



International
Energy Agency

ENERGY TECHNOLOGY PERSPECTIVES

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Executive
Summary

Scenarios &
Strategies
to 2050

INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its mandate is two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply and to advise member countries on sound energy policy.

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

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

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International
Energy Agency

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EXECUTIVE SUMMARY

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

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

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

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

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

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

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

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

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

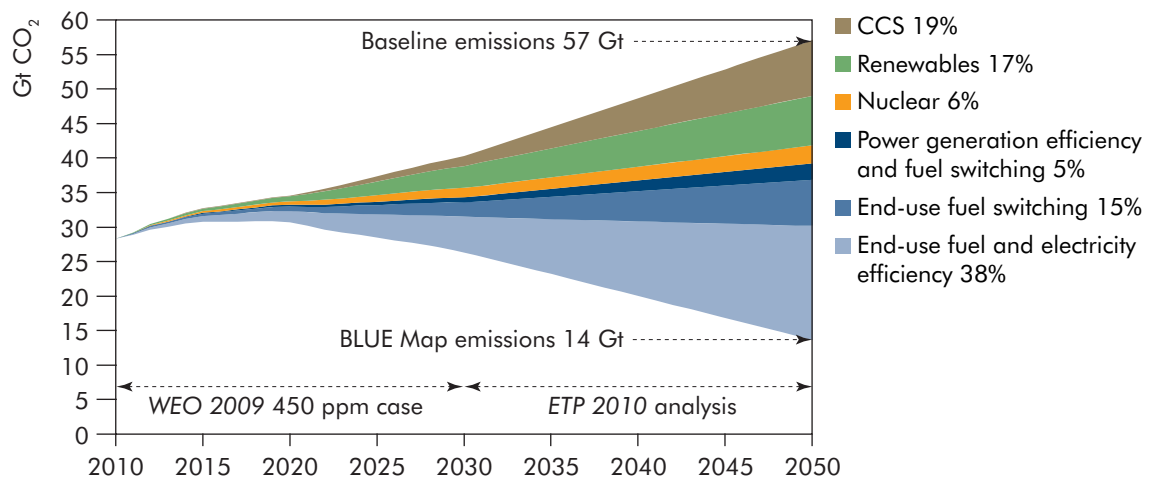
step change in the rate of progress and broader engagement of the full range of countries, sectors and stakeholders.

ETP scenarios present options rather than forecasts

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

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

Figure ES.1 ► Key technologies for reducing CO₂ emissions under the BLUE Map scenario



Key point

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

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

Baseline scenario	BLUE Map scenario
<ul style="list-style-type: none"> • Energy-related CO₂ emissions roughly double 	<ul style="list-style-type: none"> • Energy-related CO₂ emissions reduced by 50%
<ul style="list-style-type: none"> • Primary energy use rises by 84%; carbon intensity of energy use increases by 7% 	<ul style="list-style-type: none"> • Primary energy use rises by 32%; carbon intensity of energy use falls by 64%
<ul style="list-style-type: none"> • Liquid fuel demand rises by 57% requiring significant use of unconventional oil and synthetic fuels; primary coal demand increases by 138%; gas demand is 85% higher 	<ul style="list-style-type: none"> • Liquid fuel demand falls by 4% and biofuels meet 20% of total; coal demand drops by 36%; natural gas falls by 12%; renewables provide almost 40% of primary energy supply
<ul style="list-style-type: none"> • CO₂ emissions from power generation more than double; CO₂ intensity of power generation declines slightly to 459 g/kWh 	<ul style="list-style-type: none"> • CO₂ emissions from power generation are cut by 76%; its CO₂ intensity falls to 67 g/kWh
<ul style="list-style-type: none"> • Fossil fuels supply more than two-thirds of power generation; the share of renewable energy increases slightly to 22% 	<ul style="list-style-type: none"> • Renewables account for 48% of power generation; nuclear provides 24% and plants equipped with CCS 17%
<ul style="list-style-type: none"> • Carbon capture and storage (CCS) is not commercially deployed 	<ul style="list-style-type: none"> • CCS is used to capture 9.4 Gt of CO₂ from plants in power generation (55%), industry (21%) and fuel transformation (24%)
<ul style="list-style-type: none"> • CO₂ emissions in the buildings sector, including those associated with electricity use, nearly double 	<ul style="list-style-type: none"> • CO₂ emissions in buildings are reduced by two-thirds through low-carbon electricity, energy efficiency and the switch to low- and zero-carbon technologies (solar heating and cooling, heat pumps and CHP)
<ul style="list-style-type: none"> • Almost 80% of light-duty vehicles (LDVs) sales rely on conventional gasoline or diesel technology; petroleum products meet more than 90% of transport energy demand 	<ul style="list-style-type: none"> • Almost 80% of LDVs sales are plug-in hybrid, electric or fuel-cell vehicles; the share of petroleum products in final transport demand falls to 50%
<ul style="list-style-type: none"> • CO₂ emissions in industry grow by almost half, as industrial production increases 	<ul style="list-style-type: none"> • CO₂ emissions in industry fall by around a quarter mainly thanks to energy efficiency, fuel switching, recycling, energy recovery and CCS
<ul style="list-style-type: none"> • Total investment in energy supply and use totals USD 270 trillion 	<ul style="list-style-type: none"> • Investment is USD 46 trillion (17%) more than in Baseline; cumulative fuel savings are USD 112 trillion higher than in Baseline
<ul style="list-style-type: none"> • Non-OECD countries are responsible for almost 90% of growth in energy demand and account for nearly three-quarters of global CO₂ emissions 	<ul style="list-style-type: none"> • Non-OECD countries achieve CO₂ emissions reduction of around 30% compared to 2007; OECD countries account for less than one-quarter of global CO₂ emissions, having reduced emissions by 70% to 80% below 2007 levels

Box ES.1 ► Messages from the models

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

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

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

- A portfolio of low-carbon technologies, with costs of up to USD 175/tCO₂ when fully commercialised, will be necessary to halve CO₂ emissions by 2050. No one technology or small group of technologies can deliver the magnitude of change required.
- Widespread deployment of low-carbon technologies can reduce global oil, coal and gas demand below current levels by 2050. Even so, fossil fuels will remain an important element of the world's energy supply for the foreseeable future.
- Increasing energy efficiency, much of which can be achieved through low-cost options, offers the greatest potential for reducing CO₂ emissions over the period to 2050. It should be the highest priority in the short term.
- Decarbonising the power sector, the second-largest source of emissions reductions, is crucial and must involve dramatically increasing the shares of renewables and nuclear power, and adding carbon capture and storage (CCS) to generation from fossil fuels.
- A decarbonised electricity supply offers substantial opportunities to reduce emissions in end-use sectors through electrification (for example, switching from internal combustion engine vehicles to electric vehicles (EVs) and plug-in hybrids (PHEVs), or from fossil fuel heating to efficient heat pumps).
- New low-carbon technologies will be needed to sustain emissions reductions beyond 2030, particularly in end-use sectors such as transport, industry and buildings.

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

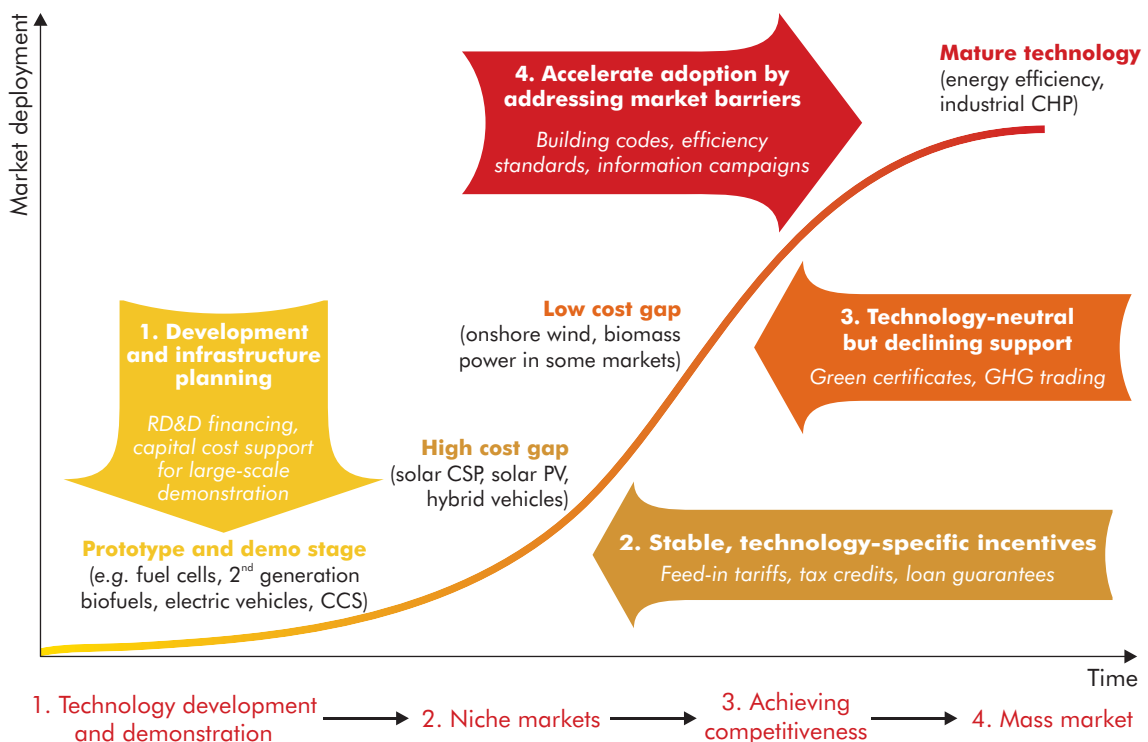
Technology policy

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

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

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

Figure ES.2 ► Policies for supporting low-carbon technologies



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

Key point

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

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

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

ETP 2010 estimates that to achieve the 50% CO₂ emissions reduction, government funding for RD&D in low-carbon technologies will need to be two to five times higher than current levels. This message is being taken seriously by many countries. Governments of both the Major Economies Forum and the IEA have agreed to dramatically increase and co-ordinate public-sector investments in low-carbon RD&D, with a view to doubling such investments by 2015. Simply increasing funding will not, however, be sufficient to deliver the necessary low-carbon technologies. Current government RD&D programmes and policies need to be improved by adopting best practices in design and implementation. This includes the design of strategic programmes to fit national policy priorities and resource availability; the rigorous evaluation of results and adjusting support if needed; and the increase of linkages between government and industry, and between the basic science and applied energy research communities to accelerate innovation.

Reducing CO₂ emissions ultimately depends on the uptake of low-carbon technologies by industry, businesses and individual consumers. To date, efforts to encourage the adoption of energy-efficient and low-carbon technologies have focused primarily on overcoming technological and economic barriers. In fact, research suggests that consumer choices are more heavily influenced by social and behavioural factors. Improved understanding of the human dimensions of energy consumption, particularly in the residential and commercial sectors and in personal transport, will help policy makers to catalyse and amplify technology-based savings. A sampling of successful programmes highlighted in *ETP 2010* indicates that policy strategies to influence consumer choices should target, inform, motivate and empower consumers.

Governments also have an important role in encouraging others to take the lead in relevant areas. Industry can demonstrate leadership through active involvement in public-private partnerships. Universities can expand training and education to develop and deploy the human capacity needed to exploit the innovative energy technologies. Non-governmental organisations can help engage the public and communicate the urgency of the need to deploy new energy technologies on a large scale, including the costs and benefits of doing so. Finally, all stakeholders must work together to strengthen international technology collaboration to accelerate RDD&D, diffusion and investment. Technology roadmaps can be an effective tool to help this process.

Box ES.2 ▶ IEA technology roadmaps

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

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

Increasing international technology diffusion

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

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

To be successful, a low-carbon economy should be based on market principles in which energy technologies spread primarily through commercial transactions. The challenge is to reorient these transactions to support the transfer of low-carbon technologies while also helping emerging countries to become technology

developers and market players. Careful consideration must be given to the capacity of countries to absorb new technologies. Some emerging economies, led by China, are rapidly improving their capability to develop and deploy key low-carbon technologies. Given their economic growth rates, they must advance at an even more rapid pace to decouple CO₂ emissions from economic activity.

Financing and returns on investment

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

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

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

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

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

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

1. Excluding upstream investments in the production and transportation of coal, oil and gas.

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

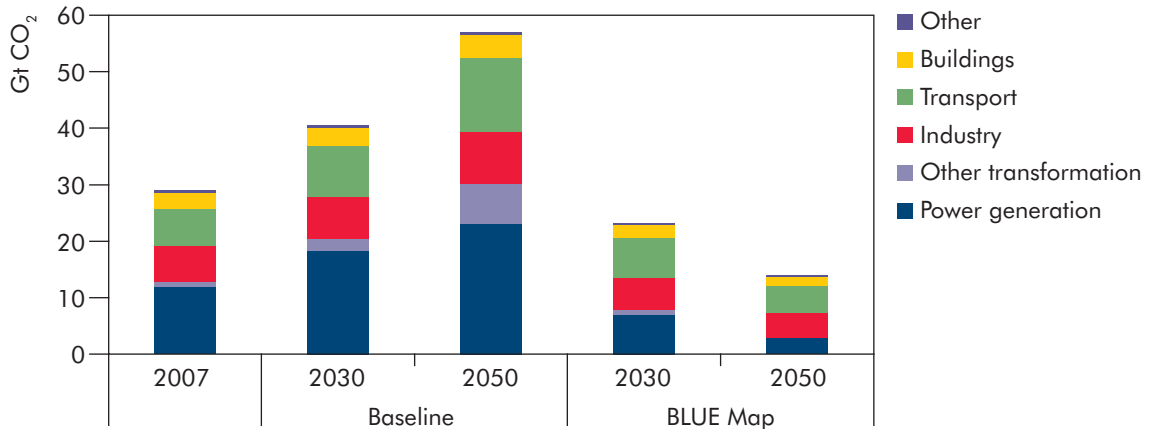
Further work is needed to refine the estimates in this assessment, including ways to leverage potential co-benefits and to ensure that any negative co-impacts are understood, quantified and, where possible, mitigated. It is equally important to assess co-benefits and potential conflicts at regional,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

Sectoral findings

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

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

Figure ES.3 ► Global CO₂ emissions in the Baseline and BLUE Map scenarios



Key point

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

Power sector

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

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

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

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

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

Electricity networks

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

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

Industry

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

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

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

Buildings

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

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

Most buildings have long life spans, meaning that more than half of the current global building stock will still be standing in 2050. The low retirement rate of buildings in the OECD and in economies in transition, combined with relatively modest growth, means that most of the energy and CO₂ savings potential lies in retrofitting and purchasing new technologies for the existing building stock. In developing countries, where new building growth will be very rapid, opportunities exist to secure significant energy savings (rather quickly and strongly) through improved efficiency standards for new buildings.

The implementation of currently available, low-cost energy-efficient and low-carbon options is essential to achieve cost-effective CO₂ emissions reductions in the short run. This will buy time to develop and deploy less mature and currently more expensive technologies that can play an important role in the longer term. For space and water heating, these include highly efficient heat pumps, solar thermal systems, and combined heat and power (CHP) systems with hydrogen fuel cells.

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

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

Recent years show some encouraging signs of a shift in consumer preferences towards new technologies that can reduce CO₂ emissions. In 2007/08, sales of heat pumps showed double-digit growth in a number of major European markets. Demand has also been growing rapidly for solar thermal systems that can provide low-temperature heat for cooling and/or space and water heating.

Transport

The transport sector is currently responsible for 23% of energy-related CO₂ emissions. Given the increases in all modes of travel, especially passenger light-duty vehicles (LDVs) and aviation, the Baseline scenario shows a doubling of current transport energy use by 2050 and slightly more than a doubling of associated CO₂ emissions. Achieving deep cuts in CO₂ emissions by 2050 will depend on slowing the rise in transport fuel use through greater energy efficiency and increasing the

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

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

Prospects are good for cutting fuel use and CO₂ emissions from LDVs by improving the efficiency of ICEs, and through vehicle hybridisation and adoption of PHEVs, EVs and fuel-cell vehicles. Virtually all incremental efficiency improvements to gasoline and diesel vehicles seen in the BLUE Map scenario are paid for by fuel savings over the vehicle lifetime. Most OECD governments now have strong fuel economy standards and many governments worldwide have announced plans to support wider use of EVs and PHEVs. Taken together, these commitments could place more than 5 million EVs and PHEVs on the road by 2020.

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

Despite promising signs that governments are introducing policies to reduce CO₂ emissions from transport, much more effort is needed to increase RDD&D funding and co-ordination especially to more rapidly cut the costs of advanced technologies. In addition, greater attention must be directed toward encouraging consumers to adopt the technologies and lifestyle choices that underpin the transition away from energy-intensive, fossil-fuel based transport systems.

Box ES.3 ► Regional differences

ETP 2010 undertook a more detailed analysis of CO₂ trends and abatement options for four countries or regions that will have a major role in reducing global emissions: OECD Europe, the United States, China and India. Each faces unique challenges, reflecting current and future levels of economic development and diverse endowments of natural resources (represented in their energy mixes). Thus, each will have very different starting points and future trajectories in terms of their CO₂ emissions and develop in different ways in both the Baseline and the BLUE Map scenarios. Although many of the same technology options are needed to reduce emissions, the policy options associated with their application may be dramatically different.

In the Baseline scenario, CO₂ emissions in India show the largest relative increase, rising almost fivefold by 2050. China also shows a substantial rise, with emissions almost tripling between 2007 and 2050. The United States show a much more modest rise, of 1% and emissions in OECD Europe decline by 8%. In the BLUE Map scenario, all countries show considerable reductions from the Baseline scenario: emissions in 2050 (compared to 2007) are 81% lower for the United States, 74% lower for OECD Europe and 30% lower in China, while India's emissions rise by 10%.

The BLUE Map scenario also brings significant security of supply benefits to all four countries or regions, particularly through reduced oil use. In the United States and OECD Europe, oil demand in 2050 is between 62% and 51% lower than 2007 levels (gas demand shows similar declines). In China and India, oil demand still grows in the BLUE Map scenario, but is between 51% and 56% lower by 2050 than in the Baseline scenario.

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

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

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

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

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

Conclusion

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

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

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

In short, the most vital message of *ETP 2010* is that an energy technology revolution is within reach. Achieving it will stretch the capacities of all energy-sector stakeholders and entail substantial upfront costs, but over the long term these will be more than offset by the benefits. Governments, investors and consumers around the world need to take bold, decisive action to initiate and advance change in their respective spheres of influence – and increase their commitment to working together.



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

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With extensive data, projections and analysis, *Energy Technology Perspectives 2010* provides decision makers with the detailed information and insights needed to accelerate the switch to a more secure, low-carbon energy future.