.

13. In the case of a firm’s liquidation, a company’s debt holders are repaid first and any remaining assets after the repayment of all debt is then divided among its shareholders.
A number of factors will be considered by investors when considering projects in the power generation sector (Table 14.12). These will affect the risks associated with the successful completion of projects, and their costs and benefits in operation. The overall level of risk will affect the discount rate applied, and hence investors’ assessments of the current value of the likely returns on their investment.

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

<table>
<thead>
<tr>
<th>Technology</th>
<th>Fuel price risk</th>
<th>Permitting and licensing</th>
<th>Grid connection</th>
<th>Construction time</th>
<th>Public acceptance</th>
<th>Rate structure (assuming no feed-in tariffs)</th>
<th>CO2</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offshore wind</td>
<td>None</td>
<td>Medium</td>
<td>High</td>
<td>Medium-high</td>
<td>Medium-high</td>
<td>None</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Photovoltaic</td>
<td>None</td>
<td>Low-medium</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>None</td>
<td>None</td>
<td>High</td>
</tr>
<tr>
<td>Concentrating solar power</td>
<td>None</td>
<td>Low-medium</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>None</td>
<td>None</td>
<td>High</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Low</td>
<td>Medium-high</td>
<td>Low</td>
<td>Very high</td>
<td>High</td>
<td>Medium</td>
<td>None</td>
<td>Medium</td>
</tr>
<tr>
<td>Natural gas combined cycle</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Coal-fired</td>
<td>Medium-high</td>
<td>Low-medium</td>
<td>Low</td>
<td>Low</td>
<td>Medium-high</td>
<td>None</td>
<td>None</td>
<td>High</td>
</tr>
<tr>
<td>Fossil with carbon capture and</td>
<td>High</td>
<td>Medium-high</td>
<td>Low</td>
<td>Medium-high</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>storage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td>None</td>
<td>Low-medium</td>
<td>Medium-high</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>None</td>
<td>Medium-high</td>
</tr>
<tr>
<td>Small hydro</td>
<td>None</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>None</td>
<td>Low</td>
</tr>
<tr>
<td>Large hydro</td>
<td>None</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>None</td>
<td>None</td>
<td>Low</td>
</tr>
</tbody>
</table>

Note: Country risk is also important, but a factor that affects all technologies.
Source: IEA analysis based on discussions with various financial institutions.

Reflecting these risks, different technologies are observed to be subject to different discount rates (Table 14.13).

Table 14.13  ▶ Observed discount rates by project type

<table>
<thead>
<tr>
<th>Technology</th>
<th>Discount Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offshore wind</td>
<td>12-15%</td>
</tr>
<tr>
<td>Onshore wind</td>
<td>10-12%</td>
</tr>
<tr>
<td>Photovoltaic</td>
<td>10-12%</td>
</tr>
<tr>
<td>Concentrating solar power</td>
<td>10-15%</td>
</tr>
<tr>
<td>Geothermal</td>
<td>10-12%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>10%</td>
</tr>
<tr>
<td>Large hydro</td>
<td>8-10%</td>
</tr>
<tr>
<td>Small hydro</td>
<td>8-10%</td>
</tr>
<tr>
<td>Natural gas combined cycle</td>
<td>7-8%</td>
</tr>
<tr>
<td>Coal-fired plants</td>
<td>7-8%</td>
</tr>
</tbody>
</table>

Source: IEA analysis based on discussions with various financial institutions.
Fossil-fired technologies are already well proven. They also have shorter construction times and lower capital costs. As a result, they are subject to significantly lower discount rates than renewable power generation technologies other than hydro. Fossil-fired technology projects therefore find it easier to attract capital investment than renewable projects. As the power market evolves and more renewable technologies enter the market, the cost of these technologies should fall and confidence should rise in their performance. Discount rates for renewable technologies should therefore fall over time. And the discount rates for fossil-fired technologies, particularly those based on coal combustion without CCS, can be expected to rise to reflect the higher cost of CO₂ emissions.

Required returns

For a project to attract funding it must exceed a company’s cost of capital which is the cost to the company of raising debt or equity funding. The cost of debt can be calculated from the cost of government bonds plus a default premium. Interest rates on government bonds depend on the length of the period over which the loan is taken (Figure 14.11). The cost of equity is the cost of the risk-free rate (government bond) plus a premium for the expected risk.

The IRR of renewable energy projects needs to be higher than 10% to justify the higher risks associated with these investments. Given the large amounts of capital needed to finance the transition to low-carbon technologies, returns will need to be high enough to attract limited capital to these investments. Governments have at their disposal a range of policy and financial instruments, including loan guarantees, feed-in-tariffs, co-financing and tax credits, which they can deploy to help reduce the level of perceived risk for low-carbon generation projects.

Figure 14.11 | Interest rates on government bonds (at 6 April)

Source: Bloomberg database.

Key point

The cost of debt and required returns varies across different countries.
Policy needs

A long-term integrated policy framework is needed

Many of the most promising low-carbon technologies currently have higher initial costs than their fossil fuel competitors. Research, development, demonstration and deployment (RDD&D) is needed to lower these costs. A stable global carbon price will probably need to form the cornerstone of any successful policy in the longer term, but will not be sufficient by itself. It will need to be complemented by an integrated framework of other policies and measures. To be most effective, technology support policies need to evolve as a technology matures from the research stage to full commercialisation (see Chapter 12).

In parallel, governments need to address regulatory frameworks, such as planning and permitting systems, that create barriers to new low-carbon technologies. Public acceptance barriers also need to be overcome, for example through educating the public on the benefits of low-carbon technologies.

The development of a low-carbon economy will depend heavily on business. Many new businesses will be developed and old ones transformed. Regulation and market conditions will need to ensure that businesses and investors along the entire spectrum from RDD&D to commercialisation can secure high enough returns to justify the risk of the technology underperforming or failing at any step. The time required to develop and deploy many of the technologies needed for the energy technology transition is generally much longer than the investment horizon of most businesses and investors.

Policy predictability will be important. Policy uncertainty raises investor risk. Governments need to minimise this risk so that investors can be confident of policy stability over a longer payback period and consequently be prepared to finance a larger proportion of the needed investments. Current carbon prices are not sufficiently high or stable enough to attract the scale of the investment that is needed in new technologies. For investors, a higher and more certain carbon price would help to remove uncertainty from the carbon markets and make investment more attractive.

Many investors have already recognised the importance of climate change and a number of different initiatives such as the Institutional Investors Group on Climate Change (IIGCC), the Investor Network on Climate Risk (INCR) and the UNEP Financial Initiative have been created to promote the importance of climate change within the investment community. These initiatives are encouraging, but more active engagement between governments, industry and the financial community is needed.

Venture capital and private equity markets could help governments more effectively to distribute innovation funding. Many national governments have extensive R&D programmes for low-carbon technologies, but these technologies often fail to make the transition from the laboratory to commercialisation. Greater collaboration between government R&D institutions and the financial community
can help to advance the commercialisation of these technologies. The United States Entrepreneur in Residence programme is a good example of collaboration between government and venture capital experts working together to commercialise technologies that have been developed at national laboratories.

As new technologies move from demonstration to deployment, partnerships with large incumbent energy companies will help to raise the necessary levels of funding required for firms to scale up. In the current tight financial markets, access to affordable capital may determine whether a firm will succeed or fail. The ability of governments to fund the needed energy technology transition will be limited. Governments will need to develop coherent strategies to determine which areas of R&D they should fund, and which can be left to the private sector. Some funding will also be needed for the demonstration of capital-intensive technologies such as CCS.

Governments and industry should increase public education and raise awareness of climate change issues in the financial community. They should promote low-carbon investment opportunities to the public and private pension funds as well as to SWFs and help educate them on the strategic rationale for investment in low-carbon technologies. Many funds today are not currently set up to invest in the types of financial instruments most commonly used to fund investments in low-carbon technologies. For example, many funds can only invest in the public equity market and are not able to make direct investments or invest in the sort of debt instruments which represent the majority of current funding for low-carbon technologies.14

A number of different tax measures, including modified capital gains taxes, tax credits, tax exemptions or lower rates of tax for reinvestment in low-carbon technologies could help stimulate investment. In the United States, the tax credit scheme for low-carbon technologies has been the most effective instrument to increase financial flows to the sector. It has allowed many financial institutions with large tax liabilities to make large equity investments in projects at significantly lower required returns. Some of these have been funded at rates of return even as low as 5% to 6% as a result.

**Market structure**

The decarbonisation of the power sector will require additional investments of USD 9.3 trillion from 2010 to 2050, a 40% increase compared to the Baseline scenario. Securing such a high level of additional investments will be challenging in any market, but it will be particularly so in competitive power markets where generation has been unbundled from distribution and supply. In such markets, investment timeframes are generally very short compared to the time that is needed to plan, permit, build and start to operate a new renewable or nuclear energy plant. In contrast, vertically integrated power utilities can assume relatively lower levels of risk as they can virtually guarantee their ability to sell the power they generate through their own distribution networks.

The experience of competitive power markets has shown that investors’ decisions are based on the shorter investment timeframes that favour new investment in

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14. Additional information can be found in the summary of the workshop on Financing the energy technology revolution hosted by HSBC on 13 May 2009 in London (IEA, 2009a).
Natural gas combined cycle plants or coal plants with lower capital investments and shorter payback periods, rather than in renewable energy projects. As a result, competitive power markets are less amenable to the investments in nuclear and renewable power that will be essential in decarbonising electricity generation. Many doubt whether the current competitive market structures will be able to deliver a decarbonised power market in the timeframe needed to combat climate change.

Financing renewables

Achieving the BLUE Map scenario will require investments in renewable power generation to be half of all investments in power generation over the next 40 years. An estimated USD 12 trillion will be required for investments in renewable power generation to reach 5 700 GW of installed capacity by 2050, a fourfold increase compared to current levels (nearly fourteenfold excluding hydro). A switch from traditional power generation technologies to a greater share of renewables will significantly increase the financing needs of utilities since renewable power has higher upfront capital costs. Many renewable energy technologies require either incentives to attract investment or mechanisms to value the CO\textsubscript{2} and other environmental benefits they offer.

A number of other factors may particularly impede the financing of renewable energy projects. These may be inherent in the type of technology in question, or may vary according to project location. For example:

- A higher proportion of the cost of a renewable project is often incurred upfront than is the case with conventional, fuel-based technologies.

- Some renewable energy resources, such as wind and concentrating solar power, may be located far from demand centres. This increases the cost of interconnection. The allocation of grid connection costs is an important factor in investment decisions.

- Permitting can be a lengthy process, particularly if a project requires multiple agency approval, in some cases at local, regional and national levels of government. Projects may be delayed, and costs increased, by issues such as unforeseen public opposition or local environmental concerns.

- Perceived policy risk, driven by the possibility of negative or arbitrary changes over time in the policy environment for renewable energy technologies, can undermine investor confidence, in turn pushing up the required risk premium on investments.

Renewable energy industries are also relatively immature. Supply chain bottlenecks may lead to higher costs.

Financing renewables in developing countries

Development finance institutions (DFIs), both bilateral and multilateral, provide funding to foster the deployment of renewable energy in developing countries through project-based investments and technical assistance, typically related to capacity building.
Multilateral development banks (MDBs) are an important source of financing for joint development efforts and often offer long-term funding which may not be available in the local financial markets. Financing facilities can be designed on a case-by-case basis to support differing needs. The role of MDBs has increased since the financial crisis in providing direct lending or financial guarantees. For example in 2009, the International Finance Corporation (IFC) invested USD 720 billion in renewable energy and USD 310 billion in energy efficiency projects, which leveraged more than an additional USD 6.1 billion in investment from other sources (World Bank, 2009a). Bilateral development banks are also an important source of development finance. The German state-owned KfW Entwicklungsbank, for example, invested USD 340 million in renewable energy projects in developing economies in 2008.

DFIs are beginning to integrate public finance mechanisms into their development assistance programmes with a view to leveraging commercial investment in low-carbon energy technologies, including renewables, in developing countries. This involves loan guarantees, loan softening programmes to incentivise commercial finance institutions in developing countries to extend loans for renewable energy applications, and technical assistance grants to enhance the capacity of the main market players, for example through staff training and the development of technical standards.

Carefully designed support policy frameworks are essential if asset finance is to be used efficiently. Alongside policy support, barriers to deployment need to be identified and addressed. For example, the risk of failing to find a buyer for the electricity generated by a project can be a serious impediment to investment. Even in cases where power purchase agreements have been signed, government or DFI support may still be required to insure the credit-worthiness of the purchaser of the electricity. In some countries, assurances from the government may not be enough to meet the concerns of the investment community, for example if there is political instability or if market conditions are changing quickly, e.g. as a result of rapid inflation or deflation. Carbon-delivery guarantees such as those proposed in the World Bank’s Carbon Partnership Facility, or carbon insurance using public finance but also open to the private insurance industry, could help share the operational risks relating to renewable energy projects.

Actions that should be considered by governments to facilitate investments in renewables include:

- Establishing long-term targets for renewable energy deployment which include short-term milestones.

- Implementing support mechanisms that provide sufficient incentives to investors and ensuring that they are transparent, stable and predictable in the longer term.

- Developing effective systems to internalise the external costs of all forms of electricity production into market prices for electricity.

- Supporting investment in new grid infrastructure to facilitate the rapid connection of new renewable capacity.
Financing carbon capture and storage

CCS deployment will require additional investment between now and 2050 in the region of USD 2.5 trillion to USD 3 trillion. This is roughly 6% of the total low-carbon technology investment that is needed to achieve the outcomes implicit in the BLUE Map scenario in 2050. Of this total, the additional investment associated with carbon capture plant will be almost USD 1.3 trillion. Carbon transport infrastructure will require an estimated USD 0.5 trillion to USD 1 trillion. And carbon storage will require an additional USD 0.1 trillion to USD 0.7 trillion through to 2050. The next ten years are critical, with 100 projects required by 2020 (IEA, 2009f). This will entail an average annual additional investment of USD 5 billion to USD 6.5 billion to 2020, of which USD 3.5 billion to USD 4 billion will be required in OECD countries and USD 1.5 billion to USD 2.5 billion will be required in non-OECD countries. Currently, around USD 17 billion to USD 20 billion has been committed by governments for the deployment of CCS, well short of what is needed to get on track for the outcomes envisaged in the BLUE Map scenario.

The large-scale global deployment of CCS and other carbon mitigation technologies will be dependent on a widespread, technology-neutral, funding mechanism being in place which puts a stable cost on the emission of CO₂. Current measures are insufficient to put a price on CO₂ that will justify the additional cost of CCS. This gap will need to be significantly narrowed if CCS is to be widely implemented.

CCS technology is large scale. As a result, the investment risk associated with CCS is particularly large. It is also vulnerable to fluctuations in carbon incentives. Government support is likely to be important for the large-scale demonstration and deployment of CCS, to provide the investment security that currently does not exist in the carbon market for investments of this size.

To support investments in CCS, governments will need:

- To identify, announce and promote early demonstration project partnerships with industry.

- To provide capital and operational funding sufficient to bridge the commercial funding gap for early CCS demonstration. This may include capital grants, feed-in tariffs, carbon price guarantees, and other mechanisms (Table 14.14).

- To take action to moderate the investment risk associated with early demonstration projects. This may include project-specific agreements, long-term liability indemnification, loan guarantees, and other mechanisms.

- To implement funding mechanisms sufficient to drive the commercial deployment of CCS in the medium to long term. This may include cap-and-trade arrangements, carbon taxation, CCS mandates, emission performance standards, and other mechanisms.

In addition to these domestic actions, OECD countries will need to support the development of CCS in non-OECD countries. This will require OECD countries to contribute to the funding and support of early demonstration projects in these regions. It will also require OECD countries to work with non-OECD countries to ensure that current and future CO₂ reduction mechanisms applicable to
developing countries such as the CDM are strengthened and extended to support the deployment of CCS. Enhancement and expansion of existing multilateral and bilateral financial mechanisms, for example the World Bank and the Asian Development Bank, should also be considered.

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

<table>
<thead>
<tr>
<th>Funding Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital grants</td>
<td>Governments would make capital available to project developers to assist in the development of CCS projects. Some governments have already made capital financing available for CCS from general budgets, from specific budgets such as economic recovery packages, and from bonus credits hypothecated from ETSs.</td>
</tr>
<tr>
<td>Feed-in tariffs</td>
<td>Governments would implement new, or expand current, feed-in tariff programmes to include CCS. In a number of countries feed-in tariffs already exist for renewable energy. These should be extended to include CCS.</td>
</tr>
<tr>
<td>Price guarantees</td>
<td>Governments would set up a “contract for differences” with CCS operators in which the government would agree to supplement the market price for CO₂ reductions up to an agreed level that is sufficient to operate a CCS plant commercially. The contract could also include a provision whereby if the market price for CO₂ exceeds the agreed level, payments would be reversed.</td>
</tr>
</tbody>
</table>

### Financing nuclear power

An estimated USD 4.0 trillion will need to be invested in new nuclear capacity to reach a total capacity of 1 200 GW by 2050. With the average nuclear plant taking at least 5 to 7 years to build and costing approximately USD 3 billion to USD 5 billion per plant, the financing of nuclear projects presents challenges quite different from those inherent in the financing of most other types of power plant (NEA, 2009). The risks associated with construction delays and cost-overruns are particularly important in financing nuclear plant. Only large hydro plants entail similarly long construction times and extremely high investment costs.

Most nuclear plants under construction today have strong government involvement through government-controlled enterprises, through loan guarantees or as government-sponsored and financed projects. Few utilities have the financial muscle to develop a new nuclear power plant on their balance sheet. It is unlikely that nuclear projects will proceed on a 100% privately financed basis.

Nuclear power plants are exposed to the following factors relevant to their financing:

- **High capital costs.** They are also technically complex, increasing the risk during construction and operation.

- **Long construction periods.** This, coupled with their high capital requirements, means that they are particularly susceptible to electricity market uncertainties in the timescales in which they are expected to recoup investments or repay loans.

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15. The cost and construction time for nuclear plants varies widely, with much lower costs and construction times seen in Asia than in Europe and North America.
Political and social controversy.

The need for clear solutions and financing schemes for radioactive waste management and decommissioning.

The need to operate at high load factors.

Future nuclear investments will probably need to be financed either as consortium investments between a number of utilities or by government-controlled enterprises such as Electricité de France or Korea Electric Power Corporation (KEPCO). Government loan guarantees are likely to be an important factor in the successful financing of new nuclear projects. ECAs could also help fill some of the financing gap by offering preferred credit conditions for funding nuclear investments, e.g. under the AOSEC. ECAs have not yet had a big impact on nuclear financing.

To finance a nuclear project in partnership with one or two other companies, a company would need to have a market capitalisation of at least USD 10 billion. It would need a capitalisation of at least USD 25 billion if it was to be able to finance a project on its own. Worldwide, 15 utilities have a market capitalisation above USD 25 billion. Around 50 have a market capitalisation more than USD 10 billion.

The Finnish approach to the financing of new nuclear plant, in which a consortium of large electricity users has funded the Areva plant now under construction, may become a more common model for the financing of both nuclear and other types of generation capacity. Consortium investing enables companies to diversify their power generation capacity and technology dependence. As the risk of shortages in power generation capacity rises in many regions, electricity distribution companies are likely to increase their investments in power generation capacity to ensure a secure and forecastable cost of electricity.

To reach the levels of nuclear power envisaged in the BLUE Map scenario would require an estimated 20 to 30 nuclear projects to be constructed every year from now until 2050. This is equal to an average annual financing need of approximately USD 80 billion to USD 120 billion.

The financing of new nuclear plant may be easier in Europe than in the United States given the much larger size of European utilities compared to their United States counterparts. Europe has 10 utilities with a market capitalisation above USD 25 billion. The United States has only two. New nuclear power in the United States will be heavily reliant on government loan guarantees. The United States has already committed USD 16 billion in loan guarantees for new nuclear plants. This would cover the construction cost of about three plants. Much more funding will be needed to cover the expected construction of 10 to 13 plants in the United States within the next 20 years. In China, the government’s involvement in the power and banking sectors will facilitate financing for new nuclear build. Market structure is particularly important for funding nuclear projects. Regulated electricity markets with vertically integrated utilities are better set up for funding nuclear than competitive electricity markets with merchant utilities.

16. The 2011 United States budget proposes a tripling of the loan guarantee programme to USD 54 billion.
Governments that wish to see investment in new nuclear will need to consider:

- Providing clear and sustained policy support for the development of nuclear power, by setting out the case for a nuclear component in energy supply as part of a long-term national energy strategy.
- Working with electric utilities, financial companies and other potential investors, and the nuclear industry from an early stage to address concerns that may prevent nuclear investment.
- Establishing an efficient and effective regulatory system which provides adequate opportunities for public involvement in the decision-making process, while also providing potential investors with the certainty they require to plan investment. A one-step licensing process with pre-approval of standardised designs offers clear benefits.
- Ensuring that electricity market regulation does not disadvantage nuclear. Longer-term contracts may be necessary to provide certainty for investors.
- Enabling measures that will allow nuclear power to benefit from carbon prices.
- Providing government loan guarantees to support some of the construction risk linked to the long build time for nuclear.

**Financing low-carbon transport**

Transport accounts for the largest share of investment financing in both the Baseline and the BLUE Map scenarios. At more than USD 250 trillion between 2010 and 2050 in the BLUE Map scenario, this is about 10% higher than the expected USD 230 trillion in the Baseline scenario. Vehicles will become more expensive in the BLUE Map scenario and this increment will need additional financing.

The vast majority of LDV purchases are currently made by consumers who finance these purchases through local banks or through the car companies themselves. In the Baseline scenario, the demand for such financing will rise roughly with the rate of growth in car ownership. This has grown quickly, especially in countries such as China and India. As consumers gain wealth and shift to more expensive cars, this results in the demand for capital rising even faster than the growth in car ownership.

There will also be a need in the BLUE Map scenario for the financing of major investments in new products and infrastructure. This will include the development of a recharging infrastructure for EVs and the construction of battery manufacturing plants. These developments will each require the investment of several trillion dollars between 2010 and 2050. While this will be paid for indirectly through consumer vehicle and electricity purchases, the often quite risky upfront investments will need to be funded from other sources.

The financing of low-carbon transport investment will be influenced by the following factors:

- Relatively high transaction costs are involved in many individual buyers making many individual investments in LDVs.
Most low-carbon vehicles are currently significantly more expensive than conventional technologies and cost more than most consumers are willing to pay.

The development and deployment of low-carbon vehicles will require large capital outlays by car manufacturers, potentially ahead of market demand.

Very large infrastructure investments will need to be made to create, rather than respond to, clear market demand.

The current technology for EVs may still require significant improvements in terms of range and costs before these vehicles can move beyond niche markets.

To facilitate investment in low-carbon transport, governments may need to consider:

- Direct support for the deployment of low-carbon vehicles to reduce risks and incentivise the market.
- Support for the financing of PHEVs and EVs by encouraging public utilities or car manufacturers to lease car batteries to consumers, thereby reducing upfront costs.
- Government loan guarantees to help reduce financing risks for capital expansion to develop new product lines and infrastructure.
- The development of green banks to provide preferential lending conditions to consumers for low-carbon vehicles.
- Direct investment in infrastructure networks, where appropriate in collaboration with private investors.
Chapter 15

ACCELERATING THE DIFFUSION OF LOW-CARBON TECHNOLOGIES IN EMERGING ECONOMIES

Key findings

► If global carbon dioxide (CO₂) emissions are to be halved by 2050, non-OECD countries as well as OECD countries will have to reduce their emissions below current levels. Non-OECD countries’ economies will be growing very rapidly in this period. To cut their emissions, they will need to deploy existing and new low-carbon technologies on a very significant scale.

► Lessons can be learned from the largest emerging economies such as China, India, Brazil, Russia and South Africa. These countries are already ramping up their deployment of key low-carbon technologies and rapidly improving their capability to develop cleaner energy technologies.

► The exposure of markets and firms in emerging economies to low-carbon technologies being developed elsewhere can play an important role in the development and diffusion of those technologies. This can be achieved through the acquisition of licences, the purchase of production equipment, joint ventures, cross-border mergers and acquisitions, and training.

► Strong domestic policies that stimulate investments in clean energy, whether driven by standards and regulations or market mechanisms, are crucial. The successful absorption of foreign technology will also depend on other factors such as the country’s governance and business climate, and on infrastructure and skill capacities.

► Clear intellectual property rights (IPR) frameworks, within which firms can develop legal agreements that will enable access to new technologies, are also important. Fast tracking the patent approval of low-carbon technologies, licence of right (LOR) systems, the use of private and/or publicly facilitated patent pools, and frameworks for sharing intellectual property (IP) within collaborative RD&D may all have a part to play in strengthening the effectiveness of IP regimes in supporting technology diffusion.

► Current levels of financing for the diffusion of low-carbon technologies in non-OECD countries are insufficient to support the transition to the low carbon energy system envisaged in the BLUE Map scenario. An additional USD 400 billion a year between 2010 and 2030, rising to over USD 1 trillion a year from 2030 to 2050, will need to be invested in clean technologies in non-OECD countries.

► Both private and public investment will be needed to achieve this level of diffusion. Non-OECD governments need to structure their public finance mechanisms in ways to channel private-sector investment decisions towards low-carbon projects. Limited public funding can make a significant contribution to leveraging investment through the private sector.
Indigenous innovation capabilities can play an important part in supporting the development and diffusion of low-carbon technologies in emerging economies. Governments should set clear research, development and demonstration (RD&D) and technological priorities, and take steps to develop the technological capability needed to achieve them.

Although OECD countries still have the edge in respect of a number of cutting-edge energy technologies, some emerging economies, especially China, are rapidly improving their capability to innovate, particularly in niche areas.

Introduction

Achieving the outcomes envisaged in the BLUE Map scenario will require both the wide-scale diffusion of existing low-carbon technologies and RD&D in new, more efficient, energy-related technologies. This chapter focuses particularly on the acceleration and scale-up of such developments in non-OECD countries, especially in the largest emerging economies (Box 15.1). The objective of this chapter is to better understand the international technology flows, the barriers to technology adoption and dissemination, and the strategies to enhance low-carbon technology development and diffusion in these countries, highlighting the essential role played by domestic policies.

Box 15.1  Developing countries and emerging economies: a changing definition

A number of terms have been used to describe non-OECD countries.

“Developing countries” is a general term used to describe countries with levels of material well-being lower than those of developed countries and of countries in transition. The term is often used as a counterpart to “industrialised countries”. There is no single internationally recognised definition of industrialised or developed countries. Levels of development may vary widely within the group of so-called developing countries, some of which have relatively high average standards of living. Organisations such as the World Bank and the United Nations apply numeric definitions based on gross national income per capita to classify economies as being low-income, middle-income or high-income. Some organisations break down the group of non-OECD countries to identify smaller groupings, for example of least developed countries (LDCs), or least economically developed countries (LEDCs) or “emerging economies”. Within the United Nations Framework Convention on Climate Change (UNFCCC), developing countries are defined as the major developing countries as well as LDCs which are not included in Annex I of the Convention.

1. Countries in transition is a term used to describe countries which are developed but not yet for the most part in the OECD.
The term “emerging economies” first appeared in the early 1980s to identify middle-income emerging markets where foreign financial institutions were allowed to buy securities (Hoskisson et al., 2005). The term BRIC was coined by the investment bank Goldman Sachs in 2001 as an acronym for the four largest emerging markets (Brazil, Russia, India and China). New acronyms have come forward to broaden the list of largest emerging economies, such as BRICS (BRIC plus South Africa) and BRIICS (BRICS plus Indonesia). These countries do not traditionally share a common agenda in global negotiations on access to clean energy technologies, although they are all technically members of the 130 member-strong G-77 and China group within the United Nations (UN) negotiation framework. At the 15th Conference of the Parties to the UNFCCC in Copenhagen (COP-15), a new informal group, referred to as BASIC (Brazil, South Africa, India and China), emerged as an influential force in the negotiations.

The term emerging economies is used in this chapter to refer to BRICS-like countries (i.e. Brazil, Russia, India, China and South Africa) that have economies large enough to influence the global economy more widely. These countries will have to play an increasingly important role in low-carbon technology development and diffusion in the future.

Although the following analysis focuses primarily on the largest emerging economies, there is a need to broaden technology development and diffusion in all developing countries. The less advanced developing countries face priorities and challenges that are very different from those of the rapidly emerging economies. Even so, the approaches that are needed to help rapidly emerging countries play a part in reducing greenhouse-gas emissions are also likely to be of relevance in helping to set a low-carbon transition trajectory for less advanced developing countries to follow (Box 15.2).

The poorest developing countries are not only pursuing economic growth and social progress. They also have to adapt to the effects of climate change. Anything that slows down their development will exacerbate the effects of climate change on them. Co-ordinated and well-considered assistance needs to be provided to help them engage in reducing their own carbon emissions.

The emerging economies are increasing their exposure to new technologies through trade and foreign direct investment (FDI). These routes are unlikely to be as productive for less advanced developing countries that have generally lower levels of FDI and trade and relatively limited technological capabilities. For these countries, a more promising strategy would be to focus on facilitating and supporting access to existing clean energy technologies while in parallel strengthening domestic firms’ productive and technological capabilities. Such strategies can be reinforced by enhancing the linkages between official development assistance (ODA) and FDI.

2. See: www.g77.org/
Less advanced developing countries can secure financial support for their mitigation efforts through a number of routes. These include the bilateral and multilateral climate funds described in more detail in Chapter 14, and funds under the UNFCCC such as the Global Environment Facility (GEF) Trust Fund and the Special Climate Change Fund (SCCF). Carbon finance mechanisms also have a part to play.

A number of studies have tried to assess the sustainable energy development needs and priorities of the less advanced developing countries and the energy technologies which would most suitably help to meet those needs. A number of programmes are assisting these countries with the preparation and implementation of low-carbon emission plans and strategies. This includes support for UNFCCC activities such as the drawing-up of Technology Needs Assessments and Nationally Appropriate Mitigation Actions, and for establishing low-carbon growth or development plans, and low-carbon technology roadmaps.

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**Background**

**Non-OECD countries’ contribution to CO₂ emissions reduction in the Baseline and BLUE Map scenarios**

Between 2007 and 2050, energy demand in non-OECD countries accounts for 89% of the increase in world energy demand in the Baseline scenario (Figure 15.1). By 2050, non-OECD countries’ total emissions of energy-related CO₂ amount to 42 gigatonnes (Gt) a year, an increase of over 160% over 2007 levels. As a result of improvements in energy efficiency, CO₂ emissions per unit of GDP decline by 52% in the Baseline scenario.

The demand for energy services for mobility, heating, cooling and for specific electricity uses such as lighting or information technologies, is closely linked to economic growth. For emerging and developing economies, the challenge is to continue economic growth without locking in high emissions. For rapidly emerging economies such as China, India, Brazil and South Africa which have experienced rapid growth in fossil fuel use in recent years and are projected to continue to do so in the Baseline scenario, the decarbonising of energy systems will be particularly important.

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3. For example the “Second synthesis report on technology needs identified by Parties not included in Annex I to the Convention” prepared by the UNFCCC (2009).
4. A list of all Country Technology Needs Assessment Reports compiled so far is available at: nscp.undp.org/tna-country-list.
5. Additional information on ongoing activities in this area can be found at: en.openei.org/wiki/CLEAN; and nscp.undp.org/.
**Figure 15.1** OECD and non-OECD primary energy demand in the Baseline scenario

![Graph showing OECD and non-OECD primary energy demand](image)

**Key point**

Primary energy demand in non-OECD countries is projected to increase much faster than in OECD countries in the Baseline scenario.

Non-OECD countries make the biggest contribution to CO₂ abatement in the BLUE Map scenario (Figure 15.2). Within the non-OECD countries, a group of countries referred to collectively as other major economies (OME), which includes Brazil, China, Russia and South Africa, accounts for most of the savings by 2050. China alone makes about 27% of the total savings from the Baseline emission levels in 2050.

**Figure 15.2** World energy-related CO₂ emission abatement by region

![Graph showing world energy-related CO₂ emission abatement](image)

**Key point**

In the BLUE Map scenario, emerging economies contribute the majority of the reductions in energy-related CO₂ emissions by 2050.
To achieve the outcomes envisaged in the BLUE Map scenario, global energy-related CO₂ emissions must be reduced from the 29 Gt CO₂ emitted in 2007, to 14 Gt CO₂ by 2050. Non-OECD countries currently already emit 16 Gt CO₂. Even if OECD countries were to be able to reduce their emissions from 13 Gt CO₂ to zero by 2050, non-OECD countries would need to reduce their current emission levels by 2 Gt. This is a 12.5% reduction from today’s levels.

In practice, it is very unlikely that OECD countries will be able to become entirely carbon-neutral within this timeframe. So non-OECD countries will need to achieve much more than a 12.5% reduction from current emission levels. Achieving this, without producing additional emissions as a result of their expected very significant increases in economic growth, is an enormous challenge.

**Investment needs in emerging economies in the BLUE Map scenario**

Achieving significant overall CO₂ emissions reduction against the backdrop of a very significant growth expected in energy use will require enormous investment in both existing and new technology.

To attain the outcomes envisaged in the BLUE Map scenario, most of the additional investment between 2010 and 2050 is needed in non-OECD countries, where many of the least-cost opportunities for deploying low-carbon technologies present themselves. Average incremental investment in non-OECD countries between 2010 and 2050 amounts to USD 1.5 trillion a year, 73% more than the investment required in OECD countries. Non-OECD countries also account for the largest share of the additional investments needed by 2030, equivalent to an average of just under USD 400 billion a year, about 35% more the investment needs in OECD countries.

Investment levels in non-OECD countries rise threefold from 2030 to 2050. The additional investment needed in the OMEs will be the largest of all groups of non-OECD countries, at an average of just under USD 700 billion a year, equivalent to about 62% of all non-OECD incremental investment needs between 2030 and 2050. As described in Chapter 14, at least 53% of these investments are needed in the transport sector for alternative vehicle technologies.

There is considerable scope for deploying low-carbon technologies in emerging economies. Investment in these areas will be crucial to achieving the emissions reduction objectives of the BLUE Map scenario (Table 15.1). The shares of investment required in China and India highlight the importance of these countries in this regard.

**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)

<table>
<thead>
<tr>
<th></th>
<th>Carbon capture and storage</th>
<th>Electric and plug-in hybrid electric passenger light duty vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-OECD</td>
<td>447</td>
<td>6 085</td>
</tr>
<tr>
<td>China</td>
<td>1 185</td>
<td>2 670</td>
</tr>
<tr>
<td>India</td>
<td>68</td>
<td>1 425</td>
</tr>
</tbody>
</table>

Sources: Compiled from IEA (2009a and 2009b).
Diffusion of low-carbon technologies in emerging economies

Non-OECD countries have traditionally been assumed to access new technologies as a result of technology transfer from industrialised countries to non-industrialised countries (Box 15.3). This reflects the assumption that technological knowledge generally flows from countries with a higher technological capacity to countries with a lower one. Recently, more attention has been given to the concept of technology diffusion, a process which reflects the increasing two-way flow of technologies among and between OECD and non-OECD countries, and of the role of emerging economies as strong manufacturing bases and export markets in their own right.

Box 15.3 Technology transfer: history and initiatives

The Intergovernmental Panel on Climate Change (IPCC) defines technology transfer as the broad set of processes that govern the flows of knowledge, experience and equipment among different stakeholders (IPCC, 2000). Technology transfer encompasses the technology hardware (physical devices, equipment and infrastructure), the “software” aspects (knowledge and processes, also referred to as know-how), and the “orgware” (institutional frameworks and regulation) that underpin it (IIASA, 2009). Private firms, governments, financial institutions, non-governmental organisations (NGOs), community groups, international institutions, research organisations, consultants and individual consumers all have a part to play, each having their own motivations, interests and negotiating power.

Most technology transfer occurs within the private market through voluntary transactions between firms or across country boundaries within multinational corporations. Access to foreign technology can also be gained outside normal market mechanisms, for example through imitation or reverse engineering. Technology transfer may also be led by governments through such programmes as ODA, or may be achieved through education, return migration and training (Maskus, 2004).

The UNFCCC and the Kyoto Protocol have specific provisions which recognise the need to encourage international technology transfer. These include financial mechanisms such as specialised funds and market-based initiatives. At COP-15 in Copenhagen, the Parties to the UNFCCC prepared a draft decision to expand international collaboration at all levels in the technology development cycle. This envisaged establishing a new technology mechanism that would promote and channel finance to national and collaborative technology initiatives, catalysing the development and use of technology roadmaps or action plans, and enhancing co-operation between national, regional and international technology centres and institutions. This decision has not been adopted. Additional initiatives outside the UN framework have also emphasised technology transfer, such as the G8+5 process (involving the G8 member countries plus Brazil, China, India, Mexico and South Africa), the Asia-Pacific Partnership on Clean Development and Climate (APP), the Major Economies Forum on Energy and Climate (MEF), and a number of bilateral partnerships.

6. The G8 countries are the United States, Russia, the United Kingdom, France, Germany, Japan, Italy and Canada.
Technology moves between countries in a variety of ways, depending on the type of technology, its stage of maturity, and the recipient country’s capacity to absorb, apply and adapt it. The speed and effectiveness of technology diffusion will depend on such issues as whether the technology is under patent or trade secret protection or is in the public domain; whether the technology is a mature technology that can be relatively easily absorbed or a cutting-edge technology that involves extensive know-how and tacit skills for effective implementation; and whether the technology is already commercialised or requires further development through, for example, R&D collaboration. Insofar as emerging economies want to stimulate or steer technology diffusion beyond the level that markets would achieve on their own, they need to devise their own strategies and priorities by assessing the technology pathways available to them and adapting or designing suitable policies.

This chapter provides an overview of technology flows related to low-carbon technology diffusion. The analysis is subject to a number of important limitations that have to be taken into account. More work needs to be done to improve analysis of the trends in low-carbon technology diffusion (Box 15.4).

**Box 15.4 ▶ Tracing international technology flows: precision of the data and the need for more certainty**

Measuring international technology flows is complex. It often focuses on hardware diffusion, as the diffusion of software elements such as education and training are much more complicated to identify and assess.

This chapter uses data on patents, trade flows and international financial flows to draw some general conclusions about the diffusion of low-carbon technologies at global level. These data should be used with caution because:

- **Data on patents can be a misleading measure of technology diffusion in the absence of information on national patent laws and the extent to which patents are actually exploited. Patents are only one of the means of protecting innovation, and certain types of innovation are less suited to patenting than others. Although they are changing quickly, developing countries have less of a history of filing patents.**

- **Commodity classifications for low-carbon technologies are insufficiently granular to provide a robust basis for the measurement of trade transfer flows.**

- **Reliable data on international finance are particularly difficult to identify. This is due to inconsistencies and/or incomplete reporting by OECD countries of financial support, limited and incomplete information on multilateral development banks (MDBs) and other non-UNFCCC funds, lack of primary data on financial flows under the Kyoto Protocol’s clean development mechanism (CDM), and uncertainties regarding estimates of private financing for the deployment and diffusion of low-carbon technologies. For example, sectoral data on FDI inflows are only available periodically from the United Nations Conference on Trade and Development (UNCTAD) and at a level of aggregation that makes it difficult to extract trends in investment in low-carbon technologies.**

Although the data presented in this chapter are useful as indicators of approximate relative magnitudes, data quality clearly needs to be improved.
Low-carbon technology flows

The international technology diffusion of climate-friendly inventions, as measured by the share of inventions that are patented in at least two countries, has historically mostly taken place between OECD countries (Figure 15.3). From 2000 to 2005, 73% of exported inventions have diffused in this way. Exports from OECD countries to emerging economies, although only 22% of the total, are growing rapidly, with China alone attracting about three-quarters of the transfers. Exports from emerging economies to OECD countries account for 4% of all exported inventions and are also growing (Dechezleprêtre et al., 2010).

Figure 15.3 International trends in technology diffusion

Source: Dechezleprêtre et al. (2008).

Key point

In the last decade, the role of non-OECD countries in low-carbon technology diffusion has grown.

The rate of diffusion of low-carbon technologies to emerging economies has increased rapidly. China is the world’s largest producer and consumer of solar water heating, accounting for 65% of all installations, and recently became number three in total wind power capacity (The Climate Group, 2009). India ranks fifth in terms of cumulative wind power capacity (REN21, 2009). In Brazil, ethanol accounted for more than 52% of fuel consumption by light-duty vehicles (LDVs) in 2008 (UNEP, 2009). Each of those nations is among the top ten countries in installed renewable energy capacity (Table 15.2). Installed clean energy capacity has increased rapidly in these countries in the last five years, with China growing by 79%, India by 31%, and Brazil by 14% (The Pew Charitable Trusts, 2010).

7. Encompassing wind, solar, geothermal, ocean energy, biomass, waste-to-energy, hydropower, methane destruction, climate-friendly cement, energy conservation in buildings, motor vehicle fuel injection, energy-efficient lighting and CCS.

8. This measure is based on the assumption that a firm only patents an invention when it plans to exploit it commercially.
Table 15.2  Top 10 countries in renewable energy capacity, 2009

<table>
<thead>
<tr>
<th>Country</th>
<th>Renewable energy capacity (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>53.4</td>
</tr>
<tr>
<td>China</td>
<td>52.5</td>
</tr>
<tr>
<td>Germany</td>
<td>36.2</td>
</tr>
<tr>
<td>Spain</td>
<td>22.4</td>
</tr>
<tr>
<td>India</td>
<td>16.5</td>
</tr>
<tr>
<td>Japan</td>
<td>12.9</td>
</tr>
<tr>
<td>Rest of EU-27*</td>
<td>12.3</td>
</tr>
<tr>
<td>Italy</td>
<td>9.8</td>
</tr>
<tr>
<td>France</td>
<td>9.4</td>
</tr>
<tr>
<td>Brazil</td>
<td>9.1</td>
</tr>
</tbody>
</table>

*This comprises 22 countries: Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia and Sweden.


Emerging economies have in a number of cases acquired production capabilities through the integration of local producers into global value chains often co-ordinated by firms based in OECD countries. This has enabled emerging economies rapidly to specialise in several clean energy technologies and to export to both OECD and non-OECD countries (Box 15.5). China is the largest exporter of wind turbine towers, of static converters that change solar energy into electricity, of solar batteries for energy storage in off-grid photovoltaic systems, and of the concentrators used to intensify solar power in solar energy systems (WTO, 2009).

Box 15.5  Examples of South-South technology transfer

The two major Chinese manufacturers of heavy electric machinery, Shanghai Electric and Dongfang Electric, have received orders from India for large-scale supercritical coal-fired power plants. Dongfang Turbine has secured an order for the main machinery for a natural gas combined cycle (NGCC) power plant in Belarus (Ueno, 2009). Shanghai Power Corporation’s overseas sales account for 45% of the company’s total revenue, up from 13% in 2006. A majority of the increase comes from the export of supercritical and sub-supercritical technologies to developing countries (Tan and Gang, 2009).

Brazil’s state-controlled oil company, Petrobras, has secured contracts for ethanol imports and technology access with a range of African countries, including Senegal, Nigeria, Mozambique and Angola. Nigeria will acquire technical expertise alongside its ethanol imports, so that it can start implementing its 10% ethanol blend policy even before local ethanol manufacturers come on stream. Brazil is also investing USD 100 million in the construction of an ethanol plant in Angola (GRAIN, 2007).

Some companies based in emerging economies are currently recognised as global industry leaders in specific low-carbon technologies. The world’s best-selling developer and manufacturer of on-road electric cars is an Indian venture, the Reva
Electric Car Company. It has successfully penetrated a number of national markets, including in high-income countries (World Bank, 2009a). Beijing Jike Energy New Technology Development Co. has developed geothermal heat pumps (GHP) based on US ground-gas technologies. It is now an industry leader and holds patents for its ground-coupling pipe optimisation and burial technology, and for the software it has developed for ground-gas GHP systems design (The Climate Group, 2009).

In some cases, emerging economies’ growth in low-carbon technology expertise, such as solar PV expansion in China and the notable success of Brazil in biofuels, has resulted from strong domestic policies aimed at strengthening indigenous technology development. More often, access to technology has been facilitated through the acquisition of licences from multinational firms. For example, one of China’s largest wind technology manufacturers, Goldwind, initially acquired access to wind technology by purchasing licences from German wind turbine maker Vensys.9 China has also acquired licences to produce boilers, turbines, and generators for supercritical and ultra-supercritical coal-fired power plants. In other cases, technology has diffused through joint ventures. For example, BP Solar’s joint venture with Tata Group has driven solar PV activity in India. Toyota’s joint venture with China’s leading car manufacturer Sichuan FAW has resulted in the production of the Prius hybrid car in China. And a number of joint-venture efforts between Japanese and Indian companies have enabled the production in India of high-efficiency, low-emission coal technologies.10 Access to low-carbon technologies has also been facilitated by the purchase of production equipment or through the strategic acquisition of firms based in OECD countries (Box 15.6). Although technology may not be the primary driver in many of these purchases, technology diffusion is often a consequence. The establishment of R&D centres in developed countries by firms from non-OECD countries also enables diffusion. For example, the Indian wind turbine manufacturer Suzlon has expanded its R&D facilities in several countries in Europe, and engaged into collaborative R&D (Ueno, 2009; Barton, 2007; Lewis, 2007; MEF, 2009).

Box 15.6  Acquisition of foreign technologies through merger and acquisition

The Indian wind turbine manufacture Suzlon, founded in the 1990s and now the world’s fifth-largest turbine manufacturer, operates in 20 countries around the world. It supplies turbines to projects in Asia, North and South America and Europe. A key part of the company’s strategy has been to acquire majority shares in European technology companies. Following the purchase of rotor-blade designer AE-Rotor Techniek in 2000, in 2006 Suzlon became the largest net buyer of companies abroad through the acquisition of Belgian gearbox manufacturer Hansen International for USD 565 million (UNEP, 2007). Suzlon has subsequently sold more than half of its previous 61% stake in Hansen, in large part to pay for the acquisition of the German-based company RePower, one of the leading manufacturers of onshore and offshore wind turbines, which was completed in 2009 (Cleantech Group, 2009). Before acquiring RePower, Suzlon entered into a joint venture with the company to fund a joint Renewable Energy Technology Centre in Germany.

9. Goldwind also acquired a 70% stake in Vensys and its subsidiary companies.
10. For example, L&T-MHI Boilers Private Ltd./L&T Turbine Generators Private Ltd., covering supercritical boiler and turbine technologies, and Toshiba JSW Turbines & Generator Private Ltd., covering 500 MW to 1 000 MW supercritical steam turbines and generators.
The three major channels through which technologies spread internationally are international trade, FDI and licensing (Maskus, 2004). All have increased substantially in recent decades, especially in developing countries. The choice of channels depends on the technology being diffused and on the characteristics of the countries and firms involved in the process. Some emerging countries have adopted a strategy of technology acquisition strongly based on licensing. For instance, China has encouraged joint ventures, as opposed to FDI, to maximise technology access by local firms. This strategy is likely to work only for countries with sufficient market power, and carries the risk of transferring sub-standard technologies.

Uncertainties about the policy environment in non-OECD countries may lead multinationals to use licensing as a substitute for FDI. Factors such as the level of intellectual property protection may impact multinationals’ willingness to license the technology for fear of it being copied by domestic firms, but it may also depend on the level of development, the market structure and the imitation capability in the host country. For example, there is evidence that fears about the copying of technologies have contributed to companies’ reluctance to diffuse clean coal combustion technologies to China (Vallentin and Liu, 2005).

**Trade flows**

The trading of low-carbon capital and intermediate high-tech goods and services across borders carries some potential for supporting positive technology diffusion between countries.

Statistics on world trade in this field are very imprecise.\(^\text{11}\) Even so, data from the United Nations Commodity Trade Statistics Database (UN COMTRADE) can be used to illustrate recent trends in renewable energy technologies in BRIC countries (Table 15.3). The data show that all BRIC countries increased both imports and exports of a range of renewable energy products and associated goods in 2005-08, and that some of them are switching from being importers to net exporters of these technologies.\(^\text{12}\) Comparison of the 2005 and 2008 data shows a shift from a negative value of USD 11.5 billion to a positive value of almost USD 4.2 billion in three years (Table 15.3). The bulk of this change is attributable to China, as it managed to change its balance by more than USD 18 billion, to reach a positive value of USD 8.5 billion. Imports of renewable energy technologies to China increased by 56% from 2005 to 2008, while exports increased by 337%, reaching USD 37.2 billion in 2008.

India showed the largest increase in renewable energy technology exports among BRIC countries. Imports into India increased by 172% between 2005 and 2008, amounting to USD 2.8 billion in 2008, while exports increased by 494%, reaching

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11. This is because the sector or commodity classification systems do not have stand-alone customs codes for all low-carbon technologies, and because a number of “dual-use” categories include both environmental and non-environmental products.

12. This analysis focuses mainly on products and components used for wind, solar (both PV and solar thermal) and hydro. It excludes biofuels and geothermal.
USD 3 billion in 2008. Data for Brazil and Russia show the opposite trend to that of China and India. Brazil more than doubled its imports of renewable energy technologies, while exports only increased by 57%, resulting in net imports to the value of USD 1.1 billion in 2008. Russia had the sharpest increase of imports among BRIC countries, from USD 1.2 billion in 2005 to USD 4.4 billion in 2008, while exports doubled to reach nearly USD 1 billion in 2008.

<table>
<thead>
<tr>
<th>Table 15.3</th>
<th>Net exports* in BRIC countries related to renewable energy technologies (USD billion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>−0.35</td>
</tr>
<tr>
<td>Russia</td>
<td>−0.71</td>
</tr>
<tr>
<td>India</td>
<td>−0.50</td>
</tr>
<tr>
<td>China</td>
<td>−9.92</td>
</tr>
<tr>
<td>BRIC totals</td>
<td>−11.49</td>
</tr>
</tbody>
</table>

*Exports minus imports.

Source: Based on UN Comtrade database (2009).

### International financial flows of low-carbon energy technologies

Several types of international financial flow support technology diffusion. The main categories of financing include private flows, official flows through bilateral and multilateral ODA, and flows under the UNFCCC and the Kyoto Protocol through the CDM and the funds administered by the GEF. There are a number of different sources of data and information on these flows. For example, data on FDI enable the tracking of aggregated and occasionally sector-level flows from one country to another, and provide information on broad financial trends. Many studies have attempted to estimate investment and financial flows to address climate change, and have provided indications of the support available for mitigation technologies (UNFCCC, 2007, 2008 and 2009; Corfee-Morlot, Guay and Larsen, 2009). The analysis provided below builds on these studies but specifically focuses on low-carbon energy technologies.

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13. Analysis from Corfee-Morlot, Guay and Larsen (2009) highlights a number of limitations to the use of FDI data, as not all investments result in new production. In particular: funds moved from parent firms to their foreign affiliates do not represent the actual use of funds; most mergers and acquisitions do not add new production; net data may hide real investment trends; and the increasing role of offshore financial centres blurs the final destinations of investment. Furthermore, while it is possible to measure the amount of FDI, it is no guarantee that the quantity of FDI investments is in proportion to the amount of knowledge acquired by the recipient country.
Private flows

Global private investment for clean energy technologies is a small share of total private investment, but is growing quickly. In 2008, for the first time investment in new renewable energy power generation capacity, including large hydro, was greater than investment in fossil fuel generation (UNEP, 2009). Global private investments in energy efficiency and renewable energy increased from USD 33.2 billion to USD 155 billion between 2004 and 2008, with wind, solar and biofuels attracting most investment. Together, these three sectors accounted for 86% of new investment in 2008 (UNEP, 2008 and 2009).

Private investment in clean energy in non-OECD countries has also grown rapidly, from USD 1.8 billion in 2004 to USD 36.6 billion in 2008. In 2008, China led investment in Asia with USD 15.6 billion of new investment, mostly in new wind projects and in some biomass plant. New investment activity in India grew by 12% from 2007 to USD 3.7 billion in 2008, with the largest portion of new investment going to the wind sector. Total financial investment in Brazil was USD 10.8 billion in 2008, an increase of 76% over 2007, with ethanol representing 70% of new renewable investment in the country (UNEP, 2009). With clean energy investments up more than 50% in 2009, China for the first time accounted for more investment in clean energy than any other country, pushing the United States into second place (The Pew Charitable Trusts, 2010). Developing countries’ share of all new global financial investments in clean energy increased from 13% in 2004 to 31% in 2008. This is still well below the level that is needed to be on a path to achieve climate stabilisation.

Foreign Direct Investment (FDI)

FDI represents the largest source of private climate-related investment, especially in OECD countries, but also in those non-OECD countries where relatively strong enabling conditions exist for investment. For LDCs, official development assistance may be more important than FDI as a source of financing. The UNFCCC (2007) estimates that ODA funds represent less than 1% of investment globally, but account for 6% of investment in LDCs.

FDI inflows to developing economies are estimated to have reached USD 517 billion in 2008. The four BRIC countries are among the top five investment destinations for FDI.14 BRIC countries have the benefit of large local markets that are growing quickly, and in many cases relatively cheap labour. India benefits particularly from the presence of competent suppliers and skills and talent, and Brazil is frequently mentioned for its incentives (UNCTAD, 2009a and 2009b). In 2005, FDI investment in CO2 mitigation projects was about USD 12 billion in OECD countries and almost USD 7 billion in non-OECD countries (UNFCCC, 2008).

FDI flows are very important to developing countries in sectors such as mining, manufacturing, electricity, gas and water, and transport, storage and communications. In 2007, FDI accounted for 12.6% of total gross fixed capital

14. Based on UNCTAD’s “World Investment Prospect Survey 2009-2011” which estimates favourite investment destinations being China, the United States, India, Brazil and the Russian Federation (in that order).
formation in electricity, gas and water in developing countries, three times the amount invested through multilateral and bilateral aid programmes (Table 15.4). It is not, however, possible to distinguish from these data the investments that result in lower CO₂ emissions from those that may increase them.

**Table 15.4** Sources of investment in gross fixed capital formation in non-OECD countries, 2000

<table>
<thead>
<tr>
<th>Sectors</th>
<th>FDI flows %</th>
<th>International borrowing %</th>
<th>Bilateral ODA %</th>
<th>Multilateral ODA %</th>
<th>Domestic* %</th>
<th>Total GFCF** USD billion</th>
</tr>
</thead>
<tbody>
<tr>
<td>All sectors</td>
<td>10.2</td>
<td>3.8</td>
<td>0.7</td>
<td>0.4</td>
<td>85.0</td>
<td>1 654</td>
</tr>
<tr>
<td>Agriculture, hunting, forest, fishing</td>
<td>1.7</td>
<td>0.2</td>
<td>0.8</td>
<td>0.5</td>
<td>96.9</td>
<td>68</td>
</tr>
<tr>
<td>Mining and quarrying</td>
<td>17.8</td>
<td>0.0</td>
<td>0.4</td>
<td>0.1</td>
<td>81.8</td>
<td>69</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>15.3</td>
<td>0.5</td>
<td>0.1</td>
<td>0.0</td>
<td>84.1</td>
<td>443</td>
</tr>
<tr>
<td>Electricity, gas and water supply</td>
<td>12.6</td>
<td>5.8</td>
<td>0.6</td>
<td>3.3</td>
<td>77.7</td>
<td>67</td>
</tr>
<tr>
<td>Transport, storage and communications</td>
<td>8.9</td>
<td>1.5</td>
<td>1.7</td>
<td>1.4</td>
<td>86.4</td>
<td>248</td>
</tr>
</tbody>
</table>

* Because some FDI are partially financed from local host country sources, the distinction between international and domestic sources is not entirely accurate.

** The investment in new physical assets during a given year is reported in the national accounts of countries as gross fixed capital formation (GFCF).

Source: Brewer (2009).

**Official flows**

**Bilateral official development assistance**

Bilateral ODA is monitored by the OECD Development Assistance Committee’s Creditor Reporting System (DAC-CRS). Under the OECD system, ODA is defined as financial support that has as its main objective the promotion of the economic development and welfare of developing countries. Recent analysis shows that bilateral ODA in the period 2003 to 2007 showed large net increases, and averaged about USD 105 billion a year (Corfee-Morlot, Guay and Larsen, 2009).

Data from the OECD DAC-CRS show that bilateral ODA in 2008 for eight low-carbon technologies amounted to USD 1.2 billion, with hydro accounting for about a third of the total, and China receiving around 9% of the flows (Table 15.5). It is assumed that ODA covers only the incremental cost of those investments.

15. The Development Assistance Committee (DAC), in which bilateral donors work together to co-ordinate development co-operation, is made up of 23 OECD members (22 countries and the European Commission).

16. Power generation/renewable sources; nuclear power plants; hydro-electric power plants; geothermal energy; solar energy; wind power; ocean power; and biomass.
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>
<thead>
<tr>
<th></th>
<th>Power</th>
<th>Nuclear</th>
<th>Hydro</th>
<th>Geothermal</th>
<th>Solar</th>
<th>Wind</th>
<th>Ocean</th>
<th>Biomass</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>0.91</td>
<td>1.76</td>
<td>0.06</td>
<td>0</td>
<td>0.36</td>
<td>0</td>
<td>0</td>
<td>0.13</td>
<td>3.22</td>
</tr>
<tr>
<td>China</td>
<td>28.83</td>
<td>24.44</td>
<td>43.63</td>
<td>0</td>
<td>8.67</td>
<td>2.36</td>
<td>0</td>
<td>1.62</td>
<td>109.55</td>
</tr>
<tr>
<td>India</td>
<td>3.68</td>
<td>0.03</td>
<td>19.92</td>
<td>0</td>
<td>1.14</td>
<td>0</td>
<td>0</td>
<td>0.02</td>
<td>24.79</td>
</tr>
<tr>
<td>South Africa</td>
<td>0.43</td>
<td>0.18</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
<td>0.29</td>
<td>0</td>
<td>0.05</td>
<td>1.05</td>
</tr>
<tr>
<td>Developing countries</td>
<td>158.5</td>
<td>379.94</td>
<td>399.64</td>
<td>30.76</td>
<td>175.6</td>
<td>0.01</td>
<td>17.39</td>
<td>1 191.84</td>
<td></td>
</tr>
</tbody>
</table>

Source: Based on OECD DAC-CRS database (2009).

Although funding from bilateral ODA in support of climate-friendly technologies is growing, it is becoming increasingly difficult to build support for international finance assistance and for subsidising technology diffusion to nations such as China and India which hold substantial capital reserves and whose sovereign wealth funds and firms are buying US and EU firms. Investment in some sectors, e.g. biofuel production, may be easier to secure than in others, such as steel, where emerging economy-based producers are in direct competition with OECD steel industries, or cement, where emerging economies often have more modern kilns and run cleaner technology than developed countries. ODA should still play a role in emerging economies to demonstrate technology to scale, to create policy frameworks and to build capacity.

Export credits

Governments often promote exports of private technology by making available export credits which provide guarantees against potential risks. Long-term export credits to developing countries are provisionally estimated at USD 31.2 billion on average annually between 2002 and 2008, of which some USD 2.9 billion annually on average went to the energy sector (Corfee-Morlot, Guay and Larsen, 2009). Low-carbon energy technologies including nuclear, hydro, geothermal, solar, wind, tidal and biomass accounted for only a small share of this support, representing just over USD 534 million on average a year, i.e. about one-sixth of total export credits in the energy sector.

Multilateral official development assistance

MDBs and UN bodies are observers and not members of the DAC. Reporting to the OECD/DAC on multilateral ODA only takes place on a voluntary basis. As a result, multilateral ODA information is largely absent from the OECD/DAC-CRS database and multilateral ODA expenditure in 2008 for low-carbon technologies appears to amount to only USD 0.3 billion (Table 15.6). This is almost certainly a significant underestimate of total multilateral low-carbon investments.
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>
<thead>
<tr>
<th></th>
<th>Power</th>
<th>Nuclear</th>
<th>Hydro</th>
<th>Geothermal</th>
<th>Solar</th>
<th>Wind</th>
<th>Ocean</th>
<th>Biomass</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.18</td>
</tr>
<tr>
<td>China</td>
<td>0.23</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.23</td>
</tr>
<tr>
<td>India</td>
<td>10.3</td>
<td>N/A</td>
<td>N/A</td>
<td>0.17</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>1.27</td>
</tr>
<tr>
<td>South Africa</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Developing countries</td>
<td>99.69</td>
<td>78.21</td>
<td>39.32</td>
<td>0.17</td>
<td>23.83</td>
<td>2.55</td>
<td>N/A</td>
<td>12.56</td>
<td>256.33</td>
</tr>
</tbody>
</table>

* See footnote 16.

Note: N/A refers to data that are not available.
Source: Based on OECD DAC-CRS database (2009).

The World Bank estimates that investments in clean energy and energy efficiency activities in developing countries by MDBs have increased significantly in recent years, reaching an average of USD 4.1 billion annually for the years 2006-07 from an annual average of USD 2.2 billion between 2000 and 2005 (World Bank, 2006). This excludes the Climate Investment Funds (Box 15.7). The World Bank group alone is estimated to have committed USD 2.9 billion to low-carbon projects or programmes in 2008 (World Bank, 2009b). On the assumption that the World Bank accounts for about 70% of total MDB concessional financing (OECD, 2007), the total investment by MDBs might be expected to be of the order of USD 4.1 billion.

Box 15.7  Climate Investment Funds (CIFs)

In late 2008, the MDBs together with developed and developing countries created the Climate Investment Funds (CIFs) to which donor countries have pledged funding over three years amounting to USD 6.1 billion. The CIFs include two new trust funds. One of these, the Clean Technology Fund (CTF), focuses on scaling up investments to support the demonstration, deployment and diffusion of low-carbon technology projects in developing countries. The CTF offers highly concessionary financing, with interest rates of 0.25% and 0.75% for 20 and 40 years. But CTF lending is conditional on co-finance from a blend of grant financing and other bilateral and multilateral development lending. The main areas of focus of the CTF are the power sector (renewable energy and highly efficient technologies), the transport sector (efficiency and modal shifts), and energy efficiency (in buildings, industry and agriculture). By December 2009, clean investment plans had been submitted to the CTF by nine countries with a total proposed CTF financing of USD 2.95 billion. Given the size of the fund, this initiative could mean significant new sources for promoting technology diffusion in developing countries. The other CIF trust fund, the Strategic Climate Fund, is broader and more flexible in scope and will include adaptation as well as mitigation activities. Additional information can be found at: www.climateinvestmentfunds.org/cif/
Flows under the UNFCCC and the Kyoto Protocol

The most important mechanisms supporting technology diffusion to developing countries under the UNFCCC and the Kyoto Protocol are the CDM and the funds administered by the GEF, the financial mechanism of the UNFCCC.

Analysis of project design documents suggests that 36% of CDM projects claim to involve some form of technology transfer (Sers and Haites, 2008). These projects account for 59% of the annual emissions reduction claimed by all CDM projects. Further analysis has shown that 279 out of the 644 CDM projects registered up to May 2007 involve transfers of greenhouse-gas mitigation technologies (Dechezleprêtre, Glachant and Ménière, 2008). Very few of these projects involve the transfer of equipment alone. Most also include the transfer of knowledge and operating skills. Wind power projects often involve technology transfer. Projects in areas such as electricity production from biomass or energy efficiency measures in industry rely mainly on domestic technologies.

Under the CDM, host governments can stipulate that projects contain some level of technology transfer as a condition for national approval. China does this. Other countries do not. So the share of projects claiming elements of technology transfer varies considerably. China also requires that the ownership of a foreign party in any CDM project shall not exceed 49%. As a result, the owner of a CDM project can only be a Chinese-owned enterprise or a joint venture in which the Chinese partner holds the majority stake. This measure represents a clear disincentive for foreign high-tech firms to enter the market by engaging in CDM activities. The project-specific nature of the CDM also limits the extent to which it can promote cumulative technological learning.

There is as yet no agreed method for assessing the investment flows generated by the CDM. It is therefore not possible to determine the proportion of CDM investment that flows to developing countries from OECD countries. Different methodologies for assessing this result in very different estimates. Depending on the methodology used for measuring financial flows, estimates of the level of annual financing generated from the CDM could range between USD 6.5 billion and USD 33 billion.17

Experience with both the GEF and the CDM has shown that limited public funding can make significant contribution to leveraging investment through the private sector. The GEF has been in operation since 1991. Between 1991 and 2008 it provided just over USD 2.4 billion in grants to projects related to climate change and leveraged on average about seven times more investment capital through co-financing.18 Most of the GEF resources have been allocated to renewable energy, energy efficiency, low-carbon technologies and sustainable transport projects. Capacity-building is a part of all projects. Funding of GEF climate change projects averaged about USD 163 million a year between 2003 and 2006.

17. These figures are based on recent estimations of the size of the CDM market by the World Bank (2008).
18. The financing leveraged by the GEF for mitigation projects has averaged USD 1.15 billion per year and amounted to USD 1.5 billion in 2007 (UNFCCC, 2009). For additional information, see GEF project database, available at: gefonline.org/home.cfm
Summary of international financial flows for diffusion of low-carbon technologies

Investment in low-carbon technologies in developing countries is estimated to be between USD 56 billion and USD 83 billion a year (Table 15.7). These investment flows fall well short of the levels of investment that are needed in the deployment of low-carbon energy technologies in developing countries if the ambitions of the BLUE Map scenario are to be achieved.

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

<table>
<thead>
<tr>
<th>Source of financing</th>
<th>Estimated annual investment (USD billion)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Private flows</strong></td>
<td></td>
</tr>
<tr>
<td>Private investment</td>
<td>43.6</td>
</tr>
<tr>
<td><strong>Official flows</strong></td>
<td></td>
</tr>
<tr>
<td>Multilateral ODA</td>
<td>4.1</td>
</tr>
<tr>
<td>Bilateral ODA</td>
<td>1.2</td>
</tr>
<tr>
<td>Export credit agencies</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Flows under the UNFCCC</strong></td>
<td></td>
</tr>
<tr>
<td>GEF</td>
<td>0.2</td>
</tr>
<tr>
<td>CDM</td>
<td>6.5 – 33</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>56.1 – 82.6</td>
</tr>
</tbody>
</table>

Sources: Compiled from UNFCCC (2008); UNEP (2009); Corfee-Morlot, Guay and Larsen (2009) and OECD DAC-CRS database (2009).

In the BLUE Map scenario, additional investments in clean technologies in non-OECD countries are approximately USD 400 billion a year between 2010 and 2030, rising to over USD 1 trillion a year from 2030 to 2050. Most of this funding will have to be mobilised through the private sector. Although estimates of the private financing for deployment and diffusion of low-carbon technologies are very uncertain, it is estimated that between 89% and 93% of current financing comes from the private sector. Non-OECD governments need to take account of the importance of the private sector’s involvement in technology diffusion when setting their domestic policies, and will need to seek to stimulate investment in appropriate technologies by encouraging private-sector investment in low-carbon projects where they can.

Private-sector investment decisions are directly influenced by the conditions in the country in which firms are considering investing. They will take account of a wide range of factors, including the size and competitiveness of the market, available labour skills and costs, physical and telecommunication infrastructures, the availability of financial services, political and economic
stability and the transparency of local governance structures (Maskus, Saggi and Puttitatnun, 2005). Some of these factors are largely outside the direct control of national policy. But governments can influence a range of conditions which will attract private-sector investments in clean technologies, for instance through regulatory, infrastructure and skills improvements. The challenge for governments is to set political goals in ways which acknowledge and take advantage of business behaviours and interests.

**Enhancing technology diffusion**

Emerging economies have adopted a range of policy measures to stimulate investment in clean energy (Table 15.8).

Strong domestic policy frameworks in countries such as Brazil, India and China have enabled the relative strength of these nations’ clean energy sectors. China has some of the world’s most ambitious renewable energy targets, calling for 30 gigawatts (GW) from wind and from biomass energy by 2020. Brazil offers priority loans for renewable power projects and has ambitious targets for ethanol and biodiesel. India provides a preferential tax rate of 15% (compared with the standard rate of 30%) to renewable energy projects. India also supports wind power with provincial feed-in tariffs, while biomass and mini-hydro are supported by accelerated depreciation mechanisms (The Pew Charitable Trusts, 2010).

<table>
<thead>
<tr>
<th>Countries</th>
<th>Renewable energy standard</th>
<th>Clean energy tax incentives</th>
<th>Auto efficiency standards</th>
<th>Feed-in tariffs</th>
<th>Government procurement</th>
<th>Green bonds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>China</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>India</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>South Africa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

Source: Based on The Pew Charitable Trusts (2010).

The successful absorption of new technology by developing countries also depends on a number of factors, such as the country’s governance and the business climate, its overall macroeconomic stability, the availability of financing, the enabling infrastructure and the capacity of the industrial base to exploit innovation (Table 15.9). Governments can influence many of these factors and can put in place specific measures to support investment in particular technologies.
Table 15.9  Enabling environments for technology diffusion, examples of implementation measures and main actors involved

<table>
<thead>
<tr>
<th>Enabling environments</th>
<th>Examples of implementation measures</th>
<th>Key actors</th>
<th>Examples of technology-specific measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroeconomic policy framework</td>
<td>Stable macroeconomic conditions; energy sector reforms; removal of subsidies for conventional energy products; eliminate barriers to trade and FDI; creation of incentives such as tax preferences and export credit programmes</td>
<td>Governments, MDBs, financial institutions, World Trade Organization</td>
<td>Provide reliable, long-term incentives, e.g. well adapted feed-in tariffs for wind generation or renewable electricity standards that provide market pull for solar energy</td>
</tr>
<tr>
<td>Institutional and regulatory frameworks</td>
<td>Stable legal system; strong measures to defeat corruption; transparent policies; policies driving decarbonisation; elimination of conflicting regulation; framework for trading intellectual assets and acceptable level of IPRs; enforcement mechanisms; participatory approaches for involvement of local stakeholders</td>
<td>Governments, MDBs, NGOs, local stakeholders</td>
<td>Develop comprehensive legislative and regulatory frameworks for CCS that address, among other things, long-term storage and provide clarification on long-term liability</td>
</tr>
<tr>
<td>Financial instruments</td>
<td>Finance mechanisms able to leverage investments (e.g. carbon market); forms of risk mitigation and risk sharing; access to finance</td>
<td>Governments, firms, financial institutions, MDBs, consultants</td>
<td>Create financing programmes that use buildings as collateral in order to increase access to capital for energy efficiency projects in the building sector</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Supporting infrastructure (e.g. grid access for renewable energy producers)</td>
<td>Governments, firms, financial institutions, MDBs</td>
<td>Upgrade transmission networks using best-available cable technologies to address complexity of integrating large amounts of marine energy into the electricity grid</td>
</tr>
<tr>
<td>Human and institutional capacity</td>
<td>Train local firms and develop capacity; train workforce and government officials; increase technology literacy; promote exchange programmes; business exchanges; capacity-building activities</td>
<td>Governments, MDBs, NGOs, firms, research organisations, international organisations, the media</td>
<td>Set up green job programmes to train necessary personnel on operations and maintenance for wind energy projects</td>
</tr>
</tbody>
</table>

The legal, institutional and economic realities of emerging economies can sometimes raise additional barriers to the diffusion of low-carbon technology. For example, investors will give a higher weight to sovereignty risk in emerging economies than in OECD markets. This increases the cost of investment in emerging economies. The weak institutional track records, protective banking systems and risk-averse lending structures of some emerging economies also increase the difficulty to having access to capital and liquidity. High investment costs and incompatible prices, subsidies and tariffs also create significant economic and market barriers (Box 15.8).
Box 15.8  ▶  Barriers to trade in low-carbon energy technologies

Trade barriers on imports can hinder technology diffusion by raising the domestic price of low-carbon technologies. The removal of such barriers is important for developing countries. China, Hong Kong (China), Mexico, Singapore and Thailand are among the top ten exporters of renewable energy technologies and, therefore, have significant export interest in trade liberalisation in the sector (WTO, 2009). EU tariffs of as much as 57% on compact fluorescent lamps (CFL) imported from China have led to a significant decline in Chinese CFL exports to the European Union (Brewer, 2009).

Biofuels experience significant tariffs. Tariffs on ethanol and on some biodiesel feedstocks, including import and export duties on Brazilian ethanol, amounted to USD 6 billion in 2006. OECD countries’ subsidies to domestic biofuel producers reached USD 11 billion in 2006. As a result, investments are not being made where technology is the most cost-effective (IMF, 2008). In Egypt, the average tariffs on PV panels are 32%, ten times the 3% tariff imposed in OECD countries (World Bank, 2008).

Eliminating tariff and non-tariff barriers on clean energy technologies could increase their traded volume by an average of 14% in 18 developing countries that emit high levels of greenhouse gases (World Bank, 2009a). Barriers to trade in services also have negative impacts, since the deployment of many clean energy technologies requires a wide range of consulting, engineering or construction services. An opportunity to liberalise trade in some climate-friendly goods and services currently exists at the multilateral level within the context of the Doha Round.

Beyond such economic and market factors, other factors likely to hold back technology diffusion include a lack of information on the technical performance of often complex technologies, inefficient networking, and inadequate systems and tools for research.

The role of IPRs in technology diffusion is a matter of debate. Some commentators, usually from developed countries, argue that stronger IPR regimes encourage investment in innovation and the diffusion of low-carbon technologies, and particularly of technology-intensive goods. Others, often from developing countries, argue that IPRs slow the rate at which their firms can produce low-carbon technologies and prevent firms from producing at the cutting edge of technology. In response, there have been calls for more flexible approaches, such as joint ownership, the creation of patent pools and patent commons19 for low-carbon technologies.

Publicly facilitated patent pools have a long history. To protect the public good, governments have created collective rights organisations which have mandated the licensing of patents at established fee levels, created and managed public patent pools, directly purchased enabling technology patents and placed them in the public domain, and even created mergers between firms. Private institutions or industry-led consortia have also organised private patent pools, including small contract-based patent pools, large industry-wide patent pools, and technology standard-setting patent pools. Sewing machines, aircraft, movie projectors, videos, radios and many other technologies have been widely diffused through the use of

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19. For example, Eco-Patent Commons is an effort co-ordinated by the World Business Council for Sustainable Development (WBCSD) that puts environmentally beneficial patented technologies in the public domain without royalty.
patent pools. Private and/or publicly facilitated patent pools are being explored in the software, biotechnology and health care industries. Similar approaches may help accelerate technology diffusion in energy technologies, for instance through technology-specific or sector-specific patent pools.

Recently some countries have been entering into bilateral negotiations to explore frameworks for sharing intellectual property (IP) within collaborative RD&D programmes for climate-friendly technologies. For example, the United Kingdom and China are developing an agreement to help decide where IP rights should lie in joint work between UK and Chinese businesses and research organisations. Lack of clarity on allocating IP rights is known to be a barrier to collaborative RD&D. It is possible that experience gained through these bilateral discussions, drawing upon practical experience and working models in other RD&D fields, could present a basis for broader agreements on IP sharing as a means to facilitate stronger collaborative RD&D.

Some practical policy solutions have been proposed for streamlining IPRs. The United Kingdom, Australia, the United States and Japan have all put in place arrangements to fast track patent approvals for low-carbon technologies. An internationally co-ordinated approach to the fast tracking of patents could also be facilitated through the World Intellectual Property Organisation. Separately, some governments are providing financial and capacity-building support to IP applicants and technology developers. Licence of right (LOR) systems provide an incentive to patent holders to make patent licences available to anyone requesting such a licence, with adequate remuneration agreed upon between the patentee and the party seeking a non-exclusive licence, or, in the absence of such an agreement, established by the patent office or a court. The incentive is usually in the form of a reduced patenting fee.

Countries need to implement IPR legislation that reflects their particular circumstances, including their stage of industrial and technological development, and their goals, infrastructure and international relationships. But all countries need clear rules concerning the ownership of patents and the boundary and scope of the national protection and enforcement mechanisms, since they need to provide the frameworks within which firms can develop legal agreements that will enable access to new technologies.

Box 15.9  Rationale for intellectual property rights

The nature of a given innovation will determine what type of intellectual property it is, and the rights that the creator can claim over it. The most common categories of IP include patents, trademarks, design rights and copyright. A single innovation may encompass a number of different types of IP. Patents provide protection against the copying of innovations, thereby protecting the innovator’s investment in the innovation. IPRs provide the necessary commercial and legal protection while enabling the creation or invention to become public. Public disclosure in turn fosters competition. IPRs also protect consumer interests, insofar as the presence of a genuine trademark on the goods helps assure consumers that they are receiving the original article, not a copy that may be of lesser quality. The enforcement of IPRs plays a crucial role in sustaining the effectiveness of IP laws. Without effective enforcement in the form of such penalties as injunctions, damages or the destruction of counterfeit goods, IP laws are likely to have little effect in promoting innovation.
Even where affordable access to patents is possible, in some cases this is not enough to enable developing countries’ firms to begin producing these technologies. The lack of practical experience gained in the development phase of a technology can also act as an obstacle to diffusion. Tacit knowledge and other related knowledge such as trade secrets are often not patented but may be essential to the effective implementation of a technology (Ockwell *et al.*, 2009).

If countries are to benefit from technology diffusion, they need to be able to adapt the technology, to develop and deploy it within the specific country context, to enhance it, and eventually to innovate it so as to create a new product. Evidence suggests that the lack of human capacity to undertake such technology absorption is a much greater barrier to technology adoption in developing countries than in developed countries (Worrell *et al.*, 2000).

Government policies need to treat the diffusion and development of low-carbon technologies as sides of the same coin. Countries that innovate are more likely to benefit from innovation coming from abroad. As low-carbon technological capabilities build up in non-OECD countries, this will facilitate both the diffusion of existing low-carbon technologies within developing countries and the adoption, adaptation and development of low-carbon technologies that fit with the priorities of developing countries.

Skills and knowledge can be developed by investing in the country’s institutions responsible for creating, storing and transferring knowledge, such as universities, RD&D centres and training institutes, as well as networks. In addition, bilateral or multilateral international collaboration on RD&D can play an important role in fostering knowledge-sharing and developing capacity, particularly when it involves private-sector participation. Different kinds of absorptive capacity may be required for technologies at different stages of development (Ockwell *et al.*, 2007). The absorption of technologies at an early stage of development is likely to require the development and deployment of competences in related technologies as well as commercialisation skills.

**Strengthening low-carbon technological capacity in emerging economies**

Although developing countries need rapidly to introduce low-carbon technologies, most of the innovation is highly concentrated in developed countries. Japan, the United States and Germany are responsible for about 60% of all filed patented inventions in thirteen climate change mitigation technologies20 between 2000 and 2005. Japan alone accounts for 37% of the world’s inventions on average, and is responsible for over 50% of the world’s inventions in electric and hybrid vehicle technologies, and in waste-to-energy and lighting technologies (Dechezleprêtre *et al.*, 2010).

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20. See footnote 7.
Between 1997 and 2003, the share of climate-friendly inventions patented by emerging countries grew at an average annual rate of 18%. Emerging economies accounted for 16.3% of patented climate-friendly technologies in 2003 (Dechezleprêtre et al., 2008). China and Russia were respectively the fourth- and sixth-largest inventors between 2000 and 2005, with strong positions in particular fields such as geothermal (China) and cement (China and Russia). Brazil also figures among the top eleven countries (Table 15.10).

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

<table>
<thead>
<tr>
<th>World rank</th>
<th>Average percentage of world’s climate inventions</th>
<th>Most important energy technology classes (decreasing order)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>1</td>
<td>37.1%</td>
</tr>
<tr>
<td>United States</td>
<td>2</td>
<td>11.8%</td>
</tr>
<tr>
<td>Germany</td>
<td>3</td>
<td>10.0%</td>
</tr>
<tr>
<td>China</td>
<td>4</td>
<td>8.1%</td>
</tr>
<tr>
<td>Russia</td>
<td>6</td>
<td>2.8%</td>
</tr>
<tr>
<td>Brazil</td>
<td>11</td>
<td>1.2%</td>
</tr>
<tr>
<td>Chinese Taipei</td>
<td>21</td>
<td>1.0%</td>
</tr>
<tr>
<td>India</td>
<td>27</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

Source: Based on Dechezleprêtre et al. (2010).

Other patent-landscaping exercises show similar patterns. The joint share of the BRICS countries in world patents in renewable energies and CCS is just under 3%,21 and just over 2% in the field of energy efficiency in buildings (Walz et al., 2008). BRIICS countries accounted for only 6.5% of global renewable energy technology patents in 2005, while the European Union accounted for 36.7%, the United States for 20.2% and Japan for 19.8%. In the patenting of automobile equipment for reducing car emissions, BRIICS share was just 0.7% (OECD, 2008).

A strong upward trend in patent activity has emerged recently in non-OECD countries, especially in China22 and to a lesser extent in India. BRIIC countries are narrowing the gap relative to OECD countries, with annual renewable energy technology patenting growth rates more than twice those of the European Union and the United States. Roughly 0.7% of BRIIC country patents were filed in the renewable energy field from 2003 to 2005, compared with less than 0.3% in the United States (World Bank, 2009a).

21. China and Russia have the largest shares among BRICS countries in these fields, followed by India and South Africa.
22. More detailed analysis suggests that most patents originating from China are filed by foreign subsidiaries. Over 85% of patents in many of China’s core high-tech economic sectors are owned by companies in developed countries (Liu, 2007).
Much of the growing success of emerging economies, especially in China and India, in building up their innovation capabilities is a result of a combination of increased exposure to international technology through trade and FDI flows, and strong investment in national skills development. This has been made possible by exceptional economic growth and capital accumulation. In addition, some emerging economies have traded access to foreign technology for access to their national markets. For example, foreign manufacturers have a higher chance of being considered in public tenders in China if they set up R&D centres in the country. Several emerging economies have also established ambitious R&D policies and identified low-carbon R&D priorities (Table 15.11).

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

<table>
<thead>
<tr>
<th>Countries</th>
<th>Low-carbon R&amp;D priorities and spending</th>
<th>R&amp;D policies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>Biomass (mainly ethanol production) is the leading focus for R&amp;D. Particular R&amp;D emphasis is on the breeding of new sugar cane varieties for ethanol production, ethanol production from cellulosic biomass and sugar cane gasification to produce energy with gas turbines. Hydropower, solar electricity and wind energy are also high priorities for R&amp;D. Federal government spending on energy R&amp;D was 3.1% of all federal R&amp;D in 2006 (USD 140.5 million out of USD 4.5 billion). Brazil's estimated public RD&amp;D expenditures on bioenergy in 2008 amount to USD 62.8 million.</td>
<td>The Science Technology and Innovation Action Plan 2007-2010 aims to increase aggregate state and federal expenditures in R&amp;D, from 1.02% of GDP in 2006 to 1.5% of GDP by 2010, and to promote an increase in overall R&amp;D investment. The Plan relies on federal resources of the order of USD 22 billion. Recent efforts have sought to foster R&amp;D investment by private firms through tax incentives, grants, business incubation and support to venture capital. An Innovation Law signed in 2004 provides incentives for building and strengthening partnerships between universities, research institutes and private companies, but there have been some concerns about the effectiveness of this law in creating public-private partnerships.</td>
</tr>
<tr>
<td>Russia</td>
<td>R&amp;D top-priority themes include the efficiency of energy production (conversion of primary energy), the development of smaller hydroelectric plants and the modernisation of the transport infrastructure. The efficiency of heating supply is also a priority. Russia’s estimated public RD&amp;D expenditures in energy efficiency in buildings in 2009 amount to USD 22.6 million, while estimated expenditures in energy efficiency in industry for the same period amount to USD 23.4 million.</td>
<td>Russia’s R&amp;D expenditure per capita is among the highest of the BRICS countries, with the bulk of R&amp;D funding made by the government. However, total R&amp;D expenditures remain far below those of most OECD countries in terms of a percentage of GDP. The public R&amp;D system is highly fragmented in terms of funding and steering mechanisms, and Russia’s innovation performance remains modest. Recent policy reforms have included the creation of special economic zones in some formerly closed science cities, specialising in issues such as nuclear physics, advanced materials and nanotechnology. Tax breaks and other incentives are designed to attract private investments. The Russian government has taken control of the formerly autonomous Russian Academy of Sciences, and is expected to restructure it with the objective of enhancing the coherence of Russia’s innovation system.</td>
</tr>
</tbody>
</table>
### Table 15.11 R&D priorities, policies and expenditure for clean energy in BRICS countries (continued)

<table>
<thead>
<tr>
<th>Countries</th>
<th>Low-carbon R&amp;D priorities and spending</th>
<th>R&amp;D policies</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>The priority subjects are wind energy, smaller efficient vehicles, solar, and the utilisation of biomass, with an emphasis on jatropha and other domestically grown non-edible feedstocks for biodiesel. R&amp;D into decentralised, domestic renewable energy sources is also a priority. India’s estimated average public RD&amp;D expenditures on solar energy in 2007-2008 amount to USD 20.6 million, and estimated expenditures on bioenergy for the same period amount to USD 10.5 million.</td>
<td>R&amp;D spending has remained at about 0.8% of GDP since 1990, with the central government representing the principal source of financial support. The Eleventh Five-Year Plan establishes a target of overall spending on science and technology of 2% of GDP, of which R&amp;D spending constitutes one component. In 2007, the Ministry of New and Renewable Energy proposed total renewable energy RD&amp;D funding of USD 0.32 billion over the period 2007-12, a very significant increase over the USD 15.5 million in the previous Five-Year Plan.</td>
</tr>
<tr>
<td>China</td>
<td>Capacity-building priorities include coal gasification, coal-to-hydrogen, wind power, solar thermal energy, PV and EVs. Solar PV cells and solar water heaters have a particularly high priority. Research emphasis is also on water power, fuel-cells, geothermal energy and wave power. Major importance is also attached to energy-saving technologies, particularly in buildings, and to the transport sector (particularly in the area of electric vehicles). China’s estimated public RD&amp;D expenditures in solar energy in 2006 amount to USD 29.3 million, and estimated expenditures in wind energy in 2006 amount to USD 11.7 million.</td>
<td>In recent years, China has significantly increased its total R&amp;D spending to a level of 1.5% of GDP, or roughly USD 40 billion. This is a level similar to that of many Western countries, but still behind the world leading R&amp;D investors such as the United States and Japan. China’s National Medium- and Long-Term Programme for Science and Technology Development, issued in 2006, sets a global R&amp;D spending target of 2.5% of GDP by 2020, and calls for an increased reliance on indigenous technologies. The Chinese government has started to take a less direct role on R&amp;D management, and has encouraged research institutes and universities to capitalise on the value of their R&amp;D products and to engage in commercial activity. Private enterprises have taken on an increasing role in R&amp;D.</td>
</tr>
<tr>
<td>South Africa</td>
<td>Capacity-building priorities include coal gasification and coal-to-synfuels, leading to good preconditions for the future application of CCS. There is increasing interest in synthetic biofuels, mini-hydroelectric schemes, and commercial and domestic solar water heaters. An Energy Efficiency Strategy has been approved, and efficiency in both commercial and residential buildings has been included as a priority. Gross expenditure on energy R&amp;D in 2005 was USD 96 million.</td>
<td>The National R&amp;D Strategy of 2002 highlights a commercialisation gap between the R&amp;D and business sectors and the need to develop improved technology transfer mechanisms. Energy research, development and innovation is a strategic focus area of the National R&amp;D Strategy. The aim is to address the challenge of developing a sustainable base for national energy research. In recent years, the government has adopted the 2008 Intellectual Property Rights Act and the Technology Innovation Agency Act to bridge universities and companies, and promote technology transfer and commercialisation. Emphasis has been placed in the formation of innovation hubs and the creation of incubators.</td>
</tr>
</tbody>
</table>

Sources: Compiled from Walz et al. (2008); IEA (2009c) and OECD (2005).

It is difficult to assess emerging economies’ innovation capabilities and the rate at which they are catching up with OECD countries. Emerging economies, especially China, have strengthened their positions markedly, but OECD countries are still
producing more energy-related innovation, concentrating on major cutting-edge technologies. The concentration of clean energy patent ownership in OECD-based companies indicates that the diffusion of low-carbon technologies into emerging and developing economies will have an important part to play in enabling those countries to make their expected contribution to the BLUE Map scenario outcomes. But the speed of diffusion of these technologies will be as much influenced by policies and measures in emerging economies, and by their ability to exploit technology innovation, as by OECD countries.

The way forward

No single policy change will reduce barriers and accelerate the diffusion of low-carbon technologies into emerging economies. Integrated strategies will have to be built which are technology- and country-specific and which reflect the stage of technology maturity, the characteristics of the countries seeking to absorb the technology, and the stakeholders involved.

A number of practical policies and measures to enable diffusion could be implemented by emerging economies today.

Technologies that are already competitive are accessible to emerging economies through a number of commercial channels. Broader adoption of these technologies requires that emerging economies:

- Adopt transparent, stable and long-term national policies that provide a strong market incentive and support for low-carbon technologies, for instance driven by performance standards or policy targets and regulations.

- Encourage higher value-added FDI and domestic private investments towards clean energy technologies. This requires a low level of restriction on FDI, and putting in place a business-enabling environment and a good investment climate for attracting private-sector investments, for instance through regulatory, infrastructure and skills improvement.

- Invest abroad, for instance through FDI and mergers and acquisitions, in order to acquire technology and enter new markets. Market openness and the elimination of barriers to trade should be promoted in both directions. The creation of overseas R&D centres might also be an option to develop channels to acquire knowledge and learning.

- Provide clear IPR management regimes, through IPR protection laws and effective enforcement. At the same time, the role of patent pools and licensing backed by public support could be further explored.

- Improve the capability of domestic firms to conduct effective negotiations with technology holders, based on a clear understanding of the technology concerned.

For technologies that are technically proven but which require large-scale demonstration, or technologies that are close to competitive today, emerging economies should:
Identify common areas of interest for joint international collaborative R&D efforts with OECD and other non-OECD countries. International partnerships provide opportunities for demonstrating the viability of a relevant technology to scale, fostering knowledge sharing, and raising public acceptance, and may build on existing bilateral or regional co-operative experiences, such as the Innovation China-United Kingdom (ICUK) model or the Asia-Pacific Partnership.

Implement policies and regulations that encourage localisation of corporate R&D activities focusing on innovative technologies into their territories, for example through the provision of fiscal or financial incentives to companies that invest in R&D.

Provide a framework for IPRs that encourages innovation, within which agreements can be structured. In creating IPR regimes, emerging economies should also consider the needs of their own research institutions and industry to commercialise domestic innovation.

Promote local innovative capabilities in both basic and applied research. A major challenge for emerging economies is to strengthen their academic institutions by recruiting adequate staff and providing them with adequate resources. Such capacity-building can also be achieved through encouraging closer university-industry collaboration, for example by inviting senior managers of domestic and foreign firms to participate in the governing boards of academic institutions, and by establishing science parks and business incubators.

Provide incentives to enterprises, including small and medium-sized firms, to buy or license technologies. In developing such policies, issues related to access to finance should involve the banking sector.
Key findings

- Reaching the full greenhouse-gas mitigation potential of energy-efficient and low-carbon energy technologies will depend to a significant extent on influencing consumers’ technology choices and behaviour.

- To date, measures to encourage the adoption of low-carbon technologies have focused primarily on technological and economic barriers while relatively little attention has been paid to the influence of social and behavioural factors.

- An 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 energy savings.

- A small but growing set of energy efficiency policies and programmes are successfully addressing important aspects of consumer behaviour by integrating insights from social and behavioural research. Successful programmes use strategies that target, inform, motivate and empower energy consumers.

- To facilitate greater residential energy efficiency, governments and utilities should design programmes based on improved research on behavioural aspects of energy consumption, and provide clear information on energy use through greater use of in-home feedback devices, home energy reports, Internet tools and labels.

- Successful low-carbon transport strategies will need to be informed by behavioural research into the economic and non-economic drivers that shape transportation-related decisions and practices. More research is needed to understand people’s choice of transport mode, vehicle technology, distance travelled and driving practices.

- Subsidies and financing programmes that counterbalance higher initial vehicle costs are needed to support the development of sustainable markets for new transport technologies. Vehicle efficiency strategies should identify and address potential rebound effects, whereby drivers travel farther due to fuel cost savings.

- Policies to promote the uptake of low-carbon personal vehicles should be supplemented by the development and promotion of safe, reliable and convenient alternatives to personal transportation, including mass transit and information and communications technology alternatives.

- Eco-driving practices, including reductions in excessive vehicle acceleration and driving speeds, smoothing traffic flows and reducing congestion, should be adopted as a part of driver training and educational efforts.
Introduction

The energy technology revolution identified by the BLUE Map scenario requires the rapid and widespread adoption of a wide range of existing and new energy technologies throughout the energy system. This will depend not only on influencing traditional energy markets, but also to a large extent on influencing the decisions that are regularly made by people in respect of many millions of relatively small investments in household and personal vehicle technologies. To be successful, policies and programmes to advance household energy efficiency and promote low-carbon vehicles and renewable energy will need to be informed by a better understanding of the marketing, informational and behavioural aspects that underpin those decisions. This chapter looks more closely at the question of consumers’ propensity to adopt new technologies, with particular focus on energy efficiency in buildings and low-carbon personal vehicles.1

Energy efficiency can potentially make the largest contribution to reducing energy use and carbon dioxide (CO₂) emissions over the period to 2050. Historically, improvements in energy efficiency have been one of the most important drivers of reductions in energy intensity. Without the energy efficiency gains achieved in OECD countries over the last 35 years, current energy use would be 63% higher than it is. Although energy efficiency improvements are expected to continue to reduce energy intensity in the future, the size and speed of such savings will depend on several behavioural factors including patterns of technology adoption, maintenance and use. Consumer choices lie at the heart of the well-known gap between potential and actual levels of energy efficiency. These choices often reflect a significant disconnect between consumer attitudes and behaviours.2 To address this, policy makers need a better understanding of the dimensions of consumer behaviour and energy use.

Transportation patterns and technology choices also require a balanced approach that recognises both the human and technological dimensions of energy consumption. From vehicle choices to decisions about amounts and modes of travel, human behaviour significantly influences levels of energy demand in the transportation sector. Transportation policies that reflect people’s behaviour can enable better vehicle choices, help induce modal shifts from less efficient to more efficient modes of travel, encourage constraint in the number of vehicle kilometres (km) travelled, and help reshape driving habits in ways that will reduce fuel consumption and carbon emissions.

The potential contribution of behaviour

Recent research efforts have attempted to quantify the potential for behaviour-related energy savings and to characterise the nature of the behavioural changes that might contribute to these savings in the residential and personal transportation sectors (Dietz, Gardner and Gilligan et al., 2009; Laitner, Knight, McKinney et al., 2009; Gardner and Stern, 2008). These studies suggest a potential for behaviour-related energy and greenhouse-gas savings in the range of 20% to 30%.3

1. There are also important consumer preferences related to the use of renewable energy, particularly in households.
2. A recent Gallup Poll conducted in the United States indicated that 78% of respondents believed that they ought to be spending thousands of dollars to improve the energy efficiency of their homes. A separate Gallup Poll found that less than 2% of people reported making energy efficiency investments in their homes. www.gallup.com/poll/127220/Americans-Prioritize-Energy-Environment-First-Time.aspx
3. The BLUE Map scenario does not identify what proportion of the energy savings compared to the Baseline scenario results specifically from behavioural changes.
There is evidence that, for maximum impact, policy interventions need to be tuned specifically to the behavioural changes they are seeking to achieve (Dietz et al., 2009). To improve home weatherisation and the upgrading of heating and cooling equipment, for example, a combination of strong financial incentives and programme designs that take behaviour into account is likely to be most effective. To encourage a switch to more efficient vehicles and non-heating and cooling home equipment, measures such as improved rating/labelling systems, the provision of reliable information to households and retailers, financial incentives for households and/or vendors, and strong social marketing are likely to play a more important role. To secure changes in equipment maintenance and adjustment decisions and in daily use behaviours, a combination of mass-media messages, household- and behaviour-specific information, and communication through individuals’ social networks and communities is likely to prove most effective.

Around 22% of household energy use in the United States could potentially be saved if people were to adopt cost-effective energy conservation and efficiency behaviours (Laitner, Knight, McKinney et al., 2009). More than half of the potential energy savings could be achieved through low-cost or no-cost behavioural changes, rather than requiring more complex investment decisions (Table 16.1).

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

<table>
<thead>
<tr>
<th>Category of actions</th>
<th>Potential savings (EJ)</th>
<th>Percentage of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-cost/no-cost</td>
<td></td>
<td>57%</td>
</tr>
<tr>
<td>Smart investment decision</td>
<td></td>
<td>43%</td>
</tr>
<tr>
<td>Total energy savings</td>
<td>9.1 ± 2.6</td>
<td>22% of household energy</td>
</tr>
</tbody>
</table>

Source: Laitner, Knight, McKinney et al., (2009).

There is also evidence that, faced with shortfalls in electricity supplies, a number of countries and communities have been able very rapidly and deeply to reduce electricity consumption to avoid blackouts (IEA, 2005). Brazil, for example, was able to cut electricity demand by 20% when faced with a severe drought in 2001. A more recent crisis in Juneau, Alaska provided the impetus for electricity savings of 30% in just six weeks. After the crisis was resolved, the city’s consumption remained 10% lower than the previous year (Meier, 2009). These examples clearly show that significant energy savings can be achieved quickly through behavioural change, at least on a temporary basis. The need is to devise programmes and policies that can make such behaviours, and the savings that result from them, permanent.

### Social and behavioural frameworks

Most current approaches to the analysis of energy consumption are framed by reference to a techno-economic model in which consumption levels are driven by the availability of technologies and economic conditions that either encourage or impede their adoption (Stern, 1986). This approach assumes that energy...
efficiencies and reductions in energy consumption are achieved by making new
technologies available at the right price, and promoting them to consumers on the
basis of their rational economic benefits (Figure 16.1). Energy consumption and
technology changes are then assumed to result from a set of rational economic
calculations involving the price of energy, the cost of technologies, and the level
of disposable income. On this basis, the model inevitably tends to favour solutions
that lean heavily on the introduction of carefully crafted economic incentives and
disincentives (Archer, Pettigrew, Costanza et al., 1987). Consumers are assumed to
be logical decision makers who will take steps to alter their behaviour in a rational
manner when confronted with rising energy prices or more resource-efficient
products to increase their net benefit. Unfortunately, these assumptions have not
been proven to apply in practice (Parnell and Popovic Larsen, 2005).

**Figure 16.1** The techno-economic model of energy efficiency

The weakest aspect of this model is the assumption that individuals are economically
rational actors. This is apparently not necessarily the case. For example, even when
information on the costs and performance of technologies is available, people
do not consider it in their cost calculations when deciding whether to purchase
a residential solar unit (Archer, Pettigrew, Costanza et al., 1987). Even the most
financially skilled consumers do not necessarily use payback calculations as part of
their vehicle purchase decision making (Turrentine and Kurani, 2007). A number
of other studies have also observed flaws in the rationality of the decision-making
process of individuals (NRC, 2002; Feldman, 1987; Stern and Aronson, 1984).

In practice, consumers do not consider expenditure on energy and energy-using
equipment as investments. Rather, they are influenced by a variety of non-economic
variables including structural and institutional factors, cultural values and norms,
individual beliefs and attitudes and interpersonal dynamics. Recognising this
complex array of the social, cultural and psychological factors that shape consumer
behaviour is likely to result in more effective programmes, policies and forecasts
(Laitner, DeCanio and Peters, 2001).
Extensions and alternatives to the techno-economic model

If policies are to influence energy consumption more effectively, they need to reflect a more complex understanding of the many factors that shape or drive individual behaviours (Stern, 2002). Such policies will reflect not only the influence of financial costs and rewards and the availability of technology choices, but also the importance of personal capabilities, habits, values, norms and social and institutional contexts (Figure 16.2).

**Figure 16.2** Policy instruments and behavioural drivers

<table>
<thead>
<tr>
<th>Policy instruments</th>
<th>Behavioural drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication and diffusion instruments</td>
<td>Personal capabilities and constraints: literacy, social status, behaviour-specific knowledge and skills</td>
</tr>
<tr>
<td>Collaborative agreements</td>
<td>Habit and routine</td>
</tr>
<tr>
<td>Command and control</td>
<td>Values, attitudes, beliefs, personal norms</td>
</tr>
<tr>
<td>Economic instruments</td>
<td>Social context: social norms, persuasion, advertising, personal commitments, informal institutions</td>
</tr>
<tr>
<td>Service and infrastructure</td>
<td>Institutional, economic and technological context:</td>
</tr>
<tr>
<td></td>
<td>Laws, regulations</td>
</tr>
<tr>
<td></td>
<td>Private contracts</td>
</tr>
<tr>
<td></td>
<td>Financial costs and rewards</td>
</tr>
<tr>
<td></td>
<td>Available technology</td>
</tr>
<tr>
<td></td>
<td>Convenience</td>
</tr>
</tbody>
</table>

Source: Stern (2002).

**Key point**

A diverse set of behavioural factors must be considered in designing programmes and policies aimed at improving the adoption of energy efficiency and low-carbon technologies.
For instance, psychological models focus on a narrowly defined set of variables that shape individual behaviour including beliefs, intentions, sense of self-efficacy and subjective norms. The theory of planned behaviour suggests that conscious, choice-making behaviours result from a process in which people weigh the advantages and disadvantages of potential actions based on existing values and norms (not simply economics). As shown in Figure 16.3, these types of decision are determined by the person’s own attitudes or opinions about the behaviour, other people’s opinions about the behaviour and perceived behavioural control (Ajzen, 1988). This theory suggests that people carry out their intended behaviours in the absence of insurmountable barriers. The approach has been employed to better understand vehicle choice and the relationship between consumer attitudes and technology adoption.

**Figure 16.3**  ➤ Theory of planned behaviour

![Diagram of the theory of planned behaviour](image)


**Key point**

Models exist that provide an effective means of determining the psychological factors that shape energy technology adoption and use.

Another approach focuses on understanding the factors that shape habitual, or routine, behaviours. Such behaviours are typically performed without full conscious reasoning at the moment they are carried out. As many as 95% of household energy behaviours, such as the routine use of appliances or lighting, are habitual rather than the result of conscious, planned decisions (Wagenaar, 1992). For policy purposes, it can be helpful to distinguish between infrequent energy behaviours such as installing compact fluorescent light bulbs (CFLs) or properly inflating tyres and frequent behaviours such as slower highway driving or the air drying of laundry (Figure 16.4). These are distinguished from consumer behaviours, such as the infrequent and higher-cost investment in more energy-efficient appliances, devices and products.
**Figure 16.4** Household behaviours associated with energy consumption, efficiency and conservation

<table>
<thead>
<tr>
<th>Frequency of action</th>
<th>Infrequent</th>
<th>Frequent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low-cost / no cost</strong></td>
<td>Energy stocktaking behaviour</td>
<td>Habitual behaviours and lifestyles</td>
</tr>
<tr>
<td>Install CFLs</td>
<td>Slower highway driving</td>
<td></td>
</tr>
<tr>
<td>Pull fridge away from wall</td>
<td>Slower acceleration</td>
<td></td>
</tr>
<tr>
<td>Inflate tyres adequately</td>
<td>Air dry laundry</td>
<td></td>
</tr>
<tr>
<td>Install weather stripping</td>
<td>Turn off computer and other devices</td>
<td></td>
</tr>
<tr>
<td><strong>Higher cost / investment</strong></td>
<td>Consumer behaviour</td>
<td></td>
</tr>
<tr>
<td>New EE windows</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New EE appliances</td>
<td></td>
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<tr>
<td>Additional insulation</td>
<td></td>
<td></td>
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<tr>
<td>New EE car</td>
<td></td>
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<tr>
<td>New EE AC or furnace</td>
<td></td>
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</tr>
</tbody>
</table>


**Key point**

*Important distinctions between different types of energy-related behaviours must be considered in energy efficiency programme design.*

Using frameworks such as these to better understand energy-related behaviours can help to provide a basis for more effective programme and policy designs that take appropriate account of social, cultural and psychological factors.

**Consumer adoption of energy-efficient technologies in households**

In the BLUE Map scenario, end-use energy efficiency accounts for more than one-third of CO₂ emissions reductions by 2050. To achieve these savings, a higher rate of energy efficiency improvement must be achieved than will occur on the basis of current policies in the Baseline scenario. The BLUE Map scenario envisages this being achieved through the adoption of more efficient appliances and lighting, improved building shells, and the expanded use of heat pumps and solar heating technologies. These changes are unlikely to occur without a broad range of consumer-focused initiatives to overcome barriers to technology adoption. These initiatives include standards and other regulations, labelling schemes, information campaigns and energy audits.

If policies are to successfully catalyse and expand the adoption of new, energy-efficient technologies, they must effectively help households to overcome a range of
barriers to their adoption. Among the factors that influence household decisions to adopt new technologies are the time and inconvenience associated with searching for a better product, collecting and assessing information, and completing the transaction. Consumer perceptions of the potential risks associated with the shift to more efficient technologies may also impede their adoption. Policies can make energy-efficient technologies more attractive to would-be adopters (Figure 16.5).

**Figure 16.5 Impact of policies on different costs relating to technology choices**

Impact of policies, programmes, awareness, and by shifting preferences – all roughly approximated by the “hurdle rate” or the “implicit discount rate”

Impact of policies, R&D programmes, experience, growing expectations, and new innovations

Source: Laitner (2009).

**Key point**

Policies and programmes must identify and address the hidden costs associated with energy-efficient technology adoption.

Overcoming the costs and risks associated with new technologies is an important step towards increasing technology adoption; however emerging social science research suggests that it is unlikely to be sufficient and that other factors play equally important roles. This research highlights the emergence of successful consumer-focused programmes and policies that target, inform, motivate and empower energy users.

**Targeting people and behaviours.** The would-be adopters of more energy-efficient technologies present a diverse range of attitudes, interests, values, motivations and resources. Successful community-based social marketing
recognises that multiple internal and external barriers may hinder widespread public participation in any form of sustainable behaviour. These barriers will be different for different individuals (McKenzie-Mohr and Smith, 1999). In addition, encouraging people to adopt specific behaviours, such as installing CFLs, using low-flow shower heads or buying energy-efficient washing machines, requires the development of a range of customised tools. Survey research methods can help to identify the barriers faced by different types of individuals, households, organisations and businesses in adopting different behaviours. Promotional programmes and policies which are informed by such research are better able to remove or work around structural, social, personal and psychological barriers and to achieve desired outcomes. The success of targeting programmes is well documented in the healthcare field and is gaining increased attention among researchers and practitioners concerned with energy efficiency (Abrahamse, Steg, Vlek et al., 2005; Backhaus and Heiskanen, 2009; Breukers, Heiskanen and Mourik et al., 2009).

**Informing people about energy technologies and programmes.** People need information about energy-efficient technology options if they are to be able to make informed decisions. Many OECD countries have implemented labelling schemes for appliances, and electronic and other products to help inform consumer purchase decisions. These labelling schemes are of variable effectiveness. If designed correctly, energy labels can provide useful information to consumers and influence their purchase decisions (Thorne and Egan, 2002). European Union (EU) labelling schemes have achieved significant outcomes in terms of consumer awareness, market impacts and energy savings, although the effectiveness of the United States Energy Guide Label has been questioned as consumer comprehension has been found to be low (Thorne and Egan, 2002).

Giving people access to information about their domestic energy consumption patterns may also be important in reducing energy demand and encouraging the more efficient use of energy. For most people, the only measure they get of their energy consumption is the bill that they receive at the end of the month or quarter. This information comes far too late to be useful in influencing behaviour, except in the widest sense. And while energy bills often report the total amount of electricity consumed and the costs incurred, they do not typically identify the end uses with highest demand or suggest how individual consumers can change their energy demand or increase energy efficiency to reduce energy costs. Energy bills are insufficient to provide the level of detailed and timely feedback that consumers need if they are to manage their own energy consumption more effectively.

This problem has been recognised for many years. Kempton and Montgomery (1982) illustrated the paradox of consumption without meaningful information in the following way:

> [Imagine a grocery store without prices on individual items, which presented only one total bill at the cash register. In such a store, the shopper would have to estimate item price by weight or packaging, by experimenting with different purchasing patterns, or by using consumer bulletins based on average purchases.]
Recent research indicates that providing energy consumers with targeted information about their specific energy consumption practices can result in residential energy savings of between 5% and 15% (Ehrhardt-Martinez, Donnelly, Laitner et al., 2010; EPRI, 2009; and Darby, 2006).

Consumers can also benefit from improved information about government programmes, incentives and resources. A recent comparison of federal programmes in the United States suggests that good information and ensuring that programmes are designed for the convenience of consumers are critical to programme success and the achievement of energy savings (Stern, Gardner, Vandenberghe et al., 2010).

**Motivating the use of new technologies through social norms, networks, goals, commitments and other incentives.** Consumers are often reluctant to replace appliances that are still functioning. Just as economic incentives have had some success in helping people overcome financial barriers, other types of incentives and motivation can encourage people to replace outdated or inefficient equipment before the end of its natural life. The use of social norms, networks, goals and commitments can help achieve this objective. For example, in making decisions, people often look to their peers. This is something that governments can exploit by using communication and guidance to seek to create a critical mass in support of a policy or technological change (Griskevicius, Cialdini and Goldstein, 2008; Schultz, Nalan, Cialdini et al., 2007; and Nolan, Schultz, Cialdini et al., 2008).

Encouraging people to set personal goals or commitments can also increase energy efficiency (McKenzie-Mohr and Smith, 1999). For example:

- In California, home assessors were asked to seek a verbal energy efficiency commitment from householders. Three to four times as many people who had made such a commitment retrofitted energy efficiency measures in their homes as those who had not made such a commitment.

- In another study, homeowners were mailed a pamphlet on energy conservation. One group received a shower flow restrictor along with the pamphlet while the other did not. Homes that received the shower flow restrictor were more likely to engage in the other conservation actions mentioned in the pamphlet such as reducing the temperature on their water heaters.

**Empowering individuals by removing financial and non-financial barriers.** Consumers often lack the financial resources, incentives or time and ability to make energy-efficient choices.

Consumers can have difficulty securing the funds they need to cover the up-front investment costs associated with costly building retrofits or the purchase of energy-efficient equipment that is more expensive than less efficient models. Some energy efficiency programmes are successfully using different strategies such as on-bill financing (Consumer Energy Alliance, 2009) and green mortgages (HUD, 2009; Prior, 2009) to address this issue.

Structural barriers such as the principal-agent barrier and the home ownership transfer barrier can also impede the adoption of energy-efficient technologies.
The principal-agent barrier occurs when one party makes investment decisions and a different party carries the cost of those decisions (ACEEE, 2007; IEA, 2007). This type of barrier has important implications for technology adoption in new home construction markets, commercial building leasing markets and rental housing markets. In new homes, builders often make technology decisions that shape the subsequent, potentially very long-term, energy use of homebuyers. Similarly, in the commercial building sector and rental housing market, building owners often decide on energy-related technologies that determine tenant energy bills.

In the residential sector, the home ownership transfer barrier may present an even larger impediment to investments in energy efficiency. Home owners may be reluctant to invest in costly energy efficiency improvements if they are unlikely to remain in the house long enough to recoup the benefits of these investments. A number of policy strategies have been suggested to overcome this, including innovative financing, utility on-bill financing, loans tied to property taxes and energy-efficient mortgages. Another approach would require energy efficiency upgrades at the point of sale or major renovation (McKinsey, 2009).

Research from the fields of behavioural economics, sociology, psychology and anthropology has identified systematic biases in consumer decision making that are likely to impede the timely adoption of energy-efficient technologies (Stern, 1985; Lutzenhiser, 1992 and 1993). Households tend to use different mental accounting systems for different kinds of expenditure such as recurring gas and electricity costs, appliance purchases and financial investments (Prelec and Loewenstein, 1998). As a result, households tend to be relatively indifferent to information about returns on investment in energy efficiency. Policies and programmes can correct for some of these biases by structuring choices in more thoughtful ways so as to improve the likelihood that people will make better choices (Thaler and Sunstein, 2008).

**Consumer adoption of low-carbon transportation**

Light-duty vehicles (LDVs) accounted for about 45% of global transport energy use in 2007. The outcomes in the BLUE Map scenarios depend on significant energy savings and emissions reductions being achieved in the transport sector. For example, in the BLUE Map/Shifts scenario, CO₂ emissions from transport in 2050 could be reduced to as much as 40% below 2005 levels or by 70%, equivalent to a saving of 10 gigatonnes (Gt) of CO₂, compared to the Baseline scenario (IEA, 2009).

Achieving these reductions would require strong policies to encourage the development and implementation of alternative vehicles and fuels and to encourage consumers and businesses to take them up. Much of the projected saving arises from changes in behaviour associated with the adoption of more energy-efficient, including electric, vehicles and with a shift to less carbon-intensive modes of travel (Figure 16.6). In addition, policies will be needed to discourage potential increases in vehicle-kilometres travelled and to encourage more efficient driving behaviours.
**Figure 16.6** Transport greenhouse-gas reductions by scenario and source of reduction

![Graph showing transport greenhouse-gas reductions by scenario and source of reduction]

- **Note:** WTW is well-to-wheel, GHG is greenhouse gas.
- **Source:** IEA Mobility Model database.

**Key point**

Transport greenhouse-gas reductions come from a mix of modal shift, efficiency improvements and alternative fuels, all of which depend on behavioural changes.

**Purchase and adoption of more efficient light-duty vehicles**

The global number of passenger LDVs increased from roughly 500 million to 800 million in the 15 years from 1990 to 2005, and is projected in the Baseline scenario to reach two billion by 2050. The greenhouse-gas emissions implications of this large and growing demand for LDVs have resulted in increased attention being paid to a variety of new vehicle technologies that hold the promise of substantial improvements in vehicle fuel economy. As discussed in Chapter 7, the pathway to significant greenhouse-gas emissions reductions in LDVs will require the comprehensive adoption of a portfolio of new vehicle technologies.

The transition to low-carbon transportation will rely heavily on consumers’ vehicle choices and their adoption of new driving practices. Vehicle choices will determine which new vehicle technologies will be adopted, how quickly they are adopted, and the level of emissions that will result. Making a rapid transition towards greater fuel efficiency and the use of advanced, alternative fuel vehicle technologies will require programmes and policies that address the social and behavioural factors that influence personal vehicle choices. Drivers may also need to adapt to shorter driving ranges, to learn new refuelling procedures, and to adopt new driving practices associated with acceleration and handling.

Incremental improvements in fuel economy have so far been accomplished through the introduction of more efficient vehicles without major changes in attributes such
as their size, weight and power. Even so, vehicle choices still involve a trade-off between fuel economy on the one hand and power, size and weight on the other. These choices have been factored into the Baseline and BLUE Map scenarios, both of which assume some future increase in vehicle size, weight and power, for example through increasing sales of sport-utility vehicles (SUVs) in many countries.

In the BLUE Shifts scenario, these characteristics are held roughly constant into the future for OECD countries and evolve more slowly than in the Baseline scenario in other countries, maximising the fuel economy benefits of new technologies. This would require significant changes in vehicle choice trends.

More significant changes in consumer behaviours will be needed to accelerate the transition to advanced technology vehicles. Whether the shift is to electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs) or fuel cell vehicles (FCVs), consumers will be faced with significant changes in vehicle attributes. For example, many of these new vehicles are likely to have a much shorter driving range before they need refuelling as well as longer refuelling or recharging times than today’s vehicles. Fuel availability may also be reduced, at least during a transition period.

Many consumers do not pay significant attention to fuel economy when making vehicle purchase decisions.\(^4\) Individuals who express an interest in fuel economy appear to be interested not only in private cost savings but also in communicating a symbolic statement that they view resource conservation or thrift as an important value (Turrentine and Kurani, 2007).

In OECD countries outside the United States, consumers appear to be more sensitive to fuel prices. Some research on elasticities suggests that a 10% increase in fuel prices is likely to result in a 4% increase in fuel efficiency, a 7% decline in fuel demand, a 2% decline in average annual driving distance, and a 1% decline in the overall car stock in the long term (OECD, 2003). Both the EU and Japan have achieved improvements in new vehicle fuel economy while the United States has not (Schipper, 2008). Regardless of the location, however, the main response to increasing fuel prices is an improvement in fuel economy rather than a decrease in car travel (International Transport Forum, 2008).

Even though many consumers face real difficulties in assessing fuel economy benefits, research on consumer choice and vehicle purchase decisions suggests that vehicle labelling can play a useful role in steering people towards choosing more fuel-efficient vehicles. For example, the emission profiles of eco-labelled passenger vehicles have been found to be a significant influencer of consumer purchase decisions in Maine (Noblet, Teisl and Rubin, 2006). Although the labels did not change consumers’ vehicle class preferences, they did shape their choices within specified vehicle classes. Such labelling programmes are likely to benefit from educational activities that inform people that vehicles vary significantly in their environmental characteristics and dispel the myth that existing regulations have addressed emissions (Teisl, Rubin and Noblet, 2008). Labelling programmes could further benefit from new Internet tools; Internet sites are increasingly the preferred

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\(^4\) Some recent research (CBO, 2008) suggests that fuel prices are having a small impact on vehicle-kilometres travelled and vehicle choice in the United States. The study examined the scope and intensity of consumers’ responses to the upward trend in gasoline prices that began in 2003. According to the study, freeway motorists travelling in areas where rail transit was a viable substitute reduced the number of freeway trips by 0.7% for every 50 cent increase in the price of gasoline. Similarly, the market share of light trucks relative to all new passenger vehicles began to decline in 2004.
medium for providing consumers with access to vehicle information as well as enabling them to make meaningful comparisons before they even make the trip to a showroom.\(^5\)

Concerns about fuel economy and the environment have also resulted in a growing demand for hybrid vehicles. The shift to PHEVs and EVs will represent an even more significant technological move for consumers. Many questions remain about consumer perceptions and preferences and how they are likely to affect the speed and scale of adoption of these new and very different vehicle technologies. Consumer polling indicates that once consumers are made aware of PHEV technology, as many as 49% of United States consumers become interested in it.\(^5\) Similarly, in a study of United States car buyers, 26% said that they would pay a USD 4,000 premium for a PHEV (OPC, 2006).

A preliminary assessment of drivers’ perceptions has found that consumer concerns regarding EVs centre on the range and maximum speed of the vehicle, although many drivers expressed a desire to have one (Kurani, Heffner and Turrentine, 2007). United States-based research suggests that there is likely to be widespread interest in PHEVs, but that EVs may be more attractive to people in specific target markets. Successful target markets are likely to include (Turrentine, 1996):

- taxi services in high density urban areas;
- middle-class buyers in high density urban areas in rapidly developing countries;
- residents of gated communities, resorts, retirement towns and new cities;
- urban EV markets in medium density cities of developed economies;
- neighbourhood EVs for multi-vehicle households;
- low-cost, low-range “neighbourhood” EVs for multi-vehicle households;
- “instant” rental cars and car sharing programmes.

Social research suggests that the overall efficiency of the global vehicle stock could be significantly increased by taking consumer preferences, values and perspectives into consideration. People’s choices about vehicle size and market class seem to be primarily governed by the expected use of the vehicle. But within those classes, vehicle choices can be shaped through the thoughtful design and widespread use of vehicle fuel economy labels as well as the implementation of other programmes and policies designed to inform, motivate and empower consumers. One example is fuel economy or CO\(_2\)-based vehicle taxation, that can be linked to the fuel economy rating of each vehicle.

**Reducing driving rebound effects**

Increased energy efficiency can play an important role in lowering the energy consumption and carbon emissions associated with each kilometre travelled. Such improvements tend to make driving cheaper. This may encourage drivers to travel further or more often, so that improvements in fuel economy are offset

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6. When consumers were told that they would have to pay more for the PHEVs than they do for conventional vehicles, interest fell but was still substantial (Synovate Motoresearch, 2006).
by additional travel. This phenomenon is commonly known as the rebound or takeback effect (Schipper, 2000). The rebound effect indicates that travellers are sensitive to travel-related price signals. When the cost of a trip is high, people are less likely to take a trip, but when costs are low, people travel more or further. Such effects should be addressed through policies that help reduce their impact.7 Residual rebound effects should be factored into savings estimates.

A substantial body of research on travel-related rebound effects8 indicates that around 10% to 30% of efficiency-related savings are offset by associated increases in travel demands, i.e. that a 10% reduction in fuel costs results in a 1% to 3% increase in driving. This is consistent with recent reviews of elasticities that find similar relationships for reductions in driving as fuel costs rise (UKERC, 2007; Goodwin, Dargay and Hanly, 2004). Vehicle travel elasticities are typically estimated to be higher for the long run than the short run, and higher in Europe than in the United States. This may be due to the existence of a wider range of travel options in Europe than in the United States.

In the Baseline scenario, the average LDV has a fuel cost of around US 6.5 cents per km of driving in 2050 (Figure 16.7). Many of the technologies and vehicle types that feature prominently in the BLUE Map scenario have a much lower driving cost. Overall the average fuel cost in the BLUE Map scenario in 2050 is about US 4.5 cents per km, about a 33% reduction in cost compared to the Baseline average. With a 20% rebound effect, this would trigger a 6% to 7% increase in driving, with a similar increase in fuel use and CO2 emissions, all else being equal.

**Figure 16.7 Fuel cost per kilometre by vehicle technology, 2050**

![Fuel cost per kilometre by vehicle technology, 2050](image)

Source: IEA Mobility Model database.

**Key point**

Reductions in fuel costs per kilometre of driving could result in increases in overall travel distances which would partially offset the efficiency-related energy savings.

7. It is important to note that in none of the reported cases has the rebound effect exceeded efficiency gains and even in those instances where rebound has occurred, efficiency gains have been substantial. The concern here is with reducing the rebound effect through appropriate policies.

8. The majority of studies on travel-related rebound have been conducted in the United States, with a few in Europe.
On the basis of past trends, it appears that the rebound effects associated with vehicle efficiency improvements and new technology vehicles in the future are likely to be relatively small. Even these relatively small rebound effects could be prevented by an increase in fuel taxes of 33%, to offset the efficiency-induced reduction in driving cost and the rebound effect. Other approaches include increasing the opportunities for non-vehicle travel or reshaping the structure of vehicle-related travel costs. Of particular interest are approaches that shift some of the fixed costs of vehicle ownership such as battery costs or insurance to a payment linked to the distance driven. This type of approach could both accelerate the adoption of new car technologies by lowering the up-front cost and limit the impact of rebound effects by increasing the cost per kilometre travelled.

### Modal shifts

As described in Chapter 7 and in more detail in IEA (2009), the BLUE Shifts scenario reduces both LDV and air travel worldwide in 2050 by 25% relative to the Baseline scenario. This is achieved by a combination of shifting some trips to bus and rail transit and some to non-motorised modes such as walking and cycling, together with the elimination of some travel as a result of land use changes leading to fewer and shorter trips. This would avoid some of the shift towards car and air travel that happens in the Baseline scenario.

Reducing the rate of travel shift towards car and air travel will be challenging as countries get richer. Especially in OECD countries where cars already dominate travel choices, achieving the objectives of the BLUE Shifts scenario will require important changes in the way people plan and execute their daily travel. An important part of achieving the BLUE Shifts scenario is to develop urban and intercity transport systems that make it easier and more convenient to travel by efficient public modes. These changes would encourage some behavioural change to occur as a matter of course. People are unlikely to change their travel patterns much if doing so involves reduced convenience or comfort, or increased travel time. Creating cities that are convenient and safe to move around in without private vehicles is critical to the successful achievement of the outcomes envisaged in the BLUE Shifts scenario.

Efforts to change the modal mix of travel will depend on changes in urban and regional land use, and on creating more opportunities to people to reach destinations by walking or taking mass transit. This can be achieved through denser development patterns, more mixed use development, and improving the infrastructure for walking, cycling and transit. In the developing world, new bus rapid transit systems offer the possibility of efficient, high speed travel at low cost and represent an important opportunity for creating liveable cities that avoid becoming overly car-oriented. Creating an infrastructure that is friendly to pedestrians and cyclists will also be important in all parts of the world. Many cities currently lack pavements on many or most streets, and few have an extensive system of cycle lanes. Such infrastructure also has important benefits for safety, particularly in large developing cities where pedestrians and motor vehicles are typically not well separated at present. For intercity travel, encouraging investment in comfortable coach systems and in intercity rail systems can play an important role in reducing private vehicle travel.
Even with strong investments in public transit and non-motorised modes, there will continue to be strong incentives for people to rely on cars. This is because after a vehicle is purchased, the marginal cost per trip of using the car is low. Driving is often a very convenient, comfortable mode of transport, involving relatively little walking or exposure to the elements. Walking and cycling trips are by nature relatively short and good pavements, bus shelters, bike lanes and lighting need to be available to ensure safety, security and comfort. To encourage use of transit modes, services must be frequent, high speed, safe, and generally of high quality, and access points must be located close to dwellings.

Measures to discourage car travel may be necessary to complement the provision of high quality alternative modes. Such measures can include limiting parking spaces or increasing parking costs, implementing high fuel taxes, or implementing road pricing systems which require payment for crossing into urban areas or per kilometre of travel on specific autoroutes. The advent of electronic pricing systems has increased the viability of road pricing schemes. Car-sharing schemes can also provide car access when needed while reducing the overall reliance on cars by making the car trip the exception rather than the rule (IEA, 2009).

The continued development and adoption of new information and communications technologies (ICT) can reduce the need for travel by allowing people to communicate and work effectively without the need to travel long distances for meetings or the daily commute to their workplace. Through the use of e-commerce, teleconferencing and teleworking, people and companies increasingly have a choice as to how they conduct their business interactions and these choices have important energy implications (Laitner and Ehrhardt-Martinez, 2008; Laitner, Ehrhardt-Martinez and McKinney et al., 2009). In the United States alone, estimates indicate 3.9 million households had at least one telecommuter in 2006 (CEA, 2007). Current rates of telecommuting could double over a 10-year period. This would result in a saving of 588 million tonnes of greenhouse-gas emissions (Fuhr and Pociask, 2007). In order to maximise potential energy savings, programmes and policies need to support and encourage businesses to adopt ICT alternatives to transportation.

The use of a combination of measures including robust investments in alternative modes and some measures to discourage driving, can help shift travel patterns significantly. They might be able to cut average car travel by 25% in 2050 or earlier. In the BLUE Shifts scenario, this results in a 20% reduction both in energy use and in CO₂ emissions (IEA, 2009). More research is needed to better understand the policy interventions that will be needed to achieve specific changes in travel patterns.

**Eco-driving via feedback and programmes**

Energy and CO₂ emissions can also be reduced through interventions aimed at changing driving behaviour, such as reductions in excessive vehicle acceleration and driving speeds, smoothing traffic flows and reducing congestion. Eco-driving represents a set of changes in driving habits that can be learned through training and information guides, including through real-time information being provided by the vehicle to its driver. An increasing number of eco-driving initiatives are integrating and applying high-tech monitoring and feedback devices that provide
dynamic, real-time feedback to drivers. Early programme results suggest that fuel economy savings range between 5% and 15% with some of the best results for individual drivers resulting in fuel economy improvements of 20% to 50% (International Transport Forum, 2008).

A recent United States eco-driving programme involving real-time driver feedback achieved fuel savings of 10% to 20% without significant increases in travel time (Barth and Boriboonsomsin, 2009). The percentage saving was found to be dependent on the congestion level with the largest savings being achieved in severe traffic congestion. In Belgium, a four hour course on fuel-efficient driving achieved average fuel savings of 5.8% although with large differences between individuals (Beusen, Heisakanen, Mourik et al., 2009). These figures may underestimate the potential savings available more widely, as the drivers participating in this study had already made significant efforts to reduce their fuel consumption. Another study (ECMT/IEA, 2005) estimated that average energy savings from widespread eco-driving interventions across OECD regions could probably save approximately 5% of fuel on an ongoing basis. A small number of OECD countries currently run national eco-driving campaigns. Participants have achieved an immediate reduction of CO₂ emissions of around 10% (OECD Observer, 2008).

Since running eco-driving courses is relatively inexpensive, and the lifetime fuel savings per person can be very high, the cost-effectiveness of eco-driving is generally considered to be excellent. Fitting real-time information systems such as fuel economy computers in cars is also highly cost-effective, and provides an important reminder to drivers of the value of eco-driving on a daily basis.

**Policy implications**

Simply making energy efficiency and low-carbon transport options available and economically attractive is unlikely to bring about the rate and degree of change that is needed to mitigate climate change. Efforts to reduce energy consumption and CO₂ emissions must actively involve the people, businesses, organisations and institutions who consume energy. People-centred approaches that integrate and apply social and behavioural insights can provide the means for accelerating energy savings and closing the gap between actual and potential energy efficiencies and CO₂ reductions.

For these reasons, policy makers should take account of social and behavioural perspectives in the development of all relevant energy-related programmes and policies. This will include targeting and tailoring energy efficiency programmes so as to better inform, motivate and empower consumers to change household energy consumption practices. It will also necessitate the development of new, innovative transportation policies that are based on a more comprehensive understanding of vehicle and mode choices, decisions about vehicle-kilometres travelled and the more widespread adoption of eco-driving practices.

To better integrate behavioural issues into policy making, there is a need for more research to develop a better understanding of the energy-saving potential of social and behavioural initiatives. Economists and policy makers should develop
and use enhanced models and frameworks that recognise and incorporate social and behavioural aspects relating to energy consumption. New approaches should complement and extend the purely techno-economic model as a means of understanding, explaining and forecasting energy consumption patterns. Energy programmes and policies should be developed employing a portfolio of energy saving measures that recognise the social and behavioural dynamics of energy consumption.

To facilitate greater residential energy efficiency, governments and utilities need to identify differences in energy consumption practices across different segments of the population, identify barriers to change, and develop tailored programmes. Additional research should be performed to identify the behaviours that can most readily be influenced by policy measures and interventions. Utilities should provide households with in-home feedback devices and associated programmes to help people become better energy managers. Home energy labels should be developed and required for all residential buildings. Utilities should also provide consumers with regular home energy reports so that households have timely information about their energy consumption that is easy to read and understand. This should also provide them with appropriate benchmarks against which they can assess their current energy consumption. Internet-based tools should be developed to help consumers easily and effectively compare the energy implications of appliances and electronics.

To improve the effectiveness of low-carbon transportation options, additional research is needed to investigate existing vehicle choice preferences, how they are changing, and the ways in which preferences vary across different population segments. Policy makers also need to develop a better understanding of the ways in which consumers are likely to respond to new vehicle technologies; this should include investigating the ways in which the principles of behavioural economics might be applied to help shape vehicle choice patterns. Governments also need to investigate the rebound effect to determine the degree to which it offsets efficiency-related savings, to determine where, when and why it occurs and to identify those who are most susceptible to the effects of rebound. The outputs of this research should be used to help determine the policy options that might be most effective in reducing rebound.

In addition, vehicle-specific programmes and policies need to be supported with more comprehensive efforts to look at a more efficient transport system. This includes determining the degree to which smart land use policies have been effective in shaping transportation behaviours and how that effect varies across different population segments. It also involves developing safe, reliable, convenient alternatives to personal transportation, and encouraging drivers to break out of well-established car habits by removing barriers to change. Vehicle manufacturers also should provide greater use of in-car feedback devices which can help consumers become better energy managers. Eco-driving efforts can supplement these strategies, and should be included as a part of drivers’ training classes.
Key findings

- Low-carbon technologies often also reduce air pollution and deliver other energy-related environmental benefits. Careful assessment is needed to leverage potential co-benefits and to ensure that any negative co-impacts are understood, quantified and, where possible, mitigated.

- The fitting of CCS to an ultra-supercritical (USC) coal plant would reduce net efficiency by around 6 to 12 percentage points. CCS would increase water demand due to the carbon dioxide (CO$_2$) capture process and the extraction of additional coal. The construction of new pipeline networks for CO$_2$ transport needs to be carefully managed in order to avoid adverse impacts on ecosystems.

- Natural gas combined cycle (NGCC) power plants emit a quarter of the nitrogen oxides (NO$_x$), sulphur dioxide (SO$_2$) and particulate matter (PM) of a USC coal plant. They consume one-third as much water and use half as much land. Natural gas combustion does not produce significant amounts of solid or liquid waste, eliminating the need for holding ponds or other means of waste disposal. Methane emissions that frequently occur along the natural gas supply chain can partially offset the CO$_2$-reduction benefits of NGCC relative to coal power.

- Nuclear power plants emit no health-damaging air pollutants or greenhouse gases during electricity generation. Nuclear power plants withdraw and consume more water than coal per unit of electricity generated. Waste volumes relative to coal plants are small, but nuclear waste requires particularly careful handling and very long-term secure storage.

- Concentrating solar power (CSP) installations produce no harmful air pollutants or greenhouse gases during operation. Concentrating solar power plants with wet cooling systems consume more water than coal plants per unit of energy produced. Water consumption can be reduced by about 90% by using dry-cooling technology, but with higher upfront costs and an efficiency penalty of 1% to 5%.

- Solar photovoltaic (PV) and wind power are essentially zero-emissions technologies during electricity generation. They provide significant health and environmental benefits relative to coal power. Photovoltaic and wind consume almost no water in normal operation. Wind farms can have negative impacts in relation to their physical presence and noise levels.
The air pollution resulting from biofuel production and combustion depends on the feedstock, harvesting and processing methods, and combustion control technology applied. Where biofuels need to be irrigated, their water consumption is significantly higher than that of any other fuel source. It is important to consider the activities displaced when assessing the net greenhouse gas consequences of land clearing for biofuel production.

Electric vehicles (EVs) and hydrogen fuel-cell vehicles (HFCVs) deliver net reductions in NOx emissions compared with gasoline-powered vehicles even when they use coal-based electricity. They will need to use electricity generated from low-carbon technologies if they are to be able to play their full role in mitigating CO2 emissions. EVs and HFCVs that rely on water-intensive forms of electricity generation use similar or higher volumes of water in their fuel production as conventional gasoline vehicles.

Further study is recommended to refine the estimates in this assessment, and to make them more readily applicable at a regional, national and local level.

Introduction

Objective and scope

Many of the technologies deployed to reduce CO2 emissions will also have wider economic, social and environmental impacts (“co-impacts”). These may be positive or negative. In some cases, a particular set of actions may have both positive and negative co-impacts.

This chapter reviews some of the wider impacts of specific low-carbon technologies. It sets out an analysis of related considerations that policy makers may wish to take into account in deciding whether or not, or how best, to enable the broader deployment of low-carbon energy technology options. Many of these impacts will be setting-specific. Policy makers will need to undertake their own analyses to assess the impacts and magnitudes of specific technologies in different settings.

This chapter focuses primarily on environmental and health-related co-impacts.1 Special attention is given to the following issues that, particularly in developing countries, may raise more immediate political and social concerns than CO2 mitigation:

1. Impacts related to employment, energy security, building corrosion, accident risks, manufacturing and construction are generally outside the scope of this assessment. Construction-related environmental co-impacts result from all power plants, but differences between technologies are generally negligible compared with impacts from other stages of the power-generation life cycle.
- air quality and related impacts on human health;
- water quality and availability; and
- land use and related impacts on food availability and price stability.

This chapter provides a technology-specific review of these impacts in respect of the emerging alternatives for power production and vehicle propulsion that are expected to be more widely deployed in the BLUE Map scenario. Further analysis would be needed to produce a more detailed assessment of other technologies envisaged to come to fruition before 2050 in this scenario.

**Co-impacts in context**

The cost of some co-impacts will be reflected in the price of the products or services that give rise to them. For example, the wider growth of biomass for energy purposes may put pressure on the availability of arable land. This will reflect itself in the market rate for land and hence the cost of biomass. But it will also reflect itself in the price of food, and have an impact possibly much more widely than on just those who benefit from the use of biomass in fuel production.

In cases where the production or consumption of goods and services such as energy, creates costs or benefits that are not reflected in the prices charged for the goods and services being provided, these co-impacts are known as externalities (Khemani and Shapiro, 1993). The consequences of these co-impacts may be borne by individuals or groups who are not responsible for their occurrence and who do not benefit from the activities that cause them. For example, pollutants emitted during the combustion of fossil fuels may degrade air quality and adversely affect the health of nearby populations. In the absence of some means of bringing the external costs to bear on the users of the product or service, there is a risk that consumers will be indifferent to the negative external co-impacts they create.

Several major studies have attempted to value the co-impacts associated with various energy technologies (Box 17.1). A study financed by the European Union estimated that if external costs in the form of damage to the environment and health, excluding those associated with climate change, were taken into account, the cost of electricity produced from coal would double, and the cost of electricity produced from natural gas would increase by 30% (ExternE, 2001). The external costs of energy production and use in the United States in 2005, excluding those associated with climate change, were estimated at USD 120 billion, largely attributable to the human health consequences of the air pollution associated with electricity generation and motor vehicle transportation (NAS, 2009).²

Not all co-impacts are negative. Many low-carbon energy technologies, for example renewable energy, energy efficiency and cleaner fossil fuel technologies, offer cleaner alternatives that also eliminate or significantly reduce other forms of conventional pollution.

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² Valuations of human life and the environment often raise economic, philosophical and ethical questions. There is room for further research and discussion on the best ways to account for these issues in the energy sector.
Box 17.1  Major studies assessing the co-impacts of energy technologies

Electricity generation

• External costs of Energy (ExternE)
For more than 15 years beginning in 1991, 50 research teams in more than 20 countries worked under the auspices of the European Commission to estimate and value the socio-environmental impacts associated with energy conversion. The ultimate objective of this work was to identify ways in which energy prices could better reflect the total economic, social and environmental costs of energy conversion, including policy instruments that could best achieve that end.
www.externe.info.

• New Energy Externalities Development for Sustainability (NEEDS)
The NEEDS project, supported by the Directorate General for Research of the European Commission, refined and further developed the externalities methodology already set up in ExternE through an attempt to design, implement and test an analytical framework to assess the long-term sustainability of energy technology options and policies. The ultimate objective of NEEDS was to evaluate the full (i.e. direct and external) costs and benefits of energy policies and of future energy systems, both at the level of individual countries and for the EU as a whole. NEEDS was completed in March 2009.
www.needs-project.org.

• Renewable Energy Costs and Benefits for Society (RECaBS)
The RECaBS project was initiated by the IEA’s Implementing Agreement on Renewable Energy Technology Deployment. The primary objective of the RECaBS project was to estimate the costs and benefits of electricity from renewable energy sources compared with conventional technologies in a fully documented and transparent way. The main output from the project, completed in October 2007, is a web-based Interactive Energy Calculator, which enables cost-benefit analyses to be undertaken for specific energy technologies.
recabs.iea-retd.org

Passenger vehicle energy sources

• The Greenhouse gases, Regulated Emissions and Energy use in Transportation model (GREET)
To evaluate the full energy and emission impacts of advanced vehicle technologies and new transportation fuels, the fuel cycle from well-to-wheel (WTW) and the vehicle cycle from material recovery to vehicle disposal need to be considered. Sponsored by the United States Department of Energy’s Office of Energy Efficiency and Renewable Energy (EERE), Argonne National Laboratory has developed the GREET Model that allows researchers and analysts to evaluate various vehicle and fuel combinations on a full life-cycle basis.
www.transportation.anl.gov/modeling_simulation/GREET/index.html
It is important to take proper account of co-impacts in considering investments in emerging low-carbon energy technologies. Emerging technologies often require larger upfront investments or give rise to larger operating costs than more mature technologies. Where they produce positive co-benefits, these can in some cases help to narrow projected cost gaps. Where emerging technologies create negative co-impacts, the careful identification and estimation of such impacts and costs may help lead to more sustainable policies and investments.  

Sulphur dioxide, NOx, PM and other air pollutants are harmful to human health and the environment. Air pollution is a particularly serious threat to public health in urban areas across the developing world. Many measures to reduce CO2 emissions also have an impact on air quality. Improving energy efficiency or switching to cleaner, renewable forms of electricity production can reduce both greenhouse-gas emissions and air pollution, thereby leading to co-benefits for human health and the environment.

In the European Union (EU), China, India and the European part of Russia, more than 3.3 billion life-years were lost in 2005 due to PM2.5 (PM with a diameter of 2.5 micrometres or less) exposure alone (Table 17.1). The 2030 Baseline scenario estimates the loss of life-years rising by about 70% to 5.7 billion. The 2030 BLUE Map scenario results in more than 1.2 billion life-years saved relative to the Baseline scenario.

<table>
<thead>
<tr>
<th>Table 17.1</th>
<th>Estimated life-years (in millions) lost due to exposure to PM2.5 emissions</th>
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<tr>
<td></td>
<td>ETP Baseline scenario</td>
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<tr>
<td><strong>Country or region</strong></td>
<td><strong>2005</strong></td>
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<tr>
<td>China</td>
<td>2 233</td>
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<tr>
<td>India</td>
<td>865</td>
</tr>
<tr>
<td>Russia*</td>
<td>47</td>
</tr>
<tr>
<td>European Union</td>
<td>206</td>
</tr>
</tbody>
</table>

* European part only.

Note: The Baseline scenario figures in the table are taken from the Reference scenario in WEO 2009. The BLUE Map scenario figures are assumed to be the same as the WEO 2009 450 PPM scenario.
Sources: IEA (2009); IIASA (2009).

Impact areas

The analysis in this chapter reviews three broad impact areas:

- air impacts: impact on the emission of major pollutants;

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3. It is important also to consider local political, economic and environmental circumstances when weighing the significance of co-impacts.
4. A number of studies indicate these pollutants also have an impact on climate change.
- water impacts: impact on consumption and contamination rates; and
- land impacts: impact on area requirements, surface transformation and the displacement of other uses.

The indirect consequences of these impacts, for example on human health, are often of more interest to policy makers than the direct impacts themselves (Figure 17.1). Indirect outcomes will often depend on local circumstances. For example, the costs associated with air pollution will depend on the quantity, type, location and duration of emissions, as well as the size, geographical distribution and health sensitivity of the population. Given such variability, co-impacts are most effectively assessed and evaluated at national, regional and/or local levels.

Figure 17.1  Energy use has indirect effects on human health and the environment

Direct impact areas

- Air
- Water
- Land

Indirect outcomes

- Human health
- Ecosystems
- Food security

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

Key point

Energy technologies often affect the environment and, in turn, influence outcomes that are highly relevant to policy makers.

Co-impacts in the electricity sector

Technologies assessed

This section assesses the co-impacts of nine supply-side energy technologies in the electricity sector:

- Coal: ultra-supercritical coal combustion (USC). USC is used as a reference baseline for the evaluation of the co-benefits/costs of other technologies;
- Coal: biomass co-combustion (BCC);
- Coal: ultra-supercritical efficiency with post-combustion CCS;

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5. These technologies are expected to be commercially available by 2025. Performance levels and air pollution emission rates are based on reference cases in the NEEDS project. Estimates for water and land co-impacts are based on other studies comparing similar technologies with varying performance levels. Thermal energy technologies are assumed to use wet-cooling systems.
Energy efficiency technologies in buildings also play an important role in the BLUE Map scenario, delivering a significant proportion of total CO₂ reductions by 2050. Energy efficiency can provide environmental co-benefits larger than those that are achievable with even the cleanest forms of electricity production, and often at a lower cost (Box 17.2).

**Box 17.2  ▶ Energy efficiency in buildings**

Energy efficiency technologies for buildings play an important role in achieving the outcomes implicit in the BLUE Map scenario. Energy efficiency, by reducing electricity consumption, frees up existing supplies for other uses and reduces the need for additional generation capacity. Energy efficiency measures are not themselves free of co-impacts, however. These co-impacts, for example those associated with the production of insulation materials, need to be properly factored into any thorough cost-benefit analysis of energy efficiency options.

Energy use in buildings currently accounts for nearly 40% of the world’s total final energy consumption. IEA analysis illustrates how CO₂ emissions can be reduced significantly by applying best available technologies (BATs) to building envelopes and in heating, ventilation and air-conditioning systems, lighting and appliances. Existing buildings can often be retrofitted with improved technologies such as heat pumps, combined heat and power (CHP) and solar heating systems. Energy-efficient new buildings can reduce heating demand by as much as a factor of ten compared to the average buildings being constructed today. The additional costs are often comparatively small, and many efficiency technologies generate a return on investment within several years or less due to savings on electricity bills. The achievement of significant early CO₂ reductions will be critically dependent on retrofitting, given the low turnover rate of existing building stocks.

In addition to offering a low-cost or even cost-saving alternative for CO₂ mitigation, energy-efficient technologies in buildings provide many other benefits associated with lower levels of energy consumption. Positive co-impacts include reduced health-threatening air pollution, lower levels of fresh water consumption and contamination, and a smaller footprint on arable land and wildlife habitats from electricity generation.

Although some energy-efficient technologies carry direct negative environmental impacts, the overall effects are usually small compared to the impacts of generating additional electricity. It is important however, for example, to avoid overly “tight” building designs that trap unhealthy indoor air pollutants, and to minimise the manufacturing and demolition wastes associated with new construction.
Baseline case: USC coal combustion

Coal technology will continue to be the world’s most widely deployed means of power generation in the near future. It continues to fill new capacity needs at a high rate, making up approximately one-third of power generation capacity under construction worldwide (IEA, 2008a).

For the purposes of establishing a baseline against which to evaluate the co-impacts of other generation technologies, the analysis starts from the characteristics of a high-performance USC coal power plant.6

Air impacts

The coal combustion process emits a number of air pollutants with well-documented impacts on human health and the environment, including SO₂, NOₓ, PM, mercury, carbon monoxide, lead, arsenic, ammonia and other toxic substances. SO₂, NOₓ and PM form the primary focus in this assessment.

SO₂ is linked with a number of adverse effects on the respiratory system; is the leading cause of acid rain, which can damage forests, lakes and buildings; and contributes to the formation of lung-damaging PM. NOₓ contributes to the formation of ground-level ozone, which can trigger or exacerbate respiratory illnesses; contributes to the formation of lung-damaging PM; causes acid rain; and can lead to eutrophication of coastal estuaries. PM exposure can cause chronic bronchitis, aggravated asthma and premature death in people with heart and lung disease. PM deposition can change the nutrient balance in soils and bodies of water, and PM suspended in the air is a major cause of reduced visibility in many parts of the world.

Emissions of most air pollutants can be largely controlled with proven technologies, and control standards are expected to tighten over time in developed countries. However, many plants being built or planned, particularly in developing countries, omit available high-level emission controls to reduce construction costs.

In a year, the well-controlled USC coal baseline plant, assuming a 75% capacity factor, would emit an estimated 2 066 tonnes of SO₂, 2 862 tonnes of NOₓ and 261 tonnes of PM.

Water impacts

A typical 600 MW coal-fired power plant with open-loop cooling withdraws more than 48 million litres of water an hour to run its cooling system at full operating capacity (US DOE, 2006). Only a small percentage, around 1 million litres per hour, of this water is consumed, but some is lost to the atmosphere through evaporation.

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6. Based on USC hard-coal reference case in the NEEDS project. Peak net capacity: 600 MW; net energy conversion efficiency: 45%; PM control rate: 99% (7.3E-5 tonnes/mWh including life-cycle emissions); NOₓ control rate: 70% (8.0E-4 tonnes/mWh including life-cycle emissions); SO₂ control rate: 93% (5.8E-4 tonnes/mWh including life-cycle emissions); fuel source: hard coal with sulphur content of 0.9%.
evaporation before being returned to source. An open-loop system can negatively impact ecosystems when heated water is returned to a cooler natural source. This impact can be mitigated by using closed-loop systems, but net water consumption typically increases in such systems due to higher evaporation rates during the cooling process. The use of dry-cooling or air-cooling systems can substantially reduce water consumption in coal power stations, but this approach gives rise to additional fixed and operating costs and has not been widely adopted.

Coal combustion results in large volumes of solid and liquid waste, including fly ash, slag and sludge. Fly ash has economic value as a low-cost additive to concrete, although this can absorb only a relatively small amount of the total fly ash produced each year from coal combustion. Coal sludge contains toxic chemicals and must be stored in secure containment ponds. These waste ponds often exceed 1 billion litres in volume. Advanced control technologies are necessary to prevent acidification and the contamination of nearby water supplies due to nitrates, sulphates and other chemicals in process wastewater. Ineffective storage can result in local contamination from toxic substances such as the arsenic and mercury present in the coal waste.

Coal mining often uses water in large quantities for dust-suppression, land-reclamation and coal-washing, depending on site-specific mining conditions, methods and regulations. Water requirements can range from 40 to 400 litres per tonne of coal mined (US DOE, 2006). In some cases, additional water is used to transport coal to power plants by pipeline in the form of coal-water slurry.

Land impacts

As with all centralised forms of electricity production, coal plants require land. But the footprint of a coal-fired plant is only a very small proportion of the total amount of land that is needed to support its operation. Coal mining and waste disposal use much larger areas of land, depending on the mining method employed and the extent to which land is restored once mining is concluded. Surface mining, in which earth overlying the coal deposits is removed, often destroys large areas of vegetation, damages ecosystems and leaves behind barren soil or rock. Soil at waste sites can become contaminated and typically remains so, well beyond a coal plant’s operational lifetime.

Biomass co-combustion

Biomass co-combustion technology encompasses a range of systems that integrate biomass combustion with the burning of fossil fuels to generate heat or electricity. Modern plants can achieve 20% co-firing, and some smaller coal-fired power stations have targets to increase the proportion of biomass co-firing to 50% or higher (Cremers, 2009). The appeal of BCC is generally tied to a reduction in CO₂ emissions per unit of output compared to 100% coal combustion.

For the purposes of this evaluation, a large-scale power plant with specifications similar to those of the USC baseline is assumed to burn 80% coal and 20% perennial grasses and wood-based forestry products.
Air impacts

Co-combustion with both wood and perennial grasses such as switchgrass would lead to a slight reduction in SO₂ emissions relative to the USC baseline due to the lower sulphur content of biomass compared with coal. Without additional controls, PM emissions may increase with wood co-combustion. With the use of affordable pre-combustion and control technologies, the co-combustion of switchgrass, wood and most other biomass materials can yield modest reductions of SO₂, NOₓ and PM per unit of electricity produced in large-scale systems.

Biomass harvesting can have a negative impact with regard to air emissions if feedstocks are transported over long distances. The long-distance shipping of wood residues and energy crops is not widespread, but may become more common if local supplies are unable to meet the growing demands of large power plants in certain areas. In most cases, the processes required to prepare biomass for co-combustion result in less air pollution than coal mining.

Water impacts

Co-combustion using 20% biomass could reduce water consumption and pollution during the power generation process compared to a coal-fired plant. Although fast-growing energy crops such as switchgrass require little or no irrigation in most climates, more water may be used in the cultivation and harvesting of other types of biomass. The use of biomass waste products such as sawdust and forestry residues is likely to consume less water than would be consumed for coal mining.

Land impacts

Biomass potentially competes with agriculture for arable land. Government polices need to be formulated carefully in order not to incentivise food crop displacement or forest clearing and not to divert non-waste wood away from use in staple wood-based products.

Biomass co-combustion power plants need a reliable supply of biomass. This is a potential constraint to the wider deployment of biomass in power generation. An acute or sustained supply shortage in biomass supplies may result in switching to less efficient or unsustainably harvested biomass feedstocks. This would negate many of the environmental benefits of using biomass for energy production. A surge in demand for woody biomass could also trigger price spikes in products that compete for forest-based resources.

Policy measures need to ensure that responsible and sustainable land management and harvesting practices are employed to minimise the environmental impacts of the cultivation of short-rotation forest plantations and perennial grasses such as switchgrass on surrounding habitats. In some cases, native energy crops can benefit the soil by reducing erosion, improving nutrient retention and filtering out water impurities. With proper harvesting methods such as limiting cut-back during a single harvest, switchgrass can also provide protective habitat for wildlife.
Other considerations

Building codes and worldwide concrete standards generally prohibit the use of fly ash containing materials other than those derived from coal. So fly ash from a BCC plant cannot be used as a concrete additive in the way that fly ash from a coal-only plant can. The feasibility and timing of any revision to building codes to change this position are uncertain.

Carbon capture and storage

Carbon capture and storage technologies can be integrated with a variety of CO₂-emitting processes, although large commercial-scale CCS has not yet been applied to a coal-fired power plant. This evaluation assumes that post-combustion CCS is fitted to an USC plant and captures 90% of CO₂ emissions. Plant size, performance and other emission controls are comparable to the USC coal baseline.

There is an efficiency penalty of 6 to 12 percentage points associated with the additional energy required to capture, compress and transport CO₂ into storage (IEA, 2008b). For the USC baseline, this would translate to a reduction in net efficiency of 13% to 27%. This efficiency penalty would result in additional resource requirements, including proportionally greater amounts of coal, as well as larger volumes of limestone, ammonia and other substances used in pollutant control systems.

Air impacts

Carbon capture systems remove residual amounts of acid gases in addition to CO₂, including SO₂, during power generation. But other air emission rates per unit of output would increase with the use of CCS. Smog-forming NOₓ emissions would increase by approximately 20% to 30% (NEEDS, 2009; Rubin, 2004). Ammonia emissions would also increase as a result of chemical reactions in the capture process (IPCC, 2005). A more detailed analysis is required to determine the net human health and environmental outcomes that would be associated with a decrease in SO₂ emissions together with an increase in one or more other pollutants.

Coal mining and transport are the primary pre-generation activities influenced by CCS. The additional coal required per unit of net power generated necessitates more intensive mining operations, and increases related air pollutant emissions accordingly. Emission levels depend heavily on the method of mining, and the mode and distance of coal transport.

Water impacts

Coal-fired plants with CCS use more water than those without CCS due both to the energy penalty and to the use of water in the carbon capture process (US DOE, 2009). Compared to the USC coal baseline, the addition of CCS is
estimated approximately to double withdrawals and to increase consumption by one-third or more (ANWC, 2009; Hannegan and EPRI, 2009; US DOE, 2009). However, some of the additional water consumption may be offset by the water that is recovered in dehydrating the CO₂ stream.

The additional mining undertaken to supply the coal requirements for CCS also uses more water. Given wide differences in water use between different mines, projects need to be analysed on a case-by-case basis to determine the specific additional water needs created by the application of CCS in power generation.

**Land impacts**

Carbon capture and storage increases land use for additional mining. Land use impacts during the electricity generation process are minimal, if the land required for CO₂ transport and storage is excluded. The large-scale development of a CCS network will make demands on land use, but with proper planning and execution impacts on food crops and ecosystems should be largely avoidable, as should any potential impact on ecosystems from the crossing and compartmentalisation of habitats.8

**Integrated gasification combined cycle**

One of the main advantages of IGCC relative to USC is that it enables a cleaner and less energy-intensive carbon capture process. This section reviews IGCC without carbon capture to highlight how it otherwise differs from the USC coal baseline with respect to environmental co-impacts.9

**Air impacts**

Integrated gasification combined cycle offers some environmental benefits relative to USC, including lower emission levels of most major air pollutants. SO₂ emissions are reduced prior to combustion when acid gases and other contaminants are removed from the syngas. SO₂ emissions are controlled typically at a rate of 95% or higher. The gasification process also enables more efficient control of PM emissions due to the gasifier’s high operating pressures. NOₓ emissions are also generally lower under well-controlled conditions. Emissions of most other hazardous air pollutants from IGCC plants are comparable to, or lower than, the USC baseline.

**Water impacts**

Integrated gasification combined cycle with wet-cooling technology consumes approximately one-third less water than pulverised coal technology. Lower water consumption is due primarily to the gas turbine’s minimal cooling water requirements. This is offset only partially by the additional water required for the gasification process.

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8. There are uncertainties related to the permanence of geologic CO₂ storage and, related to this, the possibility that sequestered CO₂ may leach into and contaminate nearby water supplies. Water contamination is considered to be avoidable with proper site selection and management.

9. While higher efficiencies may be achieved in the long term, the net efficiency for IGCC in this case is assumed to be 45%.
USC requires advanced control and treatment technologies to prevent acidification or contamination of nearby water supplies due to nitrates, sulphates and other chemicals in process wastewater. These systems are even more important in an IGCC plant, which in some ways more closely resembles a chemical plant than a coal-combustion plant.

Integrated gasification combined cycle requires similar amounts of coal as USC and, therefore, results in similar levels of mining-related emissions and water consumption except where coal is transported by pipeline as coal-water slurry. This approach is more economically attractive for the direct feed-in to IGCC plants, but requires relatively large volumes of water.

Land impacts

Land-use issues for IGCC technology are similar to those of the USC baseline. The volume of the ash, slag and slurry by-products is roughly the same as that related to USC technology given equivalent levels of combustion efficiency.

Other considerations

Integrated gasification combined cycle produces large quantities of sulphur and sulphuric acid from the gasification process. These relatively pure forms of sulphur can often be sold for other industrial and chemical uses such as fertiliser production.

Natural gas combined cycle

Natural gas currently accounts for the largest share of electricity capacity under construction in OECD countries, and is heavily relied upon as a fuel for electricity generation in many parts of the world. NGCC power plants use natural gas to power one or more gas turbines and excess heat is used to power one or more steam turbines.

Air impacts

Natural gas combined cycle emits only about 25% as much NO\textsubscript{x}, SO\textsubscript{2} and PM as USC per unit of electricity generated, including upstream emissions from extraction-related activities and transport. Roughly half the NO\textsubscript{x} emissions originate from the operating power plant, with the rest emitted along the fuel supply chain. Most SO\textsubscript{2} emissions occur during gas production. SO\textsubscript{2} emissions from an NGCC power plant are low, except where an unusually high-sulphur mix of natural gas is used.

Water impacts

Natural gas combined cycle plant operation, including natural gas production and transport, consumes roughly one-third as much water as a coal plant at around 200-300 litres per hour for a 400 MW plant operating at full capacity. Most of this water is used in the cooling phase of NGCC plant operation, with relatively little used in natural gas extraction or transport.
Some water pollution can occur during natural gas distribution, if oils used during the production process are released into the environment. The potential for water contamination may increase as the practice of hydraulic fracturing, used to access unconventional natural gas resources in shale rock and coal beds, becomes more widespread. With proper environmental oversight, these impacts are relatively small. The only waste stream from the power plant itself is a small amount of spent catalyst generated every one to five years from the selective catalytic reduction system used to control NO\textsubscript{x} emissions (Spath and Mann, 2000).

**Land impacts**

Natural gas combined cycle plant operation, including onshore natural gas extraction and pipeline transport, uses roughly half as much land as the USC baseline.\textsuperscript{10} The majority of this land is used for drilling sites and for pipeline networks for transport. An NGCC plant uses a relatively small amount of land, particularly due to the smaller area needed for on-site fuel storage and emission-control equipment (Fthenakis and Kim, 2009). NGCC does not produce significant amounts of solid or liquid waste, eliminating the need for holding ponds or other means of waste disposal.

**Other considerations**

Natural gas combined cycle technology is often viewed as a low-carbon alternative to coal-fired power plants, on average emitting half as much CO\textsubscript{2} per unit of electricity output. But natural gas is largely composed of methane, which is a greenhouse gas with a warming effect roughly 20 times stronger than CO\textsubscript{2}, although with a much shorter atmospheric lifetime. Significant amounts of methane are often emitted by way of leaks in the natural gas extraction and supply chain. These emissions have the potential to reduce markedly the climate change benefits of NGCC over USC.

**Nuclear: Generation III**

Nuclear power generation has been in commercial use for more than 50 years. Most new plants commissioned up to 2020 are likely to be based on relatively new third-generation designs which offer improved safety, lower costs and smaller amounts of radioactive waste per unit of electricity generated than previous generations of nuclear power technology.

**Air impacts**

One of the primary advantages of nuclear power technology is that it emits virtually no NO\textsubscript{x}, SO\textsubscript{2}, PM, or greenhouse gases in the electricity production process. Some air pollutants are emitted as a result of electricity production for uranium mining and milling, but these emission levels are less than those associated with coal mining, processing and transport.

\textsuperscript{10} Land use associated with the natural gas fuel cycle may be considerably higher for a particular NGCC plant if a large proportion of its fuel is delivered via pipeline over a long distance.
CHAPTER 17 ENVIRONMENTAL CO-IMPACTS OF EMERGING ENERGY TECHNOLOGIES

Water impacts

Nuclear power plants typically withdraw and consume more water than coal plants per unit of electricity produced (US DOE, 2006). A 1 000 megawatt nuclear plant operating at full capacity typically consumes roughly one to two million litres of water per hour (US DOE, 2006). This demand for water can cause problems for inland nuclear plants in the event of sustained heat waves or droughts. In the case of coastal plants, sea water can be used for cooling, eliminating the need for freshwater consumption. In both cases, a proportion of the water withdrawn for cooling evaporates, and the rest is usually returned to its original source. Large volumes of effluent water that have been heated just a few degrees can adversely affect aquatic ecosystems.11

Underground and open-pit uranium mining can have negative effects with respect to water consumption and contamination. Much smaller volumes of fuel are needed for nuclear power than for coal combustion, but large amounts of ore must be mined to extract sufficient quantities of the type of uranium that is suitable for power generation.

A less invasive alternative to conventional mining for uranium extraction, known as in situ leaching (ISL), involves injecting alkaline or acidic liquids underground to separate out and recover uranium. This technique eliminates the need to physically mine land to recover the ore. It was used for 28% of the world’s uranium production in 2008 (WNA, 2008). It is generally considered to be less environmentally harmful than conventional mining, but it still requires soil and groundwater restoration. Not all uranium deposits are suitable for ISL.

Once mined, natural uranium must be milled, enriched and fabricated into fuel rods before being used in a power plant. These processes require both water and energy. Emissions are largely dependent on the energy profile of the electricity source.

Land impacts

Nuclear plants have a relatively small footprint. Land requirements are broadly similar to that of a USC plant, but much smaller if the space needed for the mining and storage of fuel is taken into account. Waste volumes relative to coal plants are very small, but the radioactivity of nuclear waste requires careful handling procedures and secure stand-off areas. High-level radioactive waste needs to be stored securely for thousands of years. Uranium mining can have negative impacts on surface vegetation and long-term land productivity depending on the site and mining methods employed.

Other considerations

High-level radioactive waste from nuclear power generation requires cooling as the process of natural radioactive decay continues to generate heat, typically for a period of several decades. There is consensus among international experts

11. Discharged cooling water does not contain unsafe levels of radiation under normal operating conditions.
that deep geological disposal provides an appropriate and safe technological route for the final disposal of high-level waste. However, no geological repository for spent fuel or high-level waste has yet been built, primarily because of public concern over safety and the consequent socio-political issues associated with the siting of repositories. As an interim strategy, spent fuel is currently stored in either spent-fuel pools or dry-cask storage on site. There is a need for continued scientific and technical work on specific storage sites, and to increase technical confidence through the further reduction of uncertainties.

Nuclear power suffers from negative perceptions, particularly around risk, which limit its public acceptability in some countries. The impacts of a major nuclear power accident on human health could be enormous, resulting in potentially thousands of premature deaths over a very wide geographical area. But the probability of such an occurrence, given effective plant management and control, is very low. Such low-risk, high-impact issues are not factored into this assessment.

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 exceeds current estimated conventional uranium resources of about 5.4 million tonnes, although so-called unconventional resources in phosphate rocks could amount to an additional 22 million tonnes (NEA, 2008). Increased uranium demand should result in more exploration, which may lead to the discovery of additional conventional resources. In the longer term, the commercial deployment of advanced nuclear reactor and fuel cycle systems may enable greater amounts of energy to be obtained from each tonne of uranium.

**Solar: concentrating solar power**

Concentrating solar power concentrates heat from solar radiation to produce electricity indirectly using conventional steam turbines or other power cycles.

**Air impacts**

Concentrating solar power generation produces no harmful air pollutants, other than from basic plant operations such as mirror-cleaning. These emissions are negligible compared to the USC coal baseline. CSP plants are sometimes coupled with natural gas plant as a backup power source so that the combined plant can generate continuously, even at night. The overall level of emissions of a CSP plant will, therefore, depend on the specific backup technology and the levels of its use.

**Water impacts**

The wet-cooling systems of most existing CSP plant configurations require larger volumes of water than coal power per unit of electricity output (US DOE, 2007). An exception is the parabolic dish-engine system, which uses heat from solar energy to power a heat cycle engine and generate electricity without the need for steam turbines. Such parabolic dish systems are best suited for small-scale power production due to their relatively high costs.
Most CSP plants are sited in sun-rich areas, some of which are water-scarce. So many new CSP projects are exploring dry-cooling technologies, which reduce water consumption by about 90%, but have higher upfront costs and impose an efficiency penalty of 1% to 5% (World Bank, 2009). In dry coastal areas, CSP can provide combined power generation and desalination, using seawater to cool the power cycle and the waste heat to convert seawater into freshwater.

**Land impacts**

Concentrating solar power produces very little solid or liquid waste. CSP plants use more land than USC plants, but the difference is small when the land used for coal mining is taken into account (Fthenakis and Kim, 2009). Linear Fresnel collectors offer the most efficient use of land among existing CSP technologies. Attractive sites for CSP are often unsuitable for agricultural use and are in relatively isolated areas with low population densities. But siting plants in remote natural habitats such as deserts with rare species of plant and animal life may amplify the negative impacts of CSP operations on local ecosystems. Ecological recovery times in arid settings also tend to be longer than in wet environments.

**Solar: photovoltaic power**

Photovoltaic displays many of the characteristics of CSP in terms of environmental co-impacts, but uses much less water than CSP with wet-cooling.

**Air impacts**

Photovoltaic is an essentially zero-emissions technology during the electricity generation process, providing potentially significant health and environmental benefits relative to the USC baseline. Some emissions associated with PV occur during the manufacturing and installation of plant components.

In addition to conventional materials such as steel, cement and aluminium used to construct all power plants, PV technologies require specialty materials such as crystalline silicon for conventional solar panels and tellurium or cadmium for thin-film technologies. Mining and processing these materials consumes energy which, depending on the means of production, can be a source of air pollution. But these emissions are insignificant compared to the cumulative life-cycle air pollution levels associated with a coal plant (Fthenakis, Kim and Alsema, 2008).

**Water impacts**

Photovoltaic energy conversion does not require turbine technology, circumventing the need for water- or air-based cooling systems. This gives PV an advantage over coal, nuclear and CSP in water-scarce regions. As with CSP, relatively small volumes of water are required for PV plant operations and upkeep, primarily to clean the solar panels. Water issues associated with the one-time mining and processing of solar specialty materials for a given plant are negligible when compared with those of coal, which carry on over the lifetime of a plant.
Land impacts

Land impacts for large-scale PV power plants are similar to CSP in that prime sites are unlikely to compete with other human uses, but may disrupt sensitive desert ecosystems. Mining and processing specialty materials for PV components consumes energy, transforms land and can generate toxic waste by-products, but the associated impacts are small compared to the USC baseline.

Unlike CSP and most other thermal energy technologies, PV technology is modular and can be readily used in micro-installations to power rural communities or individual homes. Mounting PV on existing buildings creates no additional land footprint.

Other considerations

Advanced thin-film PV technologies require specialty materials such as tellurium, selenium and cadmium that are relatively rare, highly concentrated in a few regions and in some cases are produced only as by-products of other major commodities. Rapidly increasing demand for these materials in the future could result in supply bottlenecks.

Wind

From a health and environmental perspective, the co-impacts of onshore and offshore technologies vary to some extent in nature, but not significantly in magnitude.

Air impacts

Wind power produces no emissions other than those minimal levels incurred in the manufacture and production of turbines and towers. This feature provides a significant benefit relative to coal, eliminating negative emission-related impacts on human health, ecosystems and climate.

Water impacts

Wind power requires no water for normal operation and generates no water waste or contaminants. Wind power’s ability to generate electricity without consuming water gives it a considerable advantage over most energy options in water-scarce regions where ample wind resources are available.

Land impacts

A large onshore wind farm requires considerably more space than the USC baseline. A wind farm’s relatively large footprint is driven by the need for adequate spacing between turbine blades. Most of the land between the tower bases can be used for other purposes such as agriculture or grazing. Offshore wind installations bypass
the need for land altogether, with the exception of any additional transmission lines that must be built, although they can create competition for sea space, e.g. in relation to shipping, fishing or recreational use.

Other considerations

Wind farms can have negative co-impacts in relation to their physical presence, noise levels and visual impact. If not carefully located, large wind turbines can interfere with the flight paths of birds and bats. The noise and vibration created during the installation and operation of offshore wind turbines can drive away aquatic animal species. Wind turbines may also obstruct landscape views both on and offshore. While these cumulative impacts are generally accepted to be much less significant than the health and environmental impacts of a USC plant, they create important barriers to the wider deployment of wind power in certain areas.

Quantitative results from the electricity sector

Air pollution: NO\textsubscript{x} and SO\textsubscript{2}

With respect to NO\textsubscript{x} and SO\textsubscript{2} emissions, solar, wind and nuclear technologies offer the highest co-benefits relative to the USC baseline. NGCC and, to a more limited extent, IGCC, also emit less than USC (Figure 17.2).

![Figure 17.2 NO\textsubscript{x} and SO\textsubscript{2} emissions from energy technologies in the electricity sector](image)

Note: Estimate for BCC not available; wind estimate is based on offshore technology.

Source: NEEDS Project life-cycle estimates for the year 2025.

Key point

A number of low-carbon energy technologies such as nuclear, wind, solar and NGCC also emit relatively low levels of health-damaging air pollutants.
Water consumption

In terms of water demand, wind and solar PV offer the greatest co-benefits relative to coal, using virtually no water in power generation (Figure 17.3). All forms of coal-based power production, along with nuclear and CSP, require large volumes of water. NGCC falls in between other thermal technologies and PV/wind. Dry cooling significantly reduces the water use normally associated with thermal energy technologies, but lower efficiencies and higher installation costs have prevented dry cooling from becoming widely deployed.

Figure 17.3  Water demands of energy technologies in the electricity sector

![Water demands of energy technologies in the electricity sector](image)

Notes: Coal estimates reflect a range of sub- and supercritical plant configurations. Estimate for BCC not available.
Sources: US DOE (2006); US DOE (2009); Hannegan and EPRI (2009).

Key point

Solar PV and wind power can dramatically reduce water use in the power sector.

Land use

Onshore wind power requires more land than other power technologies per unit of electricity produced (Figure 17.4). Most of this land remains available for secondary uses such as agriculture or grazing. Solar power plants occupy relatively large areas of land relative to fossil fuel combustion plants, but the gap is significantly narrowed when fuel extraction, processing and transport of fossil fuels are taken into account. Nuclear power requires the smallest land area per unit of electricity generated over a typical plant lifetime, but this simplified estimate does not reflect the long time horizon necessary (of the order of thousands of years) for the full land reclamation of nuclear waste disposal sites.
Figure 17.4  Direct land use from energy technologies in the electricity sector

Note: Land use estimates do not account for time of occupation or recovery. Most land occupied by onshore wind farms remains available for secondary uses. Solar PV does not occupy additional land when fitted to buildings.

Key point
Natural gas and nuclear power have a relatively small land footprint compared to coal.

Overall results relative to the coal baseline

Different electricity generation technologies have different environmental co-impacts on air, water and land (Table 17.2). Green shading indicates positive co-impacts are likely relative to the USC baseline; yellow indicates high levels of uncertainty or variability relative to the USC baseline; orange indicates negative co-impacts are likely relative to the USC baseline; and grey indicates minimal or no impacts relative to the USC baseline.

Relative to the USC coal baseline, other advanced coal and nuclear technologies offer lower-carbon baseload power alternatives with a mix of positive and negative environmental co-impacts. Some life-cycle impacts vary significantly depending on the mining, processing, transport and waste disposal methods employed. NGCC emits less air pollution, consumes less water, and has less negative co-impacts during the fuel extraction process than USC coal. Renewable technologies, while generally more expensive, can provide even greater CO$_2$ reductions, as well as a range of environmental benefits to air, water and land.

---

12. Estimates reflect median values where a wide range of estimates was available. The coal estimate reflects a range of sub-critical and supercritical plant configurations, as well as a range of surface and underground mining methods. Land use for coal + CCS is assumed to be 20% greater than the extraction, processing and transport portion of conventional coal, and may not adequately reflect additional impacts related to CO$_2$ transport and storage. IGCC estimate for land use is assumed to be the same as the coal baseline. Estimate for BCC not available.
<table>
<thead>
<tr>
<th>Energy technologies</th>
<th>Life-cycle impacts* (Pre- and post-generation)</th>
<th>Power generation impacts</th>
<th>CO₂ emissions (t/mWh)**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air Water Land</td>
<td>Air Water Land</td>
<td></td>
</tr>
<tr>
<td>Coal: USC</td>
<td>Baseline technology for relative assessments below</td>
<td>0.777</td>
<td></td>
</tr>
<tr>
<td>Coal: Biomass***</td>
<td>Positive Positive Variable / uncertain Variable / uncertain Minimal Minimal</td>
<td>0.622</td>
<td></td>
</tr>
<tr>
<td>Coal: CCS</td>
<td>Negative Negative Negative Variable / uncertain Negative Minimal</td>
<td>0.142</td>
<td></td>
</tr>
<tr>
<td>Coal: IGCC</td>
<td>Minimal Variable / uncertain Minimal Positive Positive Minimal</td>
<td>0.708</td>
<td></td>
</tr>
<tr>
<td>NGCC</td>
<td>Positive Positive Positive Positive Positive Positive</td>
<td>0.403</td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td>Positive Variable / uncertain Variable / uncertain Positive Negative Positive</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>Solar: CSP</td>
<td>Positive Positive Positive Positive Negative Minimal</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>Solar: PV</td>
<td>Positive Positive Positive Positive Positive Minimal</td>
<td>0.009</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>Positive Positive Positive Positive Variable / uncertain</td>
<td>0.002</td>
<td></td>
</tr>
</tbody>
</table>

* Includes co-impacts from fuel extraction, processing and transport. Does not include co-impacts from plant construction or manufacturing.

** Based on NEEDS life-cycle estimates for year 2025. Does not include non-CO₂ greenhouse gases such as methane.

*** Assumes biomass is sustainably harvested and carbon-neutral.

Transport co-impacts: passenger light-duty vehicles

Transport creates a range of co-impacts including greenhouse-gas emissions and air, water and noise pollution (Box 17.3). The following analysis reviews the environmental co-impacts associated with a variety of existing and emerging passenger light-duty vehicle (LDV) and fuel technologies.
Box 17.3  Noise pollution

Most modes of transportation produce noise. Noise levels can be measured, but perceptions of discomfort are more subjective. Even at equivalent noise levels, people are most annoyed by air transport, followed by road transport, and least by rail transport (Griefahn, Marks and Robens, 2006).

Noise reduction is high on the agenda of vehicle manufacturers, but current trends differ across transportation sub-sectors:

- For aircraft, noise levels and fuel consumption can go in opposite directions. For example, a move to efficient open-rotor designs would increase noise.
- For cars, the emergence of low-rolling-resistance tyres and near-silent electric propulsion systems offer the potential for significantly quieter vehicles and less energy use. A minimum level of noise may need to be generated by EVs to avoid increases in vehicle-pedestrian accidents.
- Train technologies are becoming generally quieter. Improving energy efficiency in most cases helps reduce noise levels.

Technologies assessed

This analysis looks at a range of co-impacts for five vehicle and fuel technologies in the passenger LDV sector:

- Gasoline: conventional internal combustion engine (ICE). Due to its extensive use and familiarity in most regions of the world, the gasoline ICE is used as a reference baseline for the evaluation of the co-benefits/costs of other technologies;
- Diesel;
- Biofuels;
- EVs; and
- HFCVs.

All of these technologies play a major role in the BLUE Map scenario.

Air impacts

All LDVs powered by an ICE emit a number of air pollutants with well-established links to human health problems and environmental degradation. Major air pollutants that have been subject to regulation include carbon monoxide (CO), NOx, SO2, PM, hydrocarbons (HC) and volatile organic compounds (VOCs). Most countries have effectively implemented stringent regulations to eliminate lead pollution (Box 17.4).
Ground-level ozone is formed partly as a result of vehicle emissions by chemical reactions in the atmosphere involving primary pollutants such as NO\textsubscript{x} and HCs. Ozone has a range of negative effects on human health and plant life. A number of other toxic pollutants and carcinogens such as benzene are also emitted from gasoline-powered automobiles.

**Box 17.4  ▶ Lead emissions from gasoline**

Lead has been used in gasoline motor fuels for many decades as an octane enhancer. Lead causes neurological damage in humans, with children being particularly vulnerable. Efforts to begin phasing out lead began in the United States in the 1970s, with the introduction of exhaust gas catalytic converters. According to UNEP and the Partnership for Clean Fuels and Vehicles (PCFV), gasoline is now completely lead-free almost everywhere in the world (Figure 17.5). The elimination of lead from fuel has also accelerated the use of catalytic converters, which generally reduce emissions of other pollutants such as NO\textsubscript{x}, CO and HC.

**Figure 17.5  ▶ Leaded petrol phase-out: global status March 2010**

In OECD countries, vehicle emission standards have been steadily tightened since the 1970s, with the emergence of new technologies enabling better control of the combustion process and the post-combustion treatment of exhaust gases. Electronic engine controls and real-time performance sensors have enabled better regulation and brought about significant reductions in many of the most harmful air pollutants around the world.
Carbon monoxide, HC, NO\textsubscript{x} and PM are now regulated in most countries where car ownership is widespread, following procedures defined locally or adapted from standards developed in other countries. Standards are regularly tightened to encourage continuous improvement of engine and exhaust post-treatment technologies. Even so, it took nearly 30 years (from 1975 to 2005) for regulated pollutants to return to the global emission volumes of 1975 when the first regulations were implemented.\textsuperscript{13}

Emission levels for several major vehicle pollutants for different vehicle fuel technologies are shown in Table 17.3. Advanced gasoline and diesel technologies offer across-the-board improvements in emission levels over older cars that still make up the vast majority of the global fleet. Most diesel-powered vehicles on the road today emit substantially higher amounts of PM and NO\textsubscript{x} than conventional gasoline vehicles. However, advances in efficiency and control technologies have narrowed this gap and, with progressively tightening fuel and emission standards, diesel engines in OECD countries are expected to perform broadly as well as gasoline engines in the future with respect to air pollutant emissions per kilometre travelled.

### Table 17.3  
Lifetime emissions from different light-duty vehicle technologies

<table>
<thead>
<tr>
<th>Fuel technology</th>
<th>Fuel consumption (Lge/100km)</th>
<th>GHGs (tCO\textsubscript{2}-eq) WTT</th>
<th>NO\textsubscript{x} (t) WTT</th>
<th>SO\textsubscript{x} (kg) WTT</th>
<th>PM (t) WTT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010 Global avg gasoline vehicle (Euro 2)</td>
<td>8.5</td>
<td>6.1</td>
<td>34.8</td>
<td>2E-03</td>
<td>84.9</td>
</tr>
<tr>
<td>2010 Global avg diesel vehicle (Euro 2)</td>
<td>6.7</td>
<td>3.7</td>
<td>27.4</td>
<td>1E-03</td>
<td>121.5</td>
</tr>
<tr>
<td>2010 New gasoline vehicle (Euro 5)</td>
<td>6.2</td>
<td>4.5</td>
<td>25.3</td>
<td>1E-03</td>
<td>9.0</td>
</tr>
<tr>
<td>2010 Advanced diesel vehicle (Euro 5)</td>
<td>5.8</td>
<td>3.2</td>
<td>24.1</td>
<td>8E-04</td>
<td>27.0</td>
</tr>
<tr>
<td>2010 Hybrid vehicle (Euro 5)</td>
<td>4.5</td>
<td>3.2</td>
<td>18.4</td>
<td>9E-04</td>
<td>9.0</td>
</tr>
<tr>
<td>2010 EV - coal electricity</td>
<td>2.2</td>
<td>25.1</td>
<td>0</td>
<td>3E-02</td>
<td>18.7</td>
</tr>
<tr>
<td>2010 EV - NG electricity</td>
<td>2.2</td>
<td>13.0</td>
<td>0</td>
<td>6E-03</td>
<td>4.7</td>
</tr>
<tr>
<td>2020 HFCV - coal electricity</td>
<td>5.4</td>
<td>60.8</td>
<td>0</td>
<td>6E-02</td>
<td>45.2</td>
</tr>
<tr>
<td>2020 HFCV - NG reforming</td>
<td>5.4</td>
<td>28.8</td>
<td>0</td>
<td>2E-02</td>
<td>11.3</td>
</tr>
</tbody>
</table>

Note: Numbers expressed as XE-0X are in scientific notation (e.g., 2E-03 equals 0.002). Vehicles are assumed to travel 15 000 km per year during a 10-year lifetime. Lge denotes litres of gasoline-equivalent; WTT denotes “well-to-tank”; TTW denotes “tank-to-wheel”. An EV powered exclusively by nuclear, solar, or wind, rather than coal-based electricity, would achieve near-zero well-to-wheel (WTW) emissions. 
Sources: IEA Mobility Model; Delucchi (2003); Bauer et al. (2008).

\textsuperscript{13} Estimate based on IEA Mobility Model.
The use of biofuels can have varying co-impacts on pollution emission levels. Blending ethanol into gasoline generally lowers CO, HC and PM emissions although at some blend levels, evaporative HC emissions can increase. Biodiesel blends result in lower PM, CO and HC emissions compared to petroleum diesel. For both ethanol and biodiesel, changes in NO\textsubscript{X} emissions are generally minor and can go up or down depending on conditions and engine calibration.

Upstream emissions from biofuel production depend on the type of feedstock used, associated changes in land use, harvesting and refinement methods, transport distances, and the combustion control technologies applied. For example, the production of sugar cane-based biofuel produces levels of CO, NO\textsubscript{X} and PM higher than corn ethanol or conventional gasoline over the course of its life-cycle if straw burning is used to harvest the sugar cane (Hess et al., 2009). Recognising this, in Brazil, where most of the world’s sugar cane for biofuels is produced, a 2007 “Agro-environmental Protocol” established jointly by government and the sugar cane industry aims to phase out most burning by 2017.\textsuperscript{14}

Zero-emission vehicles powered by electricity or hydrogen fuel cells are likely to appear in significant numbers before 2050. Such vehicles give rise to pollution only indirectly through the production of the electricity or hydrogen that they use. Conventional emission standards will, therefore, be effectively redundant for such vehicles, although they will still need to be kept in place for the relatively small proportion of conventional ICE vehicles projected by the BLUE Map scenario in 2050.

Figure 17.6 shows that the wider deployment of EVs will deliver significant NO\textsubscript{X} reductions relative to gasoline and diesel technology even with electricity generated from USC coal, but only modest greenhouse-gas reductions. EVs will need to be powered by low-carbon electricity technologies if they are to play the important role in mitigating CO\textsubscript{2} envisaged for them in the BLUE Map scenario. The electrification of vehicle fleets will also bring about a shift in the location of emission sources, as the air pollution associated with passenger vehicles moves away from densely populated urban areas to more rural areas where large power plants tend to be located.

Most OECD countries give three to ten years’ notice of the implementation of new regulations in order to allow equipment manufacturers to adapt vehicle manufacturing processes and scale up new technologies before they become mandatory in new vehicles. Long-term emission standards around the world are expected to tighten and converge by 2020, or soon thereafter (Figure 17.7). As a result, the environmental gap between different technologies and regions is expected to narrow significantly.

Over time, the impact of tighter standards in some regions will be at least partially offset by significant growth in the number of kilometres travelled. In fast-growing urban areas, especially where vehicle emission standards are still not stringent or enforcement is weak, air quality issues related to vehicle emissions will continue to be a matter of concern. In the Baseline scenario, EVs, PHEVs and HFCVs do not penetrate vehicle markets significantly in any country before 2050, and so do not contribute to improving urban air quality. Even in the BLUE Map scenario, they only reach significant shares of the vehicle stock between 2025 and 2030. Reductions in pollutant emissions over the next 15 years will need to continue to come primarily from cleaner fuels and tighter emissions standards for ICE vehicles.

\textsuperscript{14} Protocolo Agroambiental: http://www.saopaulo.sp.gov.br/spnoticias/lenoticia.php?id=87950.
Figure 17.6  ▶ Lifetime emissions from a gasoline, diesel and electric vehicle

Note: The Figure reflects a 2010 new gasoline-powered vehicle (Euro 5 standards) and EV technology powered with electricity from a coal USC power plant. Vehicle lifetime assumes 15 000 km/year for ten years. An EV powered exclusively by nuclear, solar, or wind, rather than coal-based electricity, would achieve near-zero WTW emissions.

Source: IEA Mobility Model and NEEDS project.

Key point

EVs can deliver significant reductions in NOx but will need to be powered by low-carbon electricity technologies if they are to have an important role in mitigating CO2 emissions.

Figure 17.7  ▶ Historical and projected NOx emissions from passenger vehicles

Key point

Projected NOx emissions illustrate the expected convergence of vehicle emission standards throughout the world.
**Water impacts**

Water plays a critical role in the transportation sector, where it is used in large quantities in the exploration and extraction of petroleum and in the refinement processes used to create gasoline and diesel fuels.

Waterways are negatively impacted by the pollution that occurs during oil extraction and refining and from oil and gas spills during fuel transport. Each year, between three and 7.2 billion litres of crude oil, roughly half of which is intended for use in vehicle fuels, are unintentionally released into the environment, including waterways. Biofuels can also damage aquatic ecosystems, not only from spills but also more commonly where fertiliser runoff from biofuel crops contributes to eutrophication and oxygen depletion in bodies of water.

The production of electricity for EVs and diesel consumes roughly similar amounts of water as the production of conventional gasoline (Figure 17.8). Actual water consumption will vary according to the resource extraction methods and fuel refining processes used. This is particularly the case with biofuels. The need to irrigate biofuel crops is the primary cause of water consumption associated with ethanol and biodiesel production using conventional feedstocks such as sugar cane, corn, rapeseed and soybeans. Gasoline blended with 85% ethanol (E85) produced from irrigated corn is estimated to consume 10 to 25 times the amount of water used to produce conventional gasoline and approximately 14 times more than E85 made with non-irrigated corn.

Different biofuel crops require different levels of irrigation. Switchgrass, for example, requires less water than most biofuel feedstocks, delivers energy more efficiently, and can be grown in areas less likely to compete for land with food crops. The use of agricultural waste products as feedstocks can also minimise water consumption.

Location is important in determining the irrigation needs of a given crop. It is estimated that producing one litre of ethanol from sugar cane requires nearly 3 500 litres of irrigation water in India and 2 400 in China, compared to just 90 litres in Brazil (de Fraiture, Giordano and Liao, 2007). National biofuel mandates and growing demand for fuels to power rapidly growing vehicle fleets in China and India could prove a troublesome combination in water-scarce regions unless significant advancements are made in second-generation biofuel technology.

Electric vehicles powered by wind- or PV-generated electricity would use essentially no water during their entire fuel life-cycle. EVs powered by coal-fired electricity use similar amounts of water as conventional gasoline-powered vehicles due to the high volumes of water consumed during coal mining, processing and combustion.

Hydrogen production is an energy-intensive process. The associated water requirements would depend on the mix of electricity used. Hydrogen fuel production for HFCVs, if powered by water-intensive sources of electricity, has been estimated to consume three times as much water as the production of conventional gasoline sufficient to power a vehicle the same distance (King and Webber, 2008).
**Figure 17.8** Water consumption associated with passenger vehicle fuels

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Low Estimate</th>
<th>High Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>E85 Corn ethanol</td>
<td>504 L/H₂O/100km</td>
<td></td>
</tr>
<tr>
<td>Switchgrass ethanol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional gasoline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EV Coal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced diesel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EV PV/Wind</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: US DOE (2006); Wu et al. (2009).

**Key point**

The production of biofuels can use significantly more water than the production of gasoline, if irrigation is needed. Some forms of electricity generation use significantly less.

**Land impacts**

Petroleum-based fuels and biofuels can have a number of negative impacts on land. Petroleum products, including gasoline and diesel fuels, contain toxic substances that contaminate soils and damage plant life if spilled or leaked into the environment. Some biofuel crops cause acidification of soils and biodiversity loss, particularly when forest clearing is involved. But some energy crops such as switchgrass may replenish and restore soils when grown and harvested sustainably.

Many scientists and policy experts have at least partially attributed rising food prices during 2007-2008 to the displacement of food crops in favour of biofuel production, spurred by renewable fuel mandates and government subsidies. It is unclear to what extent the higher prices can be attributed to biofuel production, as other factors such as historically high oil prices may also have played a role in driving up prices. But it is clear that biofuels are significantly more land-intensive than other fuel technologies and that they sometimes compete for a relatively limited stock of arable land.

Approximately 2% of global cropland is currently used to grow fuel crops (UNEP, 2009). Most of the world’s biofuel production today is derived from food crops, with 90% of this production taking place in the United States, Brazil and the EU (UNEP, 2009). There is a possibility that government biofuel targets in these regions, as well as in large, rapidly growing countries such as China and India, may strain food supplies.
Soybeans and sunflowers are particularly land-intensive crops for producing biodiesel, requiring several times more land than palm oil or rapeseed per litre of gasoline-equivalent produced (Figure 17.9). Similarly, corn uses more land than sugar cane or beet to produce an equivalent amount of bioethanol, as measured in litres of gasoline-equivalent.

Land area alone does not provide a complete picture of the environmental impacts of biofuels. Such impacts will also depend for example on the type of land that is given over to biofuel production. Irreparable ecosystem damage and net increases in greenhouse-gas emissions can occur where thick forests or carbon-rich peat lands are cleared for the purpose of planting energy crops.

**Figure 17.9  ▶ Land-use intensity for different types of biofuels**

<table>
<thead>
<tr>
<th>Biofuel Type</th>
<th>Land Area (m²/Lge)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn-based ethanol</td>
<td>4</td>
</tr>
<tr>
<td>Ethanol, beet</td>
<td>5</td>
</tr>
<tr>
<td>Ethanol, sugar cane</td>
<td>6</td>
</tr>
<tr>
<td>Biodiesel, rapeseed</td>
<td>8</td>
</tr>
<tr>
<td>Biodiesel, sunflower</td>
<td>12</td>
</tr>
<tr>
<td>Biodiesel, soy</td>
<td>16</td>
</tr>
<tr>
<td>Biodiesel, palm</td>
<td>17</td>
</tr>
<tr>
<td>Cellulosic</td>
<td>25</td>
</tr>
</tbody>
</table>

*Note:* m²/Lge denotes metres-squared per litre of gasoline-equivalent.

*Sources:* Bauer et al. (2008); IEA (2004); Küsters (2007); Novozymes (2007); Schmer et al. (2008); Tereos (2007).

**Key point**

Land area requirements for biofuel production depend heavily on the type of feedstock used.

Road transport also uses large areas of land for roads and other infrastructure and encourages urban sprawl. Roads can interfere with animal migration corridors. Road accidents have major health impacts on passengers, pedestrians and others, such as cyclists in urban environments. While these effects are widely acknowledged as important considerations when planning transportation infrastructure, the associated impacts do not vary notably by LDV or fuel technology. In the BLUE Shift scenario, there may be less need for cars overall compared with the Baseline scenario due to increased public transportation and to land-use planning efforts to improve non-motorised vehicle and pedestrian access.
Other considerations

In the BLUE Map scenario, EV sales make up about 33% of vehicle sales by 2050. PHEVs constitute 30% of sales. This results in a cumulative EV/PHEV demand for lithium between 2010 and 2050 that approaches the entire estimated reserve base, even with extensive recycling. If EVs are to eventually dominate LDV markets, additional cost-effective lithium resources must be discovered, less lithium must be used per unit of battery storage, or a suitable type of energy storage system that does not use lithium must be developed. Supply bottlenecks for certain rare earth metals integral to EVs may also occur as the technology becomes more widely deployed.

Recommendations for next steps

As policy makers design and implement more aggressive measures to reduce greenhouse-gas emissions, they will also need to take account of the impact of such measures on non-climate aspects of the environment. Such co-impacts can be both positive and negative. They need to be properly accounted for, evaluated and managed.

Policies such as subsidies, tax incentives, or other favourable treatments can distort markets and produce unintended consequences. Such subsidies or distortions are only generally justified where they are designed explicitly and carefully to correct market failures by internalising externalities, for example by shifting cost burdens to the source of a negative externality.

Today’s policy trends suggest that the energy sector’s CO₂ emissions will be increasingly constrained in the future. Rationed allowances, taxes, or the direct regulation of greenhouse-gas emissions can already be found in many parts of the world. Such policies seek directly to influence public- and private-sector choices about energy technology and related investments.

To ensure that such measures do not undermine other desirable policy outcomes, policy makers are recommended to:

- identify the co-impacts of energy technologies;
- quantify those co-impacts;
- monetise those co-impacts where possible or prioritise them if monetisation is not feasible; and
- take account of the value of co-impacts in policy decisions.

Identify the co-impacts of energy technologies

Well-founded policies will take proper account of all the most significant economic, social or environmental impacts they give rise to. Economic impacts can often be observed through measurable indicators such as the price of electricity, employment rates and private financial costs. Social and environmental impacts are often less obvious and more difficult to measure.
An effective assessment of the co-impacts of energy technologies requires the involvement of all stakeholders, including government, industry, academia and private citizens who might impact or be impacted by the technology.

Projects supported by the Clean Development Mechanism (CDM) of the United Nation’s Framework Convention on Climate Change have not always adequately addressed economic, environmental and social development needs even though these are often a high priority for developing countries. To address this issue, Japan’s Ministry of the Environment has launched initiatives based on a co-benefits approach and has taken steps to promote the emphasis of co-benefits through policy and technical dialogue, capacity building, bilateral statements and pilot studies. The co-benefits approach aims to address climate change concerns while also improving local environments and enabling developing countries to achieve their development goals in a more sustainable manner.15

**Quantify co-impacts**

Once an energy technology co-impact has been identified, the next step is to determine the scope and scale of its impact. For air pollution, for example, this involves quantifying the impacts on human health, such as the severity and length of related illnesses or premature deaths and the number of people likely to be affected. Other environmental impacts such as ecosystem damage or building corrosion may also be important factors.

Quantifying such impacts can be highly complex, and results can vary greatly by location depending on many regional and local factors such as population, climate, topography and natural resource profile. The process is further complicated by the need to consider the long-term implications of current decisions and behaviour.

In the United States, a number of states are collaborating with the private sector, researchers, the federal government and environmental groups to advance energy solutions that deliver co-benefits. New York State implemented its Energy $mart programme in 1998 to improve energy reliability, reduce energy costs, mitigate health and environmental effects related to energy use and to improve the state economy.16 The programme is estimated to have reduced participants’ energy bills by USD 570 million; created 4 700 jobs, prevented nearly 2 600 of NOX and 4 700 tonnes of SO2 emissions; and decreased annual CO2 emissions by 2 million tonnes (US EPA, 2010).17

**Monetise co-impacts**

Comparing and weighing technologies and their impacts against one another requires that quantified impacts are normalised with a uniform evaluative measure. This is most commonly done in economic terms by placing a monetary value on all identifiable impacts.

Assigning a monetary value to environmental impacts is often challenging, particularly when the asset affected does not have an established market value. The fact that some policy interventions impose costs on future generations further

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16. www.getenergywsmt.org/
17. www.epa.gov/statelocalclimate/state/tracking/index.html
complicates this process. Uncertainty and risks must also be taken into account, but can be managed to the extent that reasonable probabilities can be estimated. Additional difficulties in valuation arise when environmental losses may be irreversible, as in the case of species extinction.

The concept of equity – the fair distribution of costs and benefits – may also play a role in the weighing of results. Policy makers need to determine the extent to which a relatively wide distribution of benefits is more desirable than the distribution of a larger total benefit to a more limited group of beneficiaries.

If impacts cannot be monetised, they should be subject to a priority-setting process that will enable qualitative judgements to be made in the final evaluation of policy options.

In 2007, the Canadian Ministry of Environment launched a programme for air pollution and climate change mitigation intended to leverage co-benefits achievable from co-ordinated action on both issues. The Canadian government estimates that benefits from the reduced risk of death and illness associated with air quality improvements will be over USD 6 billion annually by 2015.18

Integrate value of co-impacts into policy decisions

Identifying, quantifying and, ideally, placing a value on the co-impacts of low-carbon energy technologies can play an important role in policy development. While financial considerations will continue to be an important driver for climate and energy policies, strategies designed solely based on achieving the largest greenhouse-gas reductions for the lowest direct cost may in some cases yield sub-optimal or unsustainable outcomes.

Traditional environmental co-impacts, alongside broader political, economic, social and regulatory factors, should be carefully considered by policy makers when developing climate and energy strategies.

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18. www.ec.gc.ca/doc/media/m_124/brochure/BR_c1_eng.htm
ANNEXES

Framework assumptions A

IEA energy technology collaboration programme B

Acronyms C

Definitions, abbreviations and units D

References E
This annex provides the framework assumptions used in the development of Energy Technology Perspectives 2010.

Demographic assumptions

Between now and 2050 world population will grow by more than 32% to 9.1 billion, with Asia and Africa leading the way (UN, 2009a). OECD countries will drop from 18% of the world’s population in 2007 to 15% in 2050 (Table A.1).

Table A.1  Population projections (millions)

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>2015</th>
<th>2030</th>
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<td>8 309</td>
<td>9 150</td>
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Sources: IEA (2009a); IEA (2009b); UN (2009a).

Today, about half of the world’s population lives in urban areas, the majority in developing countries. The percentage of urban dwellers has increased by 12% since 1975 and is projected to increase to 70% by 2050 (UN, 2009b).

Between 2007 and 2050, Asia’s urban population will increase from 1.7 billion to 3.5 billion, Africa’s from 0.4 billion to 1.2 billion, and that of Latin America from 0.4 billion to 0.5 billion. As a result of these shifts, developing countries will have more than 80% of the world’s urban population in 2050 (UN, 2009b).

Today, the global median age is 28 years. Over the next four decades the world’s median age will likely increase by ten years, to 38. The proportion of population 60 years or over is projected to rise from 11% in 2009 to 22% in 2050 (UN, 2009c). This ageing will have important consequences for energy consumption as the lifestyle and needs of older people differ from those of young people.
Macroeconomic assumptions

Global GDP is projected to grow by more than three times between 2007 and 2050 to a level of USD 225 trillion per year (Table A.2). In European countries and in Japan it grows by about two-thirds and in North America it more than doubles. The main growth will be outside the OECD.

<table>
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<th>Table A.2</th>
<th>GDP projections (% per year, based on purchasing power parity)</th>
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<td>World</td>
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</table>

Sources: Hawksworth (2006); IEA (2009c).

International energy prices

Energy price projections up to 2030 are taken from World Energy Outlook 2009 (IEA, 2009c). For the period between 2030 and 2050 they have been developed for this study taking account of the long-term oil supply cost curve (IEA, 2008).

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<tr>
<th>Table A.3</th>
<th>Oil, gas and coal price projections for the Baseline scenarios (in 2008 USD per unit)</th>
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<td>IEA crude oil imports</td>
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<td>Natural gas</td>
<td>United States imports</td>
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<td>European imports</td>
<td>MBtu</td>
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<tr>
<td>Japanese imports</td>
<td>MBtu</td>
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<tr>
<td>OECD steam coal imports</td>
<td>Tonne</td>
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</table>

Note: MBtu is million British thermal units. Sources: IEA (2009c); IEA analysis.
Table A.4  Oil, gas and coal price projections for the BLUE scenarios (in 2008 USD per unit)

<table>
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<tr>
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<th>2050</th>
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<td>90</td>
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<td>Natural gas</td>
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<td>United States imports</td>
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<td>10.2</td>
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<td>European imports</td>
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<td>Japanese imports</td>
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<td>OECD steam coal imports</td>
<td>Tonne</td>
<td>121</td>
<td>65</td>
<td>58</td>
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</tbody>
</table>

Note: MBtu is million British thermal units.
Sources: IEA (2009c); IEA analysis.

Methodology

The scenarios have been developed using a combination of four approaches:

- **Global perspective**: the Baseline scenario for 2007 to 2030 is based on the Reference Scenario of the IEA *World Energy Outlook 2009*. This scenario has been further elaborated to include the period 2030 to 2050 using the *Energy Technology Perspectives* (ETP) model. The ETP model of global energy supply and demand has been used to analyse the BLUE scenarios for the period 2007 to 2050.

- **Country/regional perspective**: MARKAL and TIMES models for individual countries and regions have been used to assess the potential for CO₂ emissions reductions in China, OECD Europe and the United States.

- **Sector perspective**: the IEA Secretariat has developed sector models with country- and region-level detail for industry, the residential and commercial sectors, and the transport sector. These spreadsheet models are detailed simulation tools that serve as repositories for information from experts and different models. They also serve as a communication tool between the modelling groups.

- **Technology perspective**: the present and future characteristics of technology options and their potentials have been assessed on the basis of expert information from the IEA Implementing Agreements and other sources.

The primary tool used for the analysis of the BLUE scenarios is the IEA ETP model. This global 15-region model permits the analysis of fuel and technology choices throughout the energy system, from energy extraction through fuel conversion and electricity generation to end-use. The model’s detailed representation of technology options includes about 1 000 individual technologies.

The ETP model belongs to the MARKAL family of bottom-up modelling tools (Fishbone and Abilock, 1981). MARKAL has been developed over the past 30 years by the Energy Technology Systems Analysis Programme (ETSAP), one of the IEA Implementing Agreements (ETSAP, 2004). The ETP-MARKAL model uses optimisation to identify least-cost mixes of energy technologies and fuels to meet the demand for energy services, given constraints like the availability of natural resources.
Additional analysis has been undertaken for China, India, OECD Europe and the United States. Some regions in the ETP model are large, and cover a range of areas with vastly different energy resource availability and energy demands. In such cases, the use of regionalised country models can add value. For this analysis, the IEA Secretariat co-operated with a number of modelling groups with national and/or regional models. The insights from their models, which are based on the same approach as the ETP model, were used to refine the analysis.

The ETP model has been supplemented with detailed demand-side models for all major end-uses in the industry, buildings and transport sectors. These models were developed to assess the effects of policies that do not primarily act on price. These demand-side models explicitly take capital stock turnover into account, and have been used to model the impact of new technologies as they penetrate the market over time.

**Investment modelling limitations**

The investment analysis presented is inevitably a partial assessment of the investment needs for energy-consuming equipment and, to a lesser extent, of the needs in the upstream energy sector. In the industrial, residential and commercial sectors, only major energy-consuming equipment and devices have been covered, as sufficient data do not exist to accurately project the quantity and price of a wide range of small energy-consuming devices – from telephone chargers in homes to coffee machines in business and industry.

There is a question of what boundary to place on investment costs. For example, for cars, the model uses consumer prices, because energy efficiency improvements apply to a wide range of the car’s components, including engines, drive trains, appliances, structural weight, aerodynamics and tyres. For building improvements in the residential and service sectors, however, the model only counts the marginal increase in costs for more energy-efficient homes, because a breakdown of the costs of energy efficiency compared to the fabric or structure of a building would be arbitrary, while including the total construction cost would result in buildings taking up a disproportionate share of investment needs, when their primary role is shelter.

As a result of these issues, and the generally more widely available information on the marginal cost of energy efficiency options, the relative increase or decrease in investment needs in the BLUE scenarios compared to the Baseline scenario should be treated with greater confidence than the absolute level of investment in the Baseline.
IEA Global Energy Technology Network

The IEA provides the framework to accelerate energy technology deployment through multilateral technology initiatives called Implementing Agreements (IAs). Through the IAs, IEA member countries partner with industry and IEA non-member countries to form a cost-effective, global network.

Many Implementing Agreements include participants from IEA non-member countries. China participates in six IAs (buildings, transport, fusion, hydropower and clean fossil fuels), while India participates in three (energy efficiency, clean fossil fuels, fusion). The most recent IEA non-member countries to join IAs include the United Arab Emirates (solar) and Thailand (motor fuels). In addition, the Energy Technology Data Exchange (ETDE) allows access to their extensive database of scientific information to more than 60 non-IEA countries. The Climate Technology Initiative (CTI) engages with IEA non-member countries to share best practice, to build capacity, and to facilitate technology transfer and financing. The Energy Technology Systems Analysis Programme (ETSAP) develops energy modelling software that provides countries with the tools necessary to devise national plans and strategies.

There are currently 50 industrial partners from IEA member countries largely concentrated in multilateral technology initiatives concerning clean fossil fuels and renewables. Six industrial partners to clean fossil fuels IAs are located in key IEA non-member countries: Brazil, China, India, Russia, South Africa and Thailand.

Improving energy efficiency, whether in the buildings and commercial services, electricity, industry or transport sectors, is crucial for the environment and for energy security. Fourteen IAs currently research various aspects of these end-use sectors. One recently created Agreement co-ordinates policies, promote standards and analyse issues related energy efficient electrical equipment.

Clean fossil fuels are at the core of energy demand in the transport and electricity generation sectors and will be for many more years. The work of six IAs focuses on finding ways to make the most of existing resources, while at the same time getting the most from every barrel of oil or tonne of coal while reducing costs and improving efficiency.

Renewable energy technologies provide clean, flexible, stand-alone or grid-connected electricity sources, but they need the correct policy environment and collaboration with industry to facilitate deployment and to further reduce costs. Ten Implementing Agreements research renewable energy technologies.
Figure B.1 Countries participating in the IEA global energy technology network

The boundaries shown on this map do not imply official endorsement or acceptance by the IEA.
### IEA Implementing Agreement Portfolios*

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<th>Basic Science</th>
<th>R&amp;D¹</th>
<th>Demonstration²</th>
<th>Deployment³</th>
<th>Information Exchange</th>
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* Indicates primary focus, which does not exclude significant activities in other areas.
1. Including modelling and technology assessment.
2. Including research, advice and support of demonstration of the particular technology.
3. Including market introduction and technology transfer.
### IEA Implementing Agreement energy sectors*

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</table>

* Indicates primary focus, which does not exclude significant activities in other areas.
1. Including electricity generation and distribution, industrial processes.
2. Including energy consumption and optimisation.
Lastly, nine IAs co-ordinate national and regional fusion programmes, in both IEA member and non-member countries, and share experimental results.

By combining efforts, Implementing Agreement participants save time and resources. Implementing Agreements largely respond to the goals of IEA countries: to enhance energy security, environmental protection and economic growth. The work of the IAs covers the full range of R&D portfolios, working in all aspects of energy – supply, transformation and demand.

Implementing Agreements

End-use

Transport
Advanced Fuel Cells www.ieafuelcell.com
Advanced Materials for Transportation www.iea-ia-amt.org
Advanced Motor Fuels www.iea-amf.vtt.fi
Hybrid and Electric Vehicles www.ieahev.org

Buildings
Buildings and Community Systems www.ecbcs.org
District Heating and Cooling www.iea-dhc.org
Efficient Electrical End-Use Equipment www.iea-4e.org
Energy Storage www.energy-storage.org
Heat Pumping Technologies www.heatpumpcentre.org

Electricity
Demand-Side Management www.ieadsm.org
Electricity Networks, Analysis and R&D www.iea-enard.org
High-Temperature Superconductivity www.superconductivityIEA.org

Industry
Emissions Reduction in Combustion http://ieacombustion.com
Industrial Energy-Related Technology Systems www.iea-iets.org
Fossil Fuels

Clean Coal Centre  www.iea-coal.org.uk
Clean Coal Sciences  http://iea-ccs.fossil.energy.gov
Enhanced Oil Recovery  http://iea-eor.ptrc.ca/
Fluidised Bed Conversion  www.iea-fbc.org
Greenhouse Gas R&D Programme  www.ieagreen.org.uk

Renewable Energy and Hydrogen

Bioenergy  www.ieabioenergy.com
Geothermal  www.iea-gia.org
Hydrogen  www.ieahia.org
Hydropower  www.ieahydro.org
Photovoltaic Power System  www.iea-pvps.org
Renewable Energy Technology Deployment  www.iea-retd.org
Solar Heating and Cooling  www.iea-shc.org
SolarPACES  www.solarpaces.org
Wind Turbine Systems  www.ieawind.org

Fusion

Environment, Safety, Economy of Fusion  www.iea.org/techagr
Fusion Materials  www.frascati.enea.it/ifmif
Large Tokamaks  www-jt60.naka.jaea.go.jp/LT
Nuclear Technology of Fusion Reactors  www.iea.org/techagr
Plasma Wall Interaction in TEXTOR  www.iea.org/techagr
Reversed Field Pinches  www.iea.org/techagr
Stellerator-Heliotron Concept  www.iea.org/techagr
Tokamaks with Poloidal Field Divertors  www.aug.ipp.mpg.de/iea-ia

Cross-Cutting Activities

Climate Technology Initiative  www.climateTech.net
Energy Technology Data Exchange  www.etde.org
Energy Technology Systems Analysis Programme  www.etsap.org

To access all links to Implementing Agreement websites, see www.iea.org/techag.
For more information

The free brochure *Frequently Asked Questions* provides a brief overview of the energy technology collaboration programme.


For highlights of the recent activities of the Implementing Agreements, see the free publication, *Energy Technology Initiatives*.

To learn more about the IEA Committee on Energy Research and Technology (CERT), its working parties and expert groups, consult the IEA website.
www.iea.org/about/stancert.asp

More about the strategy of the CERT can be found in the CERT Strategic Plan 2007-2011 and Action plan 2009-2011
www.iea.org/about/docs/CERT_Strategic_Plan.pdf
www.iea.org/about/docs/cert_action_plan.pdf

The free downloadable publication, *Mobilising Energy Technology* describes activities and achievements of the CERT Working Parties and Expert Groups.

To review the rules and regulations under which Implementing Agreements operate, see the free brochure, *IEA Framework*.
www.iea.org/Textbase/techno/Framework_text.pdf

To receive regular updates on the activities of the IEA Implementing Agreement and the global technology network, subscribe to the free newsletter, *OPEN Energy Technology Bulletin*.
www.iea.org/impagr/cip/index.htm
This annex provides information on acronyms used throughout this publication.

**Acronyms**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>APEC</td>
<td>Asia-Pacific Economic Co-operation</td>
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<td>APP</td>
<td>Asia-Pacific Partnership on Clean Development and Climate</td>
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<td>ARRA</td>
<td>American Recovery and Reinvestment Act</td>
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<td>ASHP</td>
<td>air-source heat pumps</td>
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<td>AST</td>
<td>active solar thermal</td>
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<td>BAT</td>
<td>best available technology</td>
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<td>BAU</td>
<td>business-as-usual</td>
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<td>BCC</td>
<td>biomass co-combustion</td>
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<td>BEE</td>
<td>Bureau of Energy Efficiency (India)</td>
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<td>BEV</td>
<td>battery electric vehicles</td>
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<td>BF</td>
<td>blast furnace</td>
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<td>BFBC</td>
<td>bubbling fluidised-bed combustion</td>
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<td>BIGCC</td>
<td>biomass-integrated gasification with combined cycle</td>
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<td>Bio-SNG</td>
<td>bio-synthetic natural gas</td>
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<td>BOF</td>
<td>basic oxygen furnace</td>
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<td>BPT</td>
<td>best practical technology</td>
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<td>BRIC</td>
<td>Brazil, Russia, India and China</td>
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<tr>
<td>BRICS</td>
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<td>BRICS</td>
<td>BRICS plus Indonesia</td>
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<td>BTL</td>
<td>biomass-to-liquids</td>
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<td>CAFE</td>
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<td>CCGT</td>
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<td>CCS</td>
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<td>CDQ</td>
<td>coke dry quenching</td>
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<td>CEQ</td>
<td>Council on Environmental Quality (United States)</td>
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<td>CER</td>
<td>certified emission reduction</td>
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<td>CERT</td>
<td>IEA Committee on Energy Research and Technology</td>
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<td>CFBC</td>
<td>circulating fluidised-bed combustion</td>
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<td>CFI</td>
<td>commercial financial institutions</td>
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<td>CFL</td>
<td>compact fluorescent lamps</td>
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<td>CHP</td>
<td>combined heat and power</td>
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<td>CIF</td>
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<td>Acronym</td>
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<td>CLEEN</td>
<td>Cluster for Energy and the Environment (Finland)</td>
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<td>CNG</td>
<td>compressed natural gas</td>
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<td>COD</td>
<td>chemical oxygen demand</td>
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<td>COG</td>
<td>coke-oven gas</td>
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<td>COP</td>
<td>coefficient of performance</td>
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<td>COP15</td>
<td>15th Conference of Parties to the United Nations Framework Convention on Climate Change</td>
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<td>CPRS</td>
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<td>CSLF</td>
<td>Carbon Sequestration Leadership Forum</td>
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<td>CSPG</td>
<td>China Southern Power Grid</td>
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<td>development finance institution</td>
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<td>demethyl ether</td>
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<td>export credit agency</td>
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<td>enhanced oil recovery</td>
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<td>European Smart Meters Industry Group</td>
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<td>energy using product</td>
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### ANNEX ACRONYMS

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<td>fluidised bed combustion</td>
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<td>fuel-cell vehicles</td>
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<td>high voltage direct current</td>
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<td>hydrogen fuel cell vehicle</td>
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<td>hi NUC</td>
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<td>high temperature superconductor</td>
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<td>high-voltage direct current</td>
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<td>information and communications technologies</td>
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<td>Innovation China-United Kingdom</td>
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<td>IEA</td>
<td>International Energy Agency</td>
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<td>IEP</td>
<td>integrated energy policy</td>
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<td>integrated gasification combined cycle</td>
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<td>IIGCC</td>
<td>Institutional Investors Group on Climate Change</td>
</tr>
<tr>
<td>ILO</td>
<td>International Labour Organization</td>
</tr>
<tr>
<td>INCR</td>
<td>Investor Network on Climate Risk</td>
</tr>
<tr>
<td>IOE</td>
<td>International Employers Organisation</td>
</tr>
<tr>
<td>IOF</td>
<td>industries of the future</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>IPO</td>
<td>initial public offering</td>
</tr>
<tr>
<td>IPR</td>
<td>intellectual property rights</td>
</tr>
<tr>
<td>IRR</td>
<td>internal rates of return</td>
</tr>
<tr>
<td>ISL</td>
<td><em>in situ</em> leaching</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organisation for Standardisation</td>
</tr>
<tr>
<td>ITUC</td>
<td>International Trade Union Confederation</td>
</tr>
<tr>
<td>LBNL</td>
<td>Lawrence Berkeley National Laboratory</td>
</tr>
<tr>
<td>LCD</td>
<td>liquid crystal display</td>
</tr>
<tr>
<td>LDCs</td>
<td>least developed countries</td>
</tr>
<tr>
<td>LDV</td>
<td>light-duty vehicle</td>
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<tr>
<td>LEDs</td>
<td>light-emitting diodes</td>
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<tr>
<td>LEDCs</td>
<td>least economically developed countries</td>
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<tr>
<td>LFR</td>
<td>linear Fresnel reflectors</td>
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<td>LNG</td>
<td>liquefied natural gas</td>
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<tr>
<td>LOR</td>
<td>licence of right</td>
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<td>LPG</td>
<td>liquefied petroleum gas</td>
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<tr>
<td>M&amp;A</td>
<td>mergers and acquisitions</td>
</tr>
<tr>
<td>MCFC</td>
<td>molten carbonate fuel cells</td>
</tr>
<tr>
<td>MDB</td>
<td>multilateral development bank</td>
</tr>
<tr>
<td>MEF</td>
<td>Major Economies Forum on Energy and Climate</td>
</tr>
<tr>
<td>MEP</td>
<td>minimum energy performance</td>
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<tr>
<td>MER</td>
<td>market exchange rates</td>
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<tr>
<td>MNRE</td>
<td>Ministry of New and Renewable Energy (India)</td>
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<tr>
<td>MOE</td>
<td>molten oxide electrolysis</td>
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<tr>
<td>MoMo</td>
<td>IEA Mobility Model</td>
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<tr>
<td>MPG</td>
<td>miles per gallon</td>
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<tr>
<td>MTO</td>
<td>methanol to olefin</td>
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<td>NAPCC</td>
<td>National Action Plan on Climate Change (India)</td>
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<td>NDRC</td>
<td>National Development and Reform Commission (China)</td>
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<td>NEA</td>
<td>Nuclear Energy Agency (OECD)</td>
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<tr>
<td>NEC</td>
<td>National Energy Commission (China)</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>NEDC</td>
<td>New European Duty Cycle</td>
</tr>
<tr>
<td>NEEDS</td>
<td>New Energy Externalities Development for Sustainability (research project for the European Commission)</td>
</tr>
<tr>
<td>NEP</td>
<td>National Electricity Policy (India)</td>
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<td>NEWNE</td>
<td>Synchronous grid operation of northern, eastern, western and north-eastern grids (India)</td>
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<td>NGCC</td>
<td>Natural gas combined cycle</td>
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<td>NGO</td>
<td>Non-governmental organisation</td>
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<td>NGOC</td>
<td>Natural gas open-cycle</td>
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<td>NMEEE</td>
<td>National Mission on Enhanced Energy Efficiency (India)</td>
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<td>NSM</td>
<td>National Solar Mission (India)</td>
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<td>NSU</td>
<td>Sector Understanding on Export Credits for Nuclear Projects</td>
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<td>NTP</td>
<td>National Tariff Policy (India)</td>
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<td>NZEC</td>
<td>Near Zero Emissions Coal project</td>
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<td>O&amp;M</td>
<td>Operation and maintenance</td>
</tr>
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<td>OCM</td>
<td>Oxidative coupling of methane</td>
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<tr>
<td>ODA</td>
<td>Official development assistance</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation for Economic Cooperation and Development</td>
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<tr>
<td>OEM</td>
<td>Original equipment manufacturer</td>
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<td>OHF</td>
<td>Open-hearth furnace</td>
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<td>OME</td>
<td>Other major economies</td>
</tr>
<tr>
<td>ORC</td>
<td>Organic Rankine cycle</td>
</tr>
<tr>
<td>OSTP</td>
<td>Office of Science and Technology Policy (United States)</td>
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<tr>
<td>OTEC</td>
<td>Ocean thermal energy conversion</td>
</tr>
<tr>
<td>p.p.</td>
<td>Percentage points</td>
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<td>PAFC</td>
<td>Phosphoric acid fuel cells</td>
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<td>PCC</td>
<td>Pulverised coal combustion</td>
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<td>PCFV</td>
<td>Partnership for Clean Fuels and Vehicles</td>
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<td>PE</td>
<td>Private equity</td>
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<td>PEM</td>
<td>Proton exchange membrane</td>
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<td>PEMFC</td>
<td>Polymer electrolyte fuel cells</td>
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<td>PHEV</td>
<td>Plug-in hybrid electric vehicles</td>
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<td>PPP</td>
<td>Purchasing power parity</td>
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<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and development</td>
</tr>
<tr>
<td>RD&amp;D</td>
<td>Research, development and demonstration</td>
</tr>
<tr>
<td>RDD&amp;D</td>
<td>Research, development, demonstration and deployment</td>
</tr>
<tr>
<td>RECaBS</td>
<td>Renewable energy costs and benefits for society</td>
</tr>
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<td>REP</td>
<td>Rural electrification policy (India)</td>
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<td>RGGI</td>
<td>Regional Greenhouse Gas Initiative (United States)</td>
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<td>ROW</td>
<td>Rest of the world</td>
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<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>RSU</td>
<td>Sector Understanding on Export Credits for Renewable Energies and Water Projects</td>
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<td>SA</td>
<td>sectoral agreement</td>
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<td>SC</td>
<td>supercritical</td>
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<td>SCCF</td>
<td>Special Climate Change Fund</td>
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<td>SGCC</td>
<td>State Grid Corporation of China</td>
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<td>SNG</td>
<td>synthetic natural gas</td>
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<td>SOFC</td>
<td>solid oxide fuel cells</td>
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<td>SUV</td>
<td>sport-utility vehicle</td>
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<tr>
<td>SWF</td>
<td>sovereign wealth funds</td>
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<td>Synfuel</td>
<td>synthetic fuel</td>
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<tr>
<td>Syngas</td>
<td>synthetic gas</td>
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<tr>
<td>T&amp;D</td>
<td>transmission and distribution</td>
</tr>
<tr>
<td>TERI</td>
<td>The Energy and Resources Institute (India)</td>
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<tr>
<td>TPES</td>
<td>total primary energy supply</td>
</tr>
<tr>
<td>TTW</td>
<td>tank-to-wheel</td>
</tr>
<tr>
<td>ULCOS</td>
<td>ultra-low CO$_2$ steelmaking</td>
</tr>
<tr>
<td>UN</td>
<td>United Nations</td>
</tr>
<tr>
<td>UN COMTRADE</td>
<td>United Nations Commodity Trade Statistics Database</td>
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<tr>
<td>UNCTAD</td>
<td>United Nations Conference on Trade and Development</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environmental Programme</td>
</tr>
<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
</tr>
<tr>
<td>US AID</td>
<td>United States Agency for International Development</td>
</tr>
<tr>
<td>USC</td>
<td>ultra-supercritical</td>
</tr>
<tr>
<td>USCSC</td>
<td>ultra-supercritical steam cycle</td>
</tr>
<tr>
<td>USD</td>
<td>United States dollar</td>
</tr>
<tr>
<td>UT</td>
<td>Union Territories (India)</td>
</tr>
<tr>
<td>V2G</td>
<td>vehicle to grid</td>
</tr>
<tr>
<td>varRE</td>
<td>variable renewable energy</td>
</tr>
<tr>
<td>VC</td>
<td>venture capital</td>
</tr>
<tr>
<td>WBCSD</td>
<td>World Business Council for Sustainable Development</td>
</tr>
<tr>
<td>WRI</td>
<td>World Resources Institute</td>
</tr>
<tr>
<td>WTT</td>
<td>well-to-tank</td>
</tr>
<tr>
<td>WTW</td>
<td>well-to-wheel</td>
</tr>
</tbody>
</table>
This annex provides information on definitions, abbreviations and units used throughout this publication.

Fuel and process definitions

Aquifer
An underground water reservoir. If the water contains large quantities of minerals, it is a saline aquifer.

Arbitrage
Arbitrage is the practice of taking advantage of a price difference between two or more markets.

Asset finance
Asset finance is a secured business loan in which the borrower pledges its assets as collateral.

Biomass
Biological material that can be used as fuel or for industrial production. Includes solid biomass such as wood, plant and animal products, gases and liquids derived from biomass, industrial waste and municipal waste.

Black liquor
A by-product from chemical pulping processes which consists of lignin residue combined with water and the chemicals used for the extraction of the lignin.

Bond market/bonds
Bond is a formal contract to repay borrowed money with interest at fixed intervals.

Brown coal
Sub-bituminous coal and lignite. Sub-bituminous coal is defined as non-agglomerating coals with a gross calorific value between 4 165 kcal/kg and 5 700 kcal/kg. Lignite is defined as non-agglomerating coal with a gross calorific value less than 4 165 kcal/kg.

Clean coal technologies (CCT)
Technologies designed to enhance the efficiency and the environmental acceptability of coal extraction, preparation and use.

1. More detailed information can be obtained by consulting the annual IEA publications Energy Balances of OECD Countries, Energy Balances of Non-OECD Countries, Coal Information, Oil Information, Gas Information and Electricity Information.
Coal
Unless stated otherwise, coal includes all coal: both coal primary products (including hard coal and lignite, or as it is sometimes called, brown coal) and derived fuels (including patent fuel, coke oven coke, gas coke, coke oven gas and blast furnace gas). Peat is also included in this category.

Coal-to-liquid (CTL)
Coal can be converted into liquid fuels using two different approaches: by direct or indirect coal liquefaction (DCL and ICL). The DCL process involves the dissolution of coal in a mixture of solvents, followed by thermal cracking whereby hydrogen is added as a donor solvent. In the ICL process, the first step is the gasification of coal to produce a synthetic gas, which is then converted in a second step to a liquid fuel through Fischer-Tropsch or methanol synthesis.

Coking coal
Hard coal of a quality that allows the production of coke suitable to support a blast furnace charge.

Coke oven coke
The solid product obtained from the carbonisation of coal, principally coking coal, at high temperature. Semi-coke, the solid product obtained from the carbonisation of coal at low temperatures, is also included, along with coke and semi-coke.

Corporate debt
Corporate debt is the liabilities held by a company used to fund investments.

Derivatives
Derivatives are generally used as an instrument to hedge risk, but can also be used for speculative purposes.

Direct equity investment
Direct equity investments refer to the acquisition of equity (or shares) in a company.

Electricity production
The total amount of electricity generated by a power plant. It includes own-use electricity, as well as transmission and distribution losses.

Energy intensity
A measure of total primary energy use per unit of gross domestic product.

Enhanced oil recovery (EOR)
Also known as tertiary oil recovery, it follows primary recovery (oil produced by the natural pressure in the reservoir) and secondary recovery (using water injection). Various EOR technologies exist, such as steam injection, hydrocarbon injection, underground combustion and CO₂ flooding.

Fischer-Tropsch (FT) synthesis
Catalytic production process for the production of synthetic fuels. Natural gas, coal and biomass feedstocks can be used.

Fuel cell
A device that can be used to convert hydrogen or natural gas into electricity. Various types exist that can be operated at temperatures ranging from 80°C to 1 000°C. Their efficiency ranges from 40% to 60%. For the time being, their application is
limited to niche markets and demonstration projects due to their high cost and the
immature status of the technology, but their use is growing fast.

Futures
Futures are tradable financial contracts.

Gas
Includes natural gas (both associated and non-associated, but excludes natural gas
liquids) and gas-works gas.

Gas-to-liquids (GTL)
The production of synthetic crude from natural gas using a Fischer-Tropsch process.

Hard coal
Coal of gross calorific value greater than 5 700 kcal/kg on an ash-free but moist
basis and with a mean random reflectance of vitrinite of at least 0.6. Hard coal is
further disaggregated into coking coal and steam coal.

Heat
In IEA energy statistics, heat refers to heat produced for sale only. Most heat
included in this category comes from the combustion of fuels, although some small
amounts are produced from geothermal sources, electrically powered heat pumps
and boilers.

Heavy petroleum products
Heavy petroleum products including heavy fuel oil.

Hedge funds
A hedge fund is an investment fund opened to a limited range of investors. These
funds aggressively manage a portfolio of investments that use advanced investment
strategies such as leveraged, long, short and derivative positions with the goal of
generating high returns.

Hydro
The energy content of the electricity produced in hydropower plants assuming
100% efficiency.

Integrated gasification combined-cycle (IGCC)
A technology in which a solid or liquid fuel (coal, heavy oil or biomass) is gasified,
followed by use for electricity generation in a combined-cycle power plant. It is
widely considered a promising electricity generation technology, due to its potential
to achieve high efficiencies and low emissions.

Light petroleum products
Light petroleum products include liquefied petroleum gas, naphtha and gasoline.

Liquefied natural gas (LNG)
Natural gas that has been liquefied by reducing its temperature to -162°C at
atmospheric pressure. In this way, the space requirements for storage and transport
are reduced by a factor of over 600.

Liquidity
Liquidity is the ability to sell assets without significant movement in the price and
with minimum loss of value.
Low-carbon energy technologies
Lower CO₂ emissions, higher-efficiency energy technologies from all sectors (buildings, industry, power and transport) that are being pursued in an effort to mitigate climate change.

Markets
Markets are structures which allow buyers and sellers to exchange any type of goods, services and information.

Middle distillates
Middle distillates include jet fuel, diesel and heating oil.

Nuclear
Nuclear refers to the primary heat equivalent of the electricity produced by a nuclear plant with an assumed average thermal efficiency of 33%.

Oil
Oil includes crude oil, natural gas liquids, refinery feedstocks and additives, other hydrocarbons and other petroleum products (such as refinery gas, ethane, liquefied petroleum gas, aviation gasoline, motor gasoline, jet fuel, kerosene, gas/diesel oil, heavy fuel oil, naphtha, white spirit, lubricants, paraffin waxes and petroleum coke).

On-balance sheet funding
On-balance sheet funding is debt and equity issued by a company which appears on the company’s balance sheet to fund investments.

Options
Options are instruments that convey the rights, but not the obligation to engage in a future transaction on an underlying security or in a future contract.

Other renewables
Includes geothermal, solar, wind, tide/wave/ocean energy for electricity generation. The direct use of geothermal and solar heat is also included in this category.

Private equity
Private equity is money invested in companies that are not publicly traded on a stock exchange or invested as part of buyouts of publicly traded companies in order to make them private companies.

Project finance
Project finance is the financing of long-term infrastructure, industrial projects and public services, based upon a non-recourse or limited recourse financial structure where project debt and equity used to finance the project are paid back from the cashflow generated by the project.

Renewables
Energy resources, where energy is derived from natural processes that are replenished constantly. They include geothermal, solar, wind, tide/wave/ocean, hydropower, biomass and biofuels.

Purchasing power parity (PPP)
The rate of currency conversion that equalises the purchasing power of different currencies. It makes allowance for the differences in price levels and spending patterns between different countries.
Spot
Spot price is the price that is quoted for immediate settlement of a transaction.

Steam coal
All other hard coal that is not classified as coking coal. Also included are recovered slurries, middlings and other low-grade coal products not further classified by type. Coal of this quality is also commonly known as thermal coal.

Synthetic fuels
Synthetic fuel or synfuel is any liquid fuel obtained from coal, natural gas or biomass. The best known process is the Fischer-Tropsch synthesis. An intermediate step in the production of synthetic fuel is often syngas, a mixture of carbon monoxide and hydrogen produced from coal which is sometimes directly used as an industrial fuel.

Technology transfer
The term “technology transfer” has two definitions. The first definition is the process of converting scientific findings from research laboratories into useful products by the private sector. The second definition is used more in economic development literature and involves cross-border transmission of technology from one country to another.

Traditional biomass
Refers mainly to non-commercial biomass use.

Transactions
Transaction is a condition under a contract between a buyer and seller to exchange an asset for payment.

Total final consumption (TFC)
The sum of consumption by the different end-use sectors. Total final consumption is broken down into energy demand in the following sectors: industry, transport, other (includes agriculture, residential, commercial and public services) and non-energy uses. Industry includes manufacturing, construction and mining industries. In final consumption, petrochemical feedstocks appear under industry use. Other non-energy uses are shown under non-energy use.

Total primary energy supply (TPES)
Total primary energy supply is equivalent to total primary energy demand. This represents inland demand only and, except for world energy demand, excludes international marine and aviation bunkers.

Unconventional oil
Includes oil shale, oil sands-based extra heavy oil and bitumen, derivatives such as synthetic crude products, and liquids derived from natural gas – gas-to-liquid (GTL) or coal-to-liquid (CTL).

Venture capital
Venture capital is a form of private capital typically provided for early stage, high potential growth companies.

Regional definitions

Africa
Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of Congo,

Central and South America
Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, the Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, St. Kitts-Nevis-Anguilla, Saint Lucia, St. Vincent-Grenadines and Suriname, Trinidad and Tobago, Uruguay and Venezuela.

China
China refers to the People’s Republic of China including Hong Kong.

Developing countries
China, India and other developing Asia, Central and South America, Africa and the Middle East.

Former Soviet Union (FSU)
Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan.

Group of Eight (G8)
Canada, France, Germany, Italy, Japan, Russia, the United Kingdom and the United States.

G8+5 countries
The G8 nations (Canada, France, Germany, Italy, Japan, Russia, the United Kingdom and the United States), plus the five leading emerging economies – Brazil, China, India, Mexico and South Africa.

IEA member countries
Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Republic of Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

Middle East
Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, the United Arab Emirates and Yemen. For oil and gas production, it includes the neutral zone between Saudi Arabia and Iraq.

OECD member countries
Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

Organisation of Petroleum Exporting Countries (OPEC)
Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates and Venezuela.
Other developing Asia

Transition economies
Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Estonia, the Federal Republic of Yugoslavia, the former Yugoslav Republic of Macedonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Romania, Russia, Slovenia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan.

Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>CO</td>
<td>carbon monoxide</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>carbon dioxide</td>
</tr>
<tr>
<td>CO$_2$-eq</td>
<td>carbon dioxide-equivalent</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>methane</td>
</tr>
<tr>
<td>H$_2$</td>
<td>hydrogen</td>
</tr>
<tr>
<td>H$_2$O</td>
<td>water</td>
</tr>
<tr>
<td>HC</td>
<td>hydrocarbons</td>
</tr>
<tr>
<td>N$_2$O</td>
<td>nitrous oxide</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>nitrogen oxides</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>particulate matter with a diameter of 2.5 micrometers or less</td>
</tr>
<tr>
<td>PM</td>
<td>particulate matter</td>
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<td>SO$_2$</td>
<td>sulphur dioxide</td>
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<tr>
<td>VOC</td>
<td>volatile organic compound</td>
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Units of measure

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<td>barrel</td>
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<tr>
<td>bcm</td>
<td>billion cubic metres</td>
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<td>bn</td>
<td>billion</td>
</tr>
<tr>
<td>bt</td>
<td>billion tonne</td>
</tr>
<tr>
<td>°C</td>
<td>degrees Celsius</td>
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<tr>
<td>EJ</td>
<td>exajoule = 10$^{18}$ joules</td>
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<tr>
<td>g</td>
<td>grammes</td>
</tr>
<tr>
<td>gce</td>
<td>grammes of coal equivalent</td>
</tr>
<tr>
<td>GJ</td>
<td>gigajoule = 10$^{9}$ joules</td>
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<tr>
<td>Gt</td>
<td>gigatonne = 10$^{9}$ tonnes</td>
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<tr>
<td>GW</td>
<td>gigawatt = 10$^{9}$ watt</td>
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<td>GWh$_{h}$</td>
<td>gigawatt-hours = 10$^{9}$ watt x 1 hour</td>
</tr>
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<td>GW$_{th}$</td>
<td>gigawatt thermal capacity</td>
</tr>
<tr>
<td>Symbol</td>
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<tr>
<td>h</td>
<td>hours</td>
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<td>K</td>
<td>degrees Kelvin</td>
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<td>kg</td>
<td>kilogrammes = $10^3$ grammes</td>
</tr>
<tr>
<td>km</td>
<td>kilometre = $10^3$ metres</td>
</tr>
<tr>
<td>km/h</td>
<td>kilometre per hour</td>
</tr>
<tr>
<td>km²</td>
<td>square kilometre</td>
</tr>
<tr>
<td>Ktoe</td>
<td>kilotonne of oil equivalent = $10^3$ tonne of oil equivalent</td>
</tr>
<tr>
<td>kV</td>
<td>kilovolt = $10^3$ volt</td>
</tr>
<tr>
<td>kW_e</td>
<td>kilowatt electrical capacity</td>
</tr>
<tr>
<td>kWh</td>
<td>kilowatt-hour = $10^3$ watt x 1 hour</td>
</tr>
<tr>
<td>kW_th</td>
<td>kilowatt thermal capacity</td>
</tr>
<tr>
<td>l</td>
<td>litres</td>
</tr>
<tr>
<td>l/100km</td>
<td>litre per 100 kilometres</td>
</tr>
<tr>
<td>lge</td>
<td>litres of gasoline equivalent</td>
</tr>
<tr>
<td>m²</td>
<td>square metre</td>
</tr>
<tr>
<td>mbd</td>
<td>million barrels a day</td>
</tr>
<tr>
<td>MJ</td>
<td>megajoules = $10^6$ joules</td>
</tr>
<tr>
<td>Mt</td>
<td>megatonne = $10^6$ tonnes</td>
</tr>
<tr>
<td>Mtoe</td>
<td>million tonne of oil equivalent = $10^6$ tonne of oil equivalent</td>
</tr>
<tr>
<td>MW</td>
<td>megawatt = $10^6$ watt</td>
</tr>
<tr>
<td>MWh</td>
<td>megawatt-hours = $10^6$ watt x 1 hour</td>
</tr>
<tr>
<td>pkm</td>
<td>passenger-kilometre</td>
</tr>
<tr>
<td>ppm</td>
<td>parts per million</td>
</tr>
<tr>
<td>PWh</td>
<td>petawatt-hour = $10^{15}$ watt x 1 hour</td>
</tr>
<tr>
<td>t</td>
<td>tonne</td>
</tr>
<tr>
<td>t/y</td>
<td>tonne per year</td>
</tr>
<tr>
<td>tcm</td>
<td>trillion cubic metres</td>
</tr>
<tr>
<td>tkm</td>
<td>tonne-kilometres</td>
</tr>
<tr>
<td>toe</td>
<td>tonne of oil equivalent</td>
</tr>
<tr>
<td>trn</td>
<td>trillion</td>
</tr>
<tr>
<td>TWh</td>
<td>terawatt-hour = $10^{12}$ watt x 1 hour</td>
</tr>
<tr>
<td>W</td>
<td>watt</td>
</tr>
</tbody>
</table>
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Annex A


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