INTERNATIONAL ENERGY AGENCY

ENERGY TECHNOLOGY PERSPECTIVES 2008

In support of the G8 Plan of Action

Scenarios & Strategies to 2050

Executive Summary

OECD

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Scenarios & Strategies to 2050

The world needs ever increasing energy supplies to sustain economic growth and development. But energy resources are under pressure and CO_2 emissions from today's energy use already threaten our climate. What options do we have for switching to a cleaner and more efficient energy future? How much will it cost? And what policies do we need?

This second edition of *Energy Technology Perspectives* addresses these questions, drawing on the renowned expertise of the International Energy Agency and its energy technology network.

This publication responds to the G8 call on the IEA to provide guidance for decision makers on how to bridge the gap between what is happening and what needs to be done in order to build a clean, clever and competitive energy future.

The IEA analysis demonstrates that a more sustainable energy future is within our reach, and that technology is the key. Increased energy efficiency, CO_2 capture and storage, renewables, and nuclear power will all be important. We must act *now* if we are to unlock the potential of current and emerging technologies and reduce the dependency on fossil fuels with its consequent effects on energy security and the environment.

This innovative work demonstrates how energy technologies can make a difference in an ambitious series of global scenarios to 2050. The study contains technology road maps for all key energy sectors, including electricity generation, buildings, industry and transport. *Energy Technology Perspectives 2008* provides detailed technology and policy insights to help focus the discussion and debate in energy circles.

EXECUTIVE SUMMARY

Introduction

We are facing serious challenges in the energy sector. The global economy is set to grow four-fold between now and 2050 and growth could approach ten-fold in developing countries like China and India. This promises economic benefits and huge improvements in people's standards of living, but also involves much more use of energy. Unsustainable pressure on natural resources and on the environment is inevitable if energy demand is not de-coupled from economic growth and fossil fuel demand reduced.

The situation is getting worse. Since the 2006 edition of *Energy Technology Perspectives* (ETP), global CO_2 emissions and oil demand have increased steadily. At 7% above our previous outlook, today's best estimates under our "business-as-usual" Baseline scenario foreshadow a 70% increase in oil demand by 2050 and a 130% rise in CO_2 emissions. That is, in the absence of policy change and major supply constraints. According to the Intergovernmental Panel on Climate Change (IPCC), a rise in CO_2 emissions of such magnitude could raise global average temperatures by 6°C (eventual stabilisation level), perhaps more. The consequences would be significant change in all aspects of life and irreversible change in the natural environment.

A global revolution is needed in ways that energy is supplied and used. Far greater energy efficiency is a core requirement. Renewables, nuclear power, and CO_2 capture and storage (CCS) must be deployed on a massive scale, and carbon-free transport developed. **A dramatic shift is needed in government policies,** notably creating a higher level of long-term policy certainty over future demand for low carbon technologies, upon which industry's decision makers can rely. **Unprecedented levels of co-operation among all major economies** will also be crucial, bearing in mind that less than one-third of "business-as-usual" global emissions in 2050 are expected to stem from OECD countries.

In short, the **global energy economy will need to be transformed** over the coming decades. The aim of this book is to explain how. It presents an in-depth review of the status and outlook for existing and advanced clean energy technologies, offering **scenario analysis** of how a mix of these technologies can make the difference. This edition of *Energy Technology Perspectives* also offers **global roadmaps of the 17 technologies** that we believe can make the largest contributions, showing what action is needed to realise their full potential, and when**.**

Our scenario analysis deals solely with energy-related CO_2 emissions, which account for most of anthropogenic greenhouse gas emissions. However, the ultimate climate change effect of reductions in energy-related emissions will depend, to some degree, on whether other emissions can be reduced similarly. Therefore a chapter on methane, another important greenhouse gas, is included.

The analysis presented here draws on modelling work within the IEA Secretariat and expertise from the IEA international energy technology collaboration network. *Energy Technology Perspectives* is a companion to the IEA *World Energy Outlook 2007,* taking the same Baseline scenario to 2030 and extending it to 2050. The present study carries forward the analysis contained in the 2006 edition of ETP, in the light of the IPCC 4th Assessment Report released in November 2007.

Several different scenarios are presented. The set of ETP 2008 "ACT Scenarios" shows how global CO_2 emissions could be brought back to current levels by 2050. The set of ETP 2008 "BLUE Scenarios" targets a 50% reduction in CO_2 emissions by 2050. This summary focuses on just one scenario from each set, the ACT Map and the BLUE Map.

ACT scenarios

Technologies that already exist, or are in an advanced state of development, can bring global CO_2 emission back to current levels by 2050. Emissions need to peak between 2020 and 2030. The ACT Map scenario implies adoption of a wide range of technologies with marginal costs up to USD 50[1] per tonne of CO_2 saved when fully commercialised. This level of effort affects certain energy related activities profoundly. It would approximately double the generating costs of a coal power station not equipped with CO_2 capture and storage. The marginal cost figure is twice that estimated two years ago in ETP 2006, mainly reflecting accelerating trends in CO_2 emissions and an approximate doubling of some engineering costs, in part due to the declining value of the dollar.

The task is difficult and costly. Additional investment needs in the energy sector are estimated at USD 17 trillion between now and 2050. This is on average around USD 400 billion per year, roughly equivalent to the gross domestic product (GDP) of the Netherlands, or 0.4% of global GDP each year between now and 2050.

BLUE scenarios

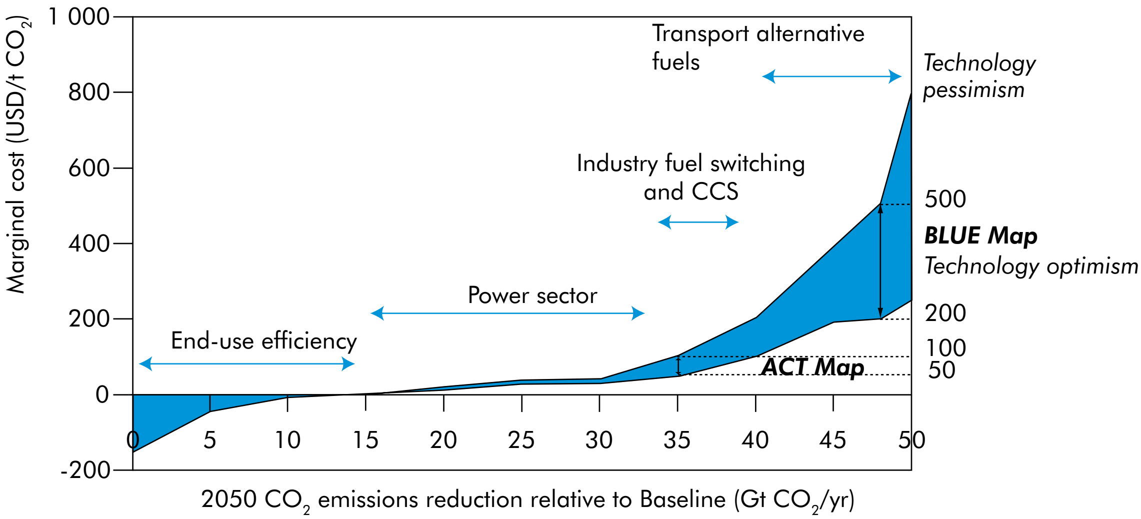
But returning emissions to 2005 levels may not be enough. The IPCC has concluded that emissions must be reduced by 50% to 85% by 2050 if global warming is to be confined to between 2°C and 2.4°C. G8 leaders agreed at the Heiligendamm Summit in 2007 to seriously consider a global 50% CO_2 reduction target.

Reducing CO_2 emissions by 50% (from current levels) by 2050 represents a tough challenge. This scenario implies a very rapid change of direction. Costs are not only substantially higher, but also much more uncertain, because the BLUE scenarios demand deployment of technologies still under development, whose progress and ultimate success are hard to predict. **While the ACT scenarios are demanding, the BLUE scenarios require urgent implementation of unprecedented and far-reaching new policies in the energy sector.**

1 All costs are in real 2005 US dollars.

Based on optimistic assumptions about the progress of key technologies, the BLUE Map scenario requires deployment of all technologies involving costs of up to USD 200 per tonne of CO_2 saved when fully commercialised. If the progress of these technologies fails to reach expectations, costs may rise to as much as USD 500 per tonne. At the margin, therefore, the BLUE Map scenario requires technologies at least four times as costly as the most expensive technology options needed for ACT Map. However, the *average* cost of the technologies needed for BLUE Map is much lower than the marginal, in the range of USD 38 to USD 117 per tonne of CO_2 saved. Figure ES.1 shows how the marginal costs of CO_2 abatement in 2050 increase as the targeted CO_2 savings increase beyond those in ACT Map to reach the higher levels needed for BLUE Map.

Figure ES.1 ▶ ***Marginal emission reduction costs for the global energy system, 2050***



Additional investment needs in the BLUE Map scenario are USD 45 trillion over the period up to 2050. They cover additional R&D, larger deployment investment in technologies not yet market-competitive (even with CO_2 reduction incentives), and commercial investment in low-carbon options (stimulated by CO_2 reduction incentives). The total is about USD 1.1 trillion per year. This is roughly equivalent to the current GDP of Italy. It represents an average of some 1.1% of global GDP each year from now until 2050. This expenditure reflects a re-direction of economic activity and employment, and not necessarily a reduction of GDP. While there will be impacts on global GDP, these are hard to predict and beyond the scope of this analysis.

Benefits from investment

While the additional investments required for both ACT and BLUE scenarios are a measure of the task ahead, they do not represent net costs. This is because technology investments in energy efficiency, in many renewables and in nuclear power all reduce fuel requirements. **In both ACT and BLUE scenarios, the estimated total undiscounted fuel cost savings for coal, oil and gas over the period to 2050 are greater than the additional investment required** (valuing these fuels at Baseline prices). If we discount at 3%, fuel savings exceed additional investment needs in the ACT Map scenario, but not in the BLUE scenarios. Discounting at 10%, results in the additional investment needs exceeding fuel savings in both the ACT and BLUE scenarios.

Some investments, of course, are very cost-effective, particularly in energy efficiency. By contrast, at the high-cost end of the range required for the BLUE scenarios, some investments are only economic with a high CO_2 reduction incentive. Not all the necessary investments reduce fuel costs, however. Investment in CCS will *increase* the amount of coal needed for a given electrical output, because of the reduction in power station efficiency.

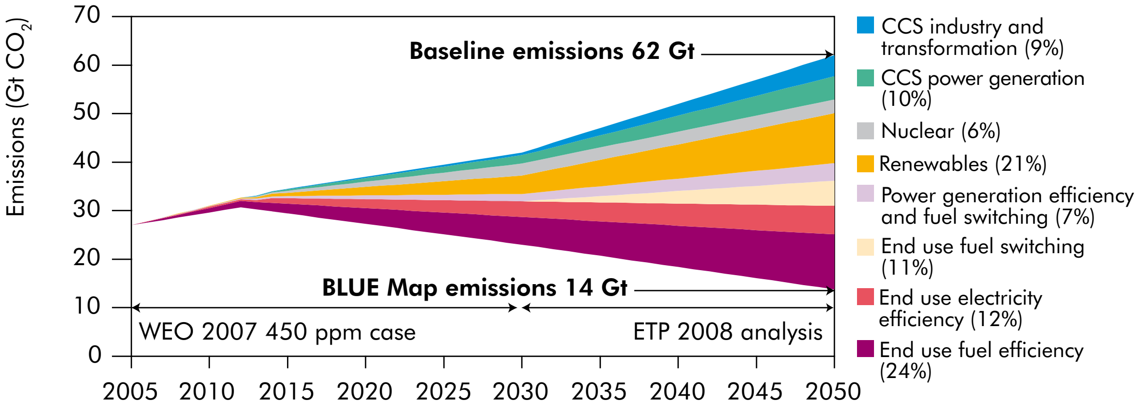
A more balanced oil market

In addition to their environmental benefits, the ACT and BLUE scenarios also show a more balanced outlook for oil markets. In the ACT Map scenario, demand for oil continues to grow. It rises by 12% between now and 2050, which is much less than in the baseline. The BLUE Map scenario shows a much more marked difference, with oil demand actually 27% *less* than today in 2050. However, in all scenarios massive investments in fossil fuel supply will be needed in the coming decades.

The technology revolution

In both ACT and BLUE scenarios, **energy efficiency improvements in buildings, appliances, transport, industry and power generation represent the largest and least costly savings**. Next in the hierarchy of importance come measures to substantially **decarbonise power generation.** This can be achieved through a combination of renewables, nuclear power, and use of CCS at fossil fuel plants. Whichever the final target, action in all these areas is urgent and necessary. It is particularly important to avoid lock-in of inefficient technologies for decades to come. In the BLUE Map scenario, higher-cost options **such as CCS in industry and alternative transport fuels need to be deployed.** Figure ES.2 shows the sources of CO_2 savings in the BLUE Map scenario compared to the Baseline scenario. Policy makers should remember that long lead times are frequently required to implement changes and that priorities in each country will vary according to national circumstances. Reducing energy sector methane emissions, moreover, is also an important part of an overall climate change strategy, as these emissions offer significant near-term and cost-effective greenhouse gas reduction opportunities.

Figure ES.2 ▶ Comparison of the *World Energy Outlook 2007* 450 ppm case and the BLUE Map scenario, 2005-2050



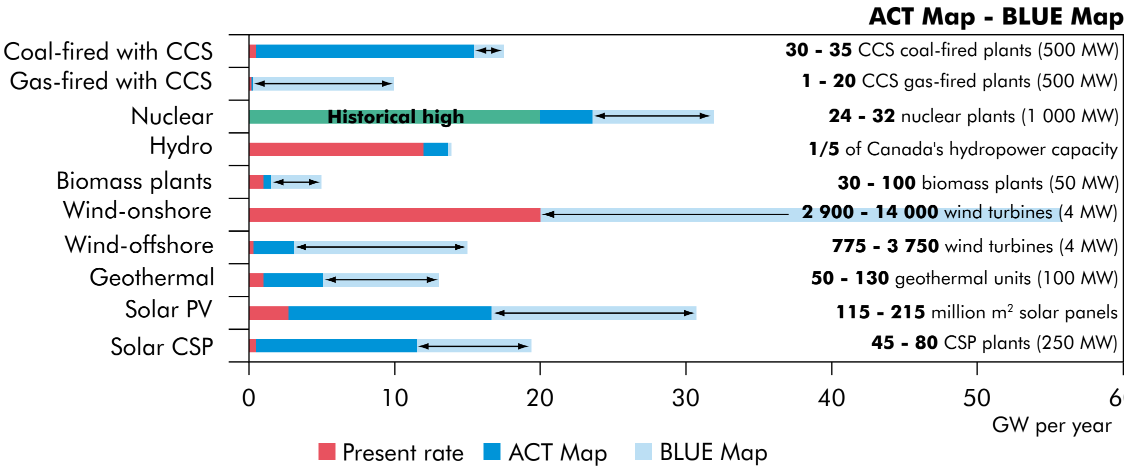
Buildings and appliances

The ACT scenarios can become reality using technologies for buildings and appliances widely available today and economically viable on a life-cycle cost basis. But the BLUE scenarios call for new and emerging technologies; in some cases technologies will be required that are only economic at relatively high CO_2 reduction costs, at least when initially deployed. Widespread conversion of buildings to very low energy consumption, and even "zero" energy buildings, are part of the scenario. **The policy implications for efficiency standards for buildings and appliances are huge.** A combination of building-shell measures, heat pumps, solar heating and highly efficient appliances and lighting reduces energy needs in buildings as well as shifting fuel use to renewables and low-carbon electricity. USD 7.4 trillion of additional investment in residential and service sector buildings is needed for the BLUE Map, against USD 2.6 trillion for the ACT Map scenario.

The power sector

CO_2 capture and storage for power generation and industry is the most important single new technology for CO_2 savings in both ACT Map and BLUE Map scenarios, in which it accounts for 14% and 19% of total CO_2 savings respectively. BLUE Map includes higher-cost applications of CCS for industry and gas power stations. **There is a massive switch to renewables for power generation, especially to wind, photovoltaics, concentrating solar power and biomass**. By 2050, 46% of global power in the BLUE Map scenario comes from renewables. Application of all renewable technologies combined, across all sectors, accounts for 21% of CO_2 savings in the BLUE Map scenario against the Baseline scenario. A substantial switch to nuclear contributes 6% of CO_2 savings, based on the construction of 32 GW of capacity each year between now and 2050. Nuclear accounts for nearly one-quarter of power generation in BLUE Map and hydro for half as much, building on the important role both technologies already play in the Baseline scenario. Figure ES.3 illustrates the annual rates at which new power generation capacity would need to be added in each scenario.

Figure ES.3 ▸ ***Additional investment in the electricity sector in the ACT Map and BLUE Map scenarios (compared to the Baseline, 2005-2050)***



A broad range of scenarios for power generation are considered, from which it can be seen that **considerable flexibility exists for individual countries to chose which precise mix of CCS, renewables and nuclear technology they will use to decarbonise the power sector.** Total additional investment in the power sector (excluding transmission and distribution) amounts to USD 0.7 trillion in the ACT Map scenario and USD 3.6 trillion in the BLUE Map scenario. These investment figures are the net result from combining higher capital costs per unit of capacity with a one-fifth reduction in electricity production due to end-use electricity savings. **Substantial early retirement of capital stock occurs in the BLUE scenarios.** For example, one-third of all coal-fired power plants not suitable for CCS will need to close before the end of their technical life. It is recognised that this will be a large step for countries heavily reliant on coal, but a necessary step requiring careful management.

Transport

In the ACT Map scenario, energy and emissions in the transport sector are saved largely through major **improvements in the efficiency of conventional vehicles** and through the increased penetration of hybrids. Low-carbon footprint biofuels play a part, principally as a replacement for gasoline to fuel cars. It is essential to curb the current trend towards larger, heavier vehicles.

The BLUE Map scenario is very challenging for the transport sector and **requires significant decarbonisation of transport,** which is likely to be **costly** in a sector dominated by oil products and the internal combustion engine. Low-carbon biofuels are expected to play a significant role in the BLUE Map scenario, within the limits of sustainable production and cropping. Trucks, shipping, and air transport are the chief users of biofuels, since other non-hydrocarbon options are likely to be very expensive to apply to these transport modes. While electric batteries and hydrogen fuel cells are the main alternatives for cars, it is difficult to judge at this stage which of these technologies – or which combination of them – will be the most competitive. Based on fairly optimistic assumptions about technology progress and cost reductions, electric and fuel cell vehicles are expected to cost around USD 6 500 more in 2050 than conventional vehicles. In the BLUE Map scenario, nearly one billion electric and fuel cell vehicles need to be on the roads by 2050. Transport represents the largest single area of investment in the scenarios. Additional investment needs in transport are USD 33 trillion in BLUE Map and USD 17 trillion in ACT Map.

Industry

Directly or indirectly, manufacturing industry accounts for more than one-third of global energy use and CO_2 emissions. The iron and steel, and cement industries represent roughly half of industry's emissions; chemicals and petrochemicals are the other very large sources. Heavy industry has a good record of energy efficiency gains in recent years, driven by the need to manage energy costs. But substantial potential exists for further efficiency gains, especially in less energy-intensive industries, notably through more efficient motor drive systems and combined heat and power. Potential also exists for technology advances that are specific to each industry and for application of CCS.

Very large reductions in CO_2 emissions from industry are hard to achieve. In the ACT Map scenario, energy-related CO_2 emissions from industry are 63% higher in 2050 than in 2005. In the BLUE Map scenario they are 22% below today's level, largely reflecting the widespread application of CCS at large, energy intensive plants. Direct and indirect CO_2 savings in the BLUE Map scenario are substantial, at nearly 10 Gt of CO_2 per year. The BLUE Map scenario requires additional investment over the Baseline of USD 2.5 trillion in the upgrading of industrial plant – mainly in the steel, cement, and pulp sectors – and for increased deployment of CCS.

Energy efficiency trends

Big improvements are needed compared to recent energy efficiency trends. Energy efficiency in OECD countries has been improving at just below 1% per year in recent times. A sharp decline from the rate achieved in the years immediately following the oil price shocks of the early 1970s. The ACT Map scenario requires sustained global energy efficiency improvements of 1.4% per year and the BLUE Map scenario calls for 1.7%. While these percentage differences may seem small, the difference of 0.3 percentage points between ACT Map and BLUE Map results in 1 544 Mtoe of additional final energy savings in 2050, 20% of total world final energy use today.

Research, development and demonstration

Some of the technologies needed for the BLUE scenarios are not yet available. Many others require further refinement and cost reductions. A huge effort of research, development, and demonstration (RD&D) will therefore be needed. Yet public- and private-sector spending on energy RD&D has been declining compared to the levels of the 1970s and 1980s and has now stabilised at a relatively low level. Many OECD countries spend less than 0.03% of GDP. The exception is Japan, which spends 0.08%. Private-sector energy RD&D spending now far exceeds public-sector outlay. While details are difficult to establish, independent studies have suggested that public-sector RD&D needs to increase by between two and ten times its current level. We do not set a specific target, but it is clear that **a major acceleration in RD&D effort is needed** both to bring forward new technologies and to reduce costs of those already available. **Further advances and lower cost solutions are needed for critical technologies such as solar PV, advanced coal plant, advanced biofuels, CO_2 capture, electric batteries, fuel cells and hydrogen production**. Even with large increases, the cost of R&D is relatively modest – typically one order of magnitude lower – than that of full scale demonstration and deployment programmes. **Well directed energy R&D represents excellent value for money.**

Government support is also needed for the larger-scale demonstration of new technology, reducing the risks of the first stage of commercialisation. **There is an urgent need for the full-scale demonstration of coal plants with CCS.**

Basic science in areas such as geology, physics, chemistry, materials, biochemistry, nanotechnology and applied mathematics can trigger breakthroughs in critical areas. **It is essential to enhance the science base and its links with technology.**

Deployment and technology learning

Most new technologies have higher costs than the incumbents. It is only through *technology learning* as a result of marketplace deployment that these costs are reduced and the product adapted to the market. **Governments must enhance their deployment programmes.** Second-generation renewables, for example solar and biofuels, are amongst the technologies with the greatest potential. In the ACT Map scenario, we estimate that USD 2.8 trillion needs to be spent between now and 2050 on the additional costs (above market value) of deploying new technology. For the BLUE Map scenario, the figure is USD 7 trillion.

Regulation

The barriers to new technology deployment are not always economic. To overcome these barriers, carefully designed regulations and standards are often the most effective policy measures. **Tough efficiency regulations for buildings, appliances and vehicles will be essential** in all scenarios. In both developed and developing countries, enhancing efficiency regulations, and strengthening their enforcement often represent attractive, cost-effective policy options for immediate action. A critical element for the success of the BLUE scenarios will be public acceptance of standards necessary to achieve very low-energy and zero-energy buildings and a four-fold reduction in the CO_2 intensity of vehicles.

Incentives

Private-sector investment is – and will remain – the primary facilitator of technology deployment and diffusion. The IEA has discussed the implications of the BLUE and ACT scenarios with chief technology officers from 30 leading international energy companies. They stressed **the urgent need to design and implement a range of policy measures that will create clear, predictable, long-term economic incentives for CO_2 reduction in the market.** Only on this basis will business be empowered to undertake the huge investment programmes required.

This analysis does not attempt to specify the mechanisms that will be needed, recognising that this is to some extent the subject of negotiations in the context of the United Nations Framework Convention on Climate Change. For the ACT scenarios, we have estimated that these mechanisms will need to be sufficient to incentivise technologies which, when fully commercialised, have a marginal cost of USD 50 per tonne of CO_2 saved. For BLUE, the figure is at least USD 200 per tonne of CO_2 saved, and could be as high as USD 500 if the progress of key technologies is disappointing. The incentives need to be applied globally, within all major economies, through a variety of policy measures.

These do not necessarily have to be uniform incentives with the same value for all technologies. Especially in the BLUE scenarios, **it may be appropriate to have targeted schemes for the most expensive technologies.** Packages of measures, which could take a variety of forms, need to be in place for OECD countries by 2020 and for other major countries by 2030. The BLUE scenario assumes significant further tightening beyond these dates. To achieve full impact, and for a smooth transition, it is essential that the expectation of the targets and incentives is clearly established well in advance.

Public opinion

Governments will need to give a lead to public opinion, making the connection between the urgent need to address climate change, which is widely recognised, and specific projects required, which often face public opposition. Neither the ACT nor the BLUE scenarios can be achieved without a major shift in priorities, and in the BLUE scenarios, **this needs to be radical and urgent.**

Taking forward international collaboration

International collaboration is essential to accelerate the development and global deployment of sustainable energy technologies in the most efficient way. A network for this already exists. The IEA itself has by far the most comprehensive network, in which thousands of technology experts from around the world co-ordinate their energy technology programmes. The EU energy technology programmes, Asia Pacific Partnership, Carbon Sequestration Leadership Forum, the Biofuels Partnership, and the International Partnership for a Hydrogen Economy, the Generation IV International Forum and the Global Nuclear Energy Partnership are other important examples. **These networks need strong international leadership from policy makers at senior level.**

This book offers first attempts at global roadmaps for key energy technologies. We have identified 17 key technologies for energy efficiency, power generation and transport. They are at the heart of the energy technology revolution. We describe the actions required to deliver their potential. They are specific to each technology and depend, in part, on their current state of development**.** Such roadmaps can be particularly useful in providing guidance on how much abatement should be sought from each sector and technology, as well as on whether this process is on track. **Further development of these roadmaps under international guidance, drawing together the energy technology programmes of all major economies, and in close consultation with industry, can provide the focus for the much closer international collaboration needed to achieve a global energy technology revolution.** The IEA is ready to support this effort to achieve a more sustainable energy future.

Table ES.1 ▶ ***Key roadmaps in this study***

Supply side	Demand side
■ CCS fossil-fuel power generation	■ Energy efficiency in buildings and appliances
■ Nuclear power plants	■ Heat pumps
■ Onshore and offshore wind	■ Solar space and water heating
■ Biomass integrated-gasification combined-cycle and co-combustion	■ Energy efficiency in transport
■ Photovoltaic systems	■ Electric and plug-in vehicles
■ Concentrating solar power	■ H_2 fuel cell vehicles
■ Coal: integrated-gasification combined-cycle	■ CCS in industry, H_2 and fuel transformation
■ Coal: ultra-supercritical	■ Industrial motor systems
■ Second-generation biofuels	

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INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA) is an autonomous body which was established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

It carries out a comprehensive programme of energy co-operation among twenty-seven of the OECD thirty member countries. The basic aims of the IEA are:

- To maintain and improve systems for coping with oil supply disruptions.
- To promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organisations.
- To operate a permanent information system on the international oil market.
- To improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use.
- To promote international collaboration on energy technology.
- To assist in the integration of environmental and energy policies.

The IEA member countries are: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States. Poland is expected to become a member in 2008. The European Commission also participates in the work of the IEA.

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of thirty democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.
The European Commission takes part in the work of the OECD.

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