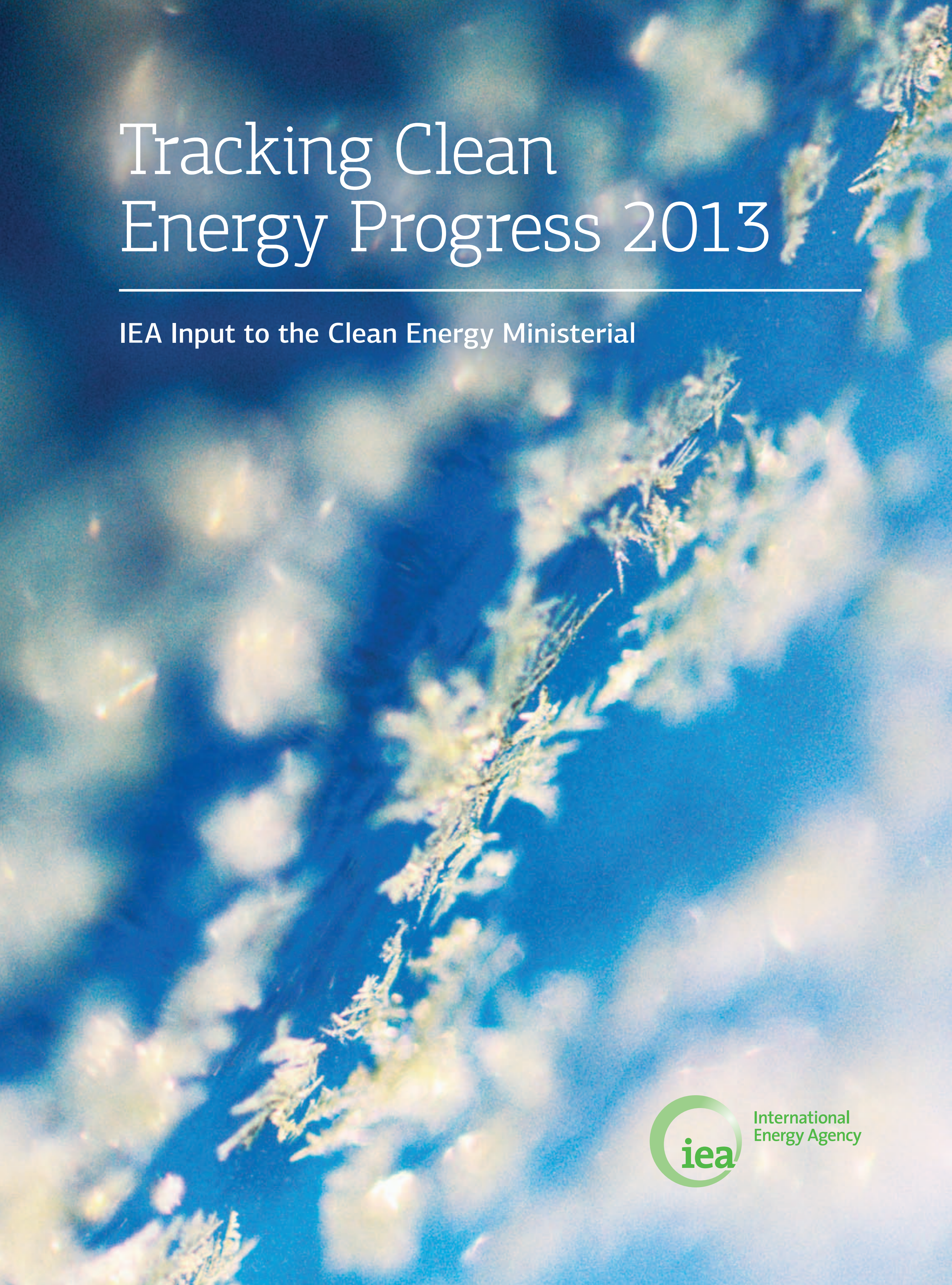


Tracking Clean Energy Progress 2013

IEA Input to the Clean Energy Ministerial

International Energy Agency

Tracking Clean Energy Progress 2013

IEA Input to the Clean Energy Ministerial

The 22 countries that participate in the Clean Energy Ministerial (CEM) share a strong interest in the development and deployment of clean energy technologies. As these same countries represent more than 75% of global energy consumption, 80% of global CO_2 emissions and 75% of global GDP, they have the power to drive the transition to a cleaner energy system and, since CEM first convened in 2010, have taken steps toward this challenging goal. So how much progress has been made thus far?

This comprehensive overview examines the latest developments in key clean energy technologies:

- Technology penetration: how much are clean energy technologies being used?
- Market creation: what is being done to foster the necessary markets?
- Technology developments: how are individual technologies performing?

Each technology and sector is tracked against interim 2020 targets in the IEA 2012 *Energy Technology Perspectives* 2°C scenario, which lays out pathways to a sustainable energy system in 2050.

www.iea.org/etp/tracking

Visit our website for interactive tools, additional data, presentations and more.

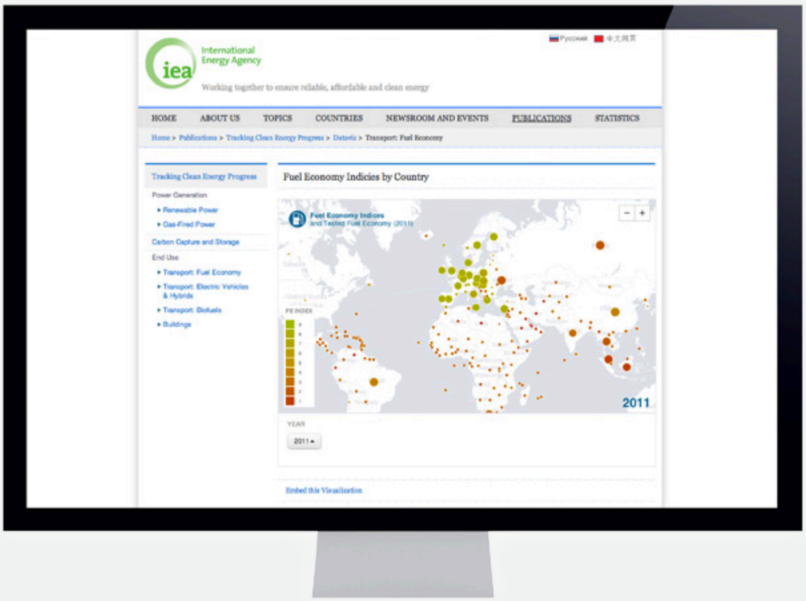
Stark messages emerge: progress has not been fast enough; large market failures are preventing clean energy solutions from being taken up; considerable energy-efficiency potential remains untapped; policies need to better address the energy system as a whole; and energy-related research, development and demonstration need to accelerate. The report also introduces a new IEA index, tracking the carbon intensity of energy supply since 1970, that shows no recent improvement and underscores the need for more concerted effort.

Alongside these grim conclusions there is positive news. In 2012, sales of hybrid electric vehicles passed the 1 million mark. Solar photovoltaic systems were being installed at a record pace. The costs of most clean energy technologies fell more rapidly than anticipated.

The report provides specific recommendations to governments on how to scale up deployment of these key technologies.

Tracking Clean Energy Progress 2013

IEA Input to the Clean Energy Ministerial



Visualise and explore the data behind *Tracking Clean Energy Progress 2013*

Visit www.iea.org/etp/tracking for interactive data visualisation tools.
The figures that appear in the report – and the data behind them – are also available for download free of charge.

International Energy Agency

INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 28 member countries and beyond. The IEA carries out a comprehensive programme of energy co-operation among its member countries, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency's aims include the following objectives:

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

IEA member countries:

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

The European Commission also participates in the work of the IEA.

International Energy Agency

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Foreword

We built our civilisation by harnessing energy, which is at the core of economic growth and prosperity. But in 2012, in a weak world economy, oil prices soared and carbon dioxide emissions from energy reached record highs. The ways we supply and use energy threaten our security, health, economic prosperity and environment. They are clearly unsustainable. We must change course before it is too late.

This is the International Energy Agency's (IEA) third comprehensive tracking of progress in clean energy technology. It is a reality check for policy makers: it reflects what is happening here and now. Stark messages emerge from our analysis: progress is not fast enough; glaring market failures are preventing adoption of clean energy solutions; considerable energy efficiency potential remains untapped; policies must better address the energy system as a whole; and energy-related research, development and demonstration all need to accelerate.

In this year's report we launch the Energy Sector Carbon Intensity Index (ESCII), which shows the carbon emitted for each unit of energy we use and provides a cumulative overview of progress in the energy sector. The picture is as clear as it is disturbing: the carbon intensity of the global energy supply has barely changed in 20 years, despite successful efforts in deploying renewable energy.

I am particularly worried about the lack of progress in developing policies to drive carbon capture and storage (CCS) deployment. Without CCS, the world will have to abandon its reliance on fossil fuels much sooner – and that will come at a cost.

There is a danger, however, in focusing on individual technologies without considering the larger picture. We must invest heavily in infrastructure that improves the system as a whole. Smart grids, for example, make it easier and cheaper to replace fossil-fired power with renewables without jeopardising the reliability of the energy system.

Alongside these grim messages there are also positive developments. In 2012, sales of hybrid-electric vehicles passed the one million mark. Solar photovoltaic systems continued to be installed at a record pace, contrary to many expectations. Emerging economies are stepping up their efforts to promote and develop clean energy. The costs of most clean energy technologies fell more rapidly than anticipated. Many countries, including emerging economies, introduced or strengthened energy efficiency regulations. Given that the world's energy demand is set to grow by 25% in the next decade, it is hard to overstate the importance of energy efficiency. The world must slow the growth of energy demand while making the energy supply cleaner.

Each time the IEA assesses the role that technology and innovation can play in transforming the energy system, we are astonished by the possibilities. The 2012 edition of *Energy Technology Perspectives* showed how the world can slash emissions and save money while doing so. In this report, besides the high-level findings and conclusions in the introduction, each chapter offers specific recommendations by technology and sector.

It is time the governments of the world took the actions needed to unleash the potential of technology. Together with industry and consumers, we can put the energy system on track to a sustainable and secure energy future. We owe it to our economies, our citizens and our children.

Maria van der Hoeven, *Executive Director*

Key Findings

Renewable energy and emerging country efforts are lights in the dark as progress on clean energy remains far below a 2°C pathway.

- **Governments have the power to create markets and policies that accelerate development and deployment of clean energy technologies, yet the potential of these technologies remains largely untapped.** This report demonstrates that for a majority of technologies that could save energy and reduce carbon dioxide (CO_2) emissions, progress is alarmingly slow (Table I.1). The broad message to ministers is clear: the world is not on track to realise the interim 2020 targets in the IEA *Energy Technology Perspectives 2012* (ETP) 2°C Scenario (2DS). Industry and consumers will provide most of the investment and actions needed, but only with adequate opportunities and the right market conditions.
- **The growth of renewable power technologies continued in 2012 despite economic, policy and industry turbulence.** Mature technologies – including solar photovoltaic (PV), onshore wind, biomass and hydro – were the most dynamic and are largely on track for 2DS targets. Solar PV capacity grew by an estimated 42%, and wind by 19% compared with 2011 cumulative levels. Investments remained high in 2012, down only 11% from the record level of 2011, but policy uncertainty is having a negative impact, notably on US and Indian wind investments.
- **Emerging economies are stepping up efforts in clean energy, but global policy development is mixed.** Markets for renewable energy are broadening well beyond OECD countries, which is very positive. This reflects generally rising ambitions in clean energy although developments are not homogenous. For instance, China and Japan strengthened policies and targets for renewables in 2012 while other governments (*e.g.* Germany, Italy and Spain) scaled back incentives. Industry consolidation continued and competition increased. Partly as a result, investment costs continued to fall rapidly, particularly for onshore wind and solar PV.

The global energy supply is not getting cleaner, despite efforts to advance clean energy.

- **Coal technologies continue to dominate growth in power generation.** This is a major reason why the amount of CO_2 emitted for each unit of energy supplied has fallen by less than 1% since 1990 (Box I.1). Thus the net impact on CO_2 intensity of all changes in supply has been minimal. Coal-fired generation, which rose by an estimated 6% from 2010 to 2012, continues to grow faster than non-fossil energy sources on an absolute basis. Around half of coal-fired power plants built in 2011 use inefficient technologies. This tendency is offsetting measures to close older, inefficient plants. For example China closed 85 GW in 2011 and was continuing these efforts in 2012, and the United States closed 9 GW in 2012.

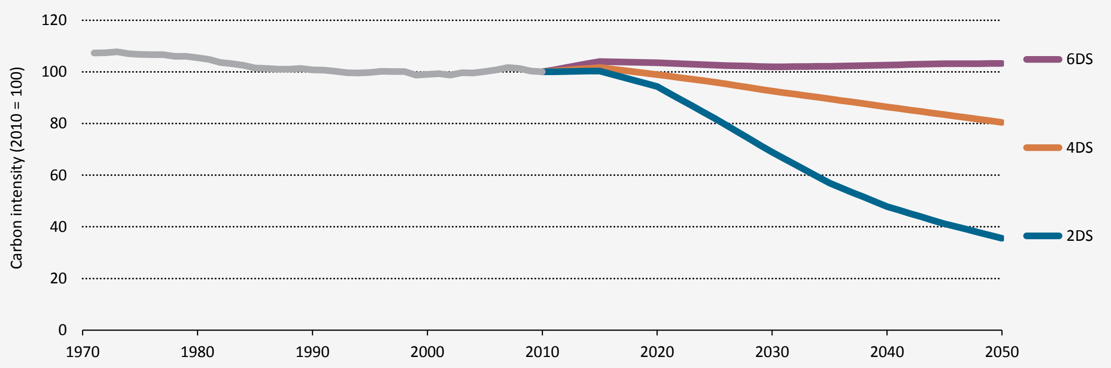
- **The dependence on coal for economic growth is particularly strong in emerging economies.** This represents a fundamental threat to a low-carbon future. China and, to a lesser extent India, continue to play a key role in driving demand growth. China's coal consumption represented 46% of global coal demand in 2011; India's share was 11%. In 2011 coal plants with a capacity of 55 GW were installed in China, more than Turkey's total installed capacity.
- **Natural gas is displacing coal-fired generation in some countries but this trend is highly regional.** Coal-to-gas fuel switching continued in 2012 in the United States, as the boom in unconventional gas extraction kept gas prices low. The opposite trend was observed in Europe, where low relative prices for coal led to increased generation from coal at the expense of gas. In total, global natural gas-fired power generation is estimated to have increased by more than 5% from 2010 to 2012, building on strong growth over the past few years.

Box I.1 The IEA Energy Sector Carbon Intensity Index (ESCII)

The IEA Energy Sector Carbon Intensity Index (ESCII) tracks how many tonnes of CO_2 are emitted for each unit of energy supplied. It shows that the global aggregate impact of all changes in supply technologies since 1970 has been minimal. Responses to the oil shocks of the 1970s made the energy supply 6% cleaner from 1971 to 1990. Since 1990, however, the ESCII has remained essentially static, changing by less than 1%, despite the important climate policy commitments at the 1992 Rio Conference and under the 1997 Kyoto Protocol as well as the boom in renewable technologies over the last decade (Figure I.1). In 1990 the underlying carbon intensity of supply was 57.1 tCO_2/TJ (2.39 tCO_2/toe); in 2010 it was 56.7 tCO_2/TJ (2.37 tCO_2/toe). This reflects the continued domination of fossil fuels - particularly coal - in the energy mix and the slow uptake of other, lower-carbon supply technologies. The ESCII shows only one side of the decarbonisation challenge: the world must slow the growth of energy demand as well as make its energy supply cleaner.

To meet 2DS targets, aggressive energy efficiency improvements are needed as well as a steep drop in the global ESCII. The index needs to break from its 40-year stable trend and decline by 5.7% by 2020, and 64% by 2050.

Figure I.1 The Energy Sector Carbon Intensity Index (ESCII)



Sources: IEA 2012a, IEA 2012b. Note: the ETP scenarios (2DS. 4DS and 6DS) are defined in Box I.2. Figures and data that appear in this report can be downloaded from www.iea.org/etp/tracking.

Key point *The carbon intensity of global energy supply has hardly improved in 40 years, despite efforts on renewable energy.*

- **Construction began on seven nuclear power plants in 2012, but meeting 2DS goals will require far more significant construction rates.** The policy landscape is starting to stabilise after Fukushima, but some key countries remain undecided. Public opinion seems to be improving in many regions. Most safety evaluations after the Fukushima accident found that existing reactors can continue to operate if safety upgrades are implemented.
- **Carbon capture and storage (CCS) technologies – essential in a world that continues to rely heavily on fossil fuels – are mature in many applications but still await their cue from governments.** While construction began on two new integrated projects in 2012, eight projects were publicly cancelled. There are signs of commercial interest in CCS technologies – public and private funds spent on CCS projects increased by USD[1] 2.6 billion in 2012 – but CCS will not be deployed in the power and industrial sectors until policies are in place that motivate industry to accelerate demonstration efforts.

A window of opportunity is opening in transport.

- **Hybrid-electric (HEV) and electric vehicles (EV) show very encouraging progress.** HEV sales broke the one million mark in 2012, and reached 1.2 million, up 43% from 2011. Japan and the United States continue to lead the market, accounting for 62% and 29% of global sales in 2012 (740 000 and 355 000 vehicles sold). In order to hit 2020 2DS targets, sales need to increase by 50% each year. EV sales more than doubled in 2012, passing 100 000. This rate of sales growth puts EV deployment on track to meet 2DS 2020 targets, which require a 80% annual growth rate. Cumulative government targets for EV sales increased in 2012, with India announcing a total target of 6 million EVs and HEVs on the road by 2020. The target is to be backed by government funding of USD 3.6 billion to USD 4.2 billion, representing more than half of total required investment.
- **Fuel economy levels for new passenger light-duty vehicles LDV vary by up to 55% from country to country, demonstrating enormous scope for improving efficiency through policy.** Fuel economy improvements accelerate where implementation of fuel economy standards and other policy measures has been scaled up. The pace of improvement in some regions shows the strong potential to bring fuel-saving technologies – most of which are already commercially available – into the market through policy action.
- **Global biofuels production – including bioethanol and biodiesel – was static in 2012.** Despite strong growth of 7% in biodiesel output in the United States (to 4 billion litres) and Latin America (to 7 billion litres), global volumes remained at roughly 110 billion litres. The slowdown in production growth reflects higher feedstock prices and lower production volumes in key producing regions. This is principally due to extreme weather conditions such as the 2012 drought that compromised the US corn harvest. The events in 2012 highlight the vulnerability of conventional biofuels production to high feedstock prices, which account for 50% to 80% of total production costs.
- **The advanced biofuels[2] sector added about 30% of capacity in 2012.** More than 100 plants are now operating, including commercial-scale projects, with 4.5 billion litres in total capacity by end-2012. Yet some large-scale projects were cancelled or shelved in 2012;[3] in part, this reflects a lack of adequate policy mechanisms for advanced biofuel deployment in most regions.

1 Unless otherwise stated, all costs and prices are in real 2010 USD, *i.e.* adjusted for inflation. Other currencies have been converted into USD using purchasing power parity (PPP) exchange rates.
2 Conversion technologies that are still in the R&D, pilot or demonstration phases.
3 For instance, the BP Biofuels 135 million litres per year (Ml/yr) cellulosic-ethanol project in Florida, United States, and the NSE Biofuels 115 Ml/yr BtL project in Finland.

More effort needed in industry, buildings and systems integration.

- **Industrial energy consumption could be reduced by around 20% in the medium to long term by using best available technologies (BAT).** To meet 2DS goals, it is necessary to optimise production and process techniques, and achieve technological advances, in both OECD and emerging economies. There has been reasonable progress in implementing these changes across industrial sectors but more is needed.
- **Several regions stepped up industry energy and emissions-reduction policies in 2012,** including Europe, South Africa and Australia. The South African Department of Trade and Industry's Manufacturing Competitive Enhancement Programme announced a new project that provides USD 640 million over five years from 2012 to support companies that invest in clean technology among other areas of investment. Australia's Clean Energy Future plan commenced in 2012. The plan includes a carbon price and complementary programmes to support energy efficiency measures in industry, including a USD 10.3 billion Clean Energy Finance Corporation and a USD 1.24 billion Clean Technology programme.
- **In 2012 governments implemented several important policy measures to promote energy-efficient buildings and appliances.** These include the EU Energy Efficiency Directive (EED), the United Kingdom's Green Deal and Japan's Innovative Strategy for Energy and Environment. All of these include measures to address financing barriers to improvements of new and existing building stock. For appliances, the Indian Bureau of Energy Efficiency increased the stringency of energy performance standards for air conditioners by 8%, following introduction of a mandatory labelling programme in 2010. Forty-six countries agreed to phase out incandescent lamps by 2016 under the "en-lighten"[4] initiative, which aims to accelerate a global market transformation to environmentally sustainable lighting technologies. Australia introduced a first-of-a-kind phase-in policy for best available lighting products.
- **Technologies for improved systems integration and flexibility, such as stronger and smarter grids, are vital. Demonstration and deployment of smart-grid technologies intensified in 2012, but better data and deployment indicators are required to provide an accurate picture of progress.** Smart-grid deployment is starting to provide experience that can be built on. Investment in advanced metering infrastructure, distribution automation and advanced smart-grid applications increased in 2012, to reach USD 13.9 billion. Progress in individual technology areas is important; what matters most is the successful transition of the whole energy system to a clean energy platform. The deployment of smart grids is vital.

4 The en-lighten initiative was established in 2009 as a partnership among UNEP, GEF, OSRAN AG, Philips Lighting and the National Test Centre in China. See www.enlighten-initiative.org.

Public investments in energy RD&D must at least triple, as the energy share of research budgets remains low.

- **Energy's share of IEA countries'[5] total RD&D investments is small;** it has varied between 3% and 4% since 2000, after peaking in 1980 when it was more than 10%. Governments have preferred other areas of research, such as health, space programmes and general university research. Defence research receives the most government support, and while it has also seen its share of funding decline, it remains dominant with 30%.
- **Nuclear fission accounts for the largest share (24% in 2010) of investment in energy technology RD&D among IEA countries, but renewables, hydrogen and fuel cells have seen the biggest increases since 2000.** In particular, spending on renewable energy RD&D has risen sharply over the last decade and now accounts for more than 24% of total public spending on clean energy RD&D. In general, the United States and Europe spend more on RD&D for renewables than the Pacific region or emerging economies.

Poor quality and availability of data are still serious constraints in tracking and assessing progress.

- **A broad concern for much energy data, quality is a particular constraint in emerging economies, for energy-efficiency data in buildings and industry, and in cross-cutting areas such as smart grids and integration of heat and electricity systems.** Data that define the energy balance of each country need to be more timely and reliable so that the energy system as a whole can be analysed accurately and so that effective policies and investments can be replicated. RD&D data in emerging economies are still scarce, and data for private RD&D are collected in few countries.

5 Due to data constraints it is not possible to aggregate CEM country investments.

Table I.1 Summary of progress

On track?	Status against 2DS objectives	Policy Recommendations
Renewable power	On track to meet 2DS objectives in terms of absolute generation and investment levels. Concentrating solar power, offshore wind, enhanced geothermal not advancing quickly enough.	■ For more mature markets and technologies, policies to enable greater market and system integration of higher penetrations of variable renewables are vital. ■ For less developed markets and technologies, strategies should focus on market expansion or stimulating early-stage deployment. ■ Policies must be predictable and transparent. ■ Markets must be designed to allow recuperation of capital cost of investments. This is particularly important for technologies with very low marginal costs.
Nuclear power	Projected 2025 capacity 15%-32% below 2DS objectives. Both new-build activity and long-term operation of existing reactors required to meet 2DS goals.	■ More favourable electricity market mechanisms and investment conditions required to de risk investments and allow investors to recuperate high upfront capital cost. ■ Post-Fukushima safety upgrades should be quickly implemented to foster public confidence.
Gas-fired power	Share in thermal generation has increased at the expense of coal in some regions, but not all.	■ Higher carbon prices and other regulatory mandates are required to drive coal-to-gas switching outside the United States. ■ Development of unconventional gas resources would help bring down gas prices and potentially trigger coal-to-gas switching in regions that currently rely heavily on coal. Scaling up unconventional gas extraction requires careful regulation and monitoring, in order to avoid adverse effects on the environment.
Coal-fired power	Growth is outpacing increases in generation from non-fossil energy sources. Projected global coal demand exceeds 2DS levels by 17% in 2017, higher than 6DS pathway.	■ Governments must explicitly recognise the impact of increasing coal-fired power generation. ■ To reduce the impact of increasing coal use, ultra-supercritical units should be installed unless there is strong reason not to do so. ■ Pricing and regulation that reduce CO_2 emissions, control pollution and reduce generation from inefficient units are vital.
CCS	Capture capacity of projects currently operational or in pipeline is only 25% of 2DS 2020 target. Still no large-scale integrated projects in power sector; and few in industry.	■ Governments must show real financial and policy commitment to CCS demonstration and deployment. ■ Near term policies should be supported by credible long-term climate change mitigation commitments. ■ Recognise the large investments and long-lead time required to discover and develop viable storage capacity. ■ Address CO_2 emissions from industrial applications and introduce CCS as a solution.
Industry	Reasonable progress in improving energy efficiency, but there remains significant potential to deploy best available technology and optimise processes.	■ Implement policies to ensure that new capacity is developed with best available technology and that industrial plant refurbishment projects are promoted to meet energy efficiency targets. ■ Measures to facilitate access to financing are vital. ■ Particular efforts are needed to improve energy efficiency in light industry and SMEs. ■ To avoid technological lock-in of inefficient technology in developing countries, technology transfer efforts must be enhanced.

● Not on track ● Improvement, but more effort needed ● On track, but sustained deployment and policies required

Table I.1 Summary of progress (continued)

On track?	Status against 2DS objectives	Policy Recommendations
Fuel economy	Annual fuel economy improvement was 1.8% between 2008 and 2011, below the 2.7% 2DS target. 55% variation between countries shows the potential for improvement.	■ Fuel economy standards should immediately be implemented in all OECD regions as part of comprehensive fuel-economy policy packages, including for heavy duty vehicles (HDV). ■ For non-OECD regions, labelling measures is a key near-term priority, and full LDV policy packages should be in place by 2015 to 2020. ■ Stronger economic incentives for consumers are critical, *e.g.* through CO_2-based vehicle taxes, fee/rebate systems (feebates), or fuel taxes.
Electric and hybrid-electric vehicles	Deployment of EVs and HEVs on track to meet 2DS 2020 targets, but sales must increase by around 80% (EVs) and 50% (HEVs) each year to 2020. Large discrepancy between government targets and stated industry plans.	■ Strengthen policies to enhance cost-competitiveness of EVs and HEVs and boost manufacturer and consumer confidence. ■ Develop standards for charging stations, integrate EVs in city mobility programmes (*e.g.* car sharing schemes) and underscore broader benefits of EVs, including lessened local air pollution. ■ Public fleet acquisitions can reduce costs of EVs and HEVs, through economies of scale.
Biofuels	Annual biofuels production must more than double to reach 2DS 2020 target. Advanced biofuels capacity must increase six-fold to 2020.	■ Lessen the risks for early investors through mechanisms such as loan guarantees, guaranteed premiums for advanced biofuels, or direct financial support for first-of-a-kind investments. ■ Targeted policy support for advanced biofuels required to ensure large-scale deployment. ■ Monitor sustainability in feedstock production.
Buildings	Large untapped potential to enhance energy performance of buildings and appliances. Only three countries have best-practice building code.	■ Enforce stringent, performance-based energy codes for entire building stock and strong minimum energy performance standards for building elements, appliances and equipment. ■ Energy reduction targets should be set with a long-term view and must ensure that renovation is deep enough to avoid "locking in" energy efficiency potential. ■ Develop dedicated renewable heat policies.
Smart grids	Demonstration and deployment of smart grid technologies is accelerating, but better data collection required for a complete picture of progress.	■ Accelerate national data collection and international data coordination. ■ Develop and demonstrate new electricity regulation that enables practical sharing of smart grid costs and benefits. Current regulation often supports conventional approaches to system development. ■ Ensure that privacy concerns do not become a barrier to smart grid deployment.

● Not on track ● Improvement, but more effort needed ● On track, but sustained deployment and policies required

CEM governments have the power to transform the global energy system. It is time to use it.

member governments 23
13 initiatives

75% of global energy consumption
390 EJ consumed in 2010

share of global CO_2 emissions 80%
22 $GtCO_2$ in 2010, up 30% from 2000

75% of global GDP

population (billion) 4.1
61% of global population

62% of global renewable production
43 EJ in 2010

90%
of global clean energy investment

69% of global energy imports
but only 49% of exports

Rapid and large-scale transition to a clean energy system requires action on an international scale; individual, isolated efforts will not bring about the required change. Governments need to give the private sector and financial community strong signals that they are committed to moving clean energy technologies into the mainstream.

Governments should:

- Make more ambitious efforts to deepen international collaboration on clean energy deployment, through joint, actionable and monitored commitments.
- Set clear and ambitious clean energy technology goals, underpinned by stringent and credible policies.

Unless we get prices and policies right, a cost-effective clean-energy transition just will not happen.

trillion USD 19
estimated business as usual energy investment to 2020

5 trillion USD
additional investment required to 2020 for the clean-energy transition

billion USD 523
fossil-fuel subsidies in 2011, up 20% from 2010

88 billion USD
renewable energy subsidies in 2011

EUR/tCO_2 50
estimated carbon price to effect coal-to-gas switch in Europe

7.1 EUR/tCO_2
2012 average carbon price in Europe

USD/bbl 112
2012 average crude oil price, almost five times 2002 levels. Energy's economic importance keeps rising

24%
drop in average EU import prices for steam coal in 2012 vs 2011

Spending on low-carbon technologies must be smart, given increasing fiscal pressure and the rate of required investment. Large-scale markets for clean energy technology will depend on appropriate energy pricing and effective government policy to boost private sector investment.

Governments should:

- Reflect the true cost of energy in consumer prices, including through carbon pricing.
- Phase out direct and indirect fossil-fuel subsidies and increase economic incentives for clean energy technologies.
- Develop and implement long-term, predictable policies that will encourage investors to switch from traditional energy sources to low-carbon technologies.

Policies must address the entire energy system and take a long-term view.

60% average share of energy input lost as heat in power generation	**46%** share of global energy consumption used for heating and cooling
10% share of wind and solar in global electricity by 2020 in the 2DS, a five-fold increase on current levels. By 2050, this share needs to be 30%	**500 000 km** length of new transmission and distribution lines needed globally by 2020. As many need refurbishing or replacing
km² 33 000 global parking space in 2010, roughly the size of Belgium; expected to grow by 40% by 2020	**1:3** typical cost/benefit ratio in smart grids investments

Smart infrastructure investments that enable system-wide gains make sense. Clean energy solutions like electric vehicles and solar PV depend on them. Integrated systems enable more effective energy delivery and consumption; they also enable investment in one sector to be leveraged in others. Infrastructure takes time to build, so action is needed now.

Governments should:

- Draw up strategic plans that support and guide long-term public and private energy infrastructure investments.
- Take a long-term view, thinking beyond electoral cycles, so that technologies that facilitate the transformation of the energy system are put in place early.
- Design policy based on analysis of local conditions that affect the operation of the system.

Energy efficiency: the easy win. Unleashing its potential requires stronger economic incentives and more ambitious regulation.

45%
share of required emissions reductions to 2020 that can be delivered by energy efficiency

56.7 tCO_2/TJ
Energy Sector Carbon Intensity in 2010. Almost static since 1990

countries 3
have performance based Building Energy Codes

Zero energy
targeted performance from 2021 for new buildings in the European Union

20%
share of energy that is converted to mobility in a typical gasoline or diesel car

130-200 gCO_2/km
range in average car fuel economy in CEM countries; global average in 2011 was 167 gCO_2/km

0.5%
annual improvement in energy intensity 2000-2010 (energy/GDP); target improvement rate is over 2%

30%
Potential energy savings in industry with implementation of an energy management system

Barriers such as high upfront capital costs, customer indifference, and lack of awareness or capacity, leave much cost-effective energy-efficiency potential untapped. Economic incentives are crucial to drive change and investment; standards and codes have also proven effective, as have awareness building and training schemes.

Governments should:

- Integrate energy efficiency into economic, health, environment and energy policies in order to achieve the full range of benefits and better value its impact.
- Set, enforce and regularly strengthen building energy codes, fuel economy standards, energy management in industry and other energy efficiency measures.
- Put in place policies that create clear economic incentives for energy efficiency investments.
- Improve awareness and knowledge in industry and among consumers about the benefits of energy efficiency.

Accelerating government RD&D support is vital to bring promising clean energy technologies to the market.

11%
proportion of IEA governments' RD&D budget dedicated to energy in 1981

4%
proportion of IEA governments' RD&D budgets dedicated to energy in 2011

billion USD 17
IEA government energy RD&D spending in 2011, down 15% since 1980, but up 75% since 2000

3.5 billion USD
government spending on renewable energy and energy efficiency research in 2011

billion USD 1.9
government spending on fossil-fuel research in 2011

50%-80%
estimated required government share in RD&D costs of energy technology development, compared to private sector

13 out of 14
top PV innovations developed with government support in the United States since 1980

3-6 times
required increase of RD&D investments. For advanced vehicles and CCS the gap is much higher

Early deployment provides vital opportunities for learning and cost reduction for more mature technologies, but strategic RD&D is also critical to enable technologies to meet the performance and cost objectives that make clean energy competitive. The private sector will not act on its own.

Governments should:

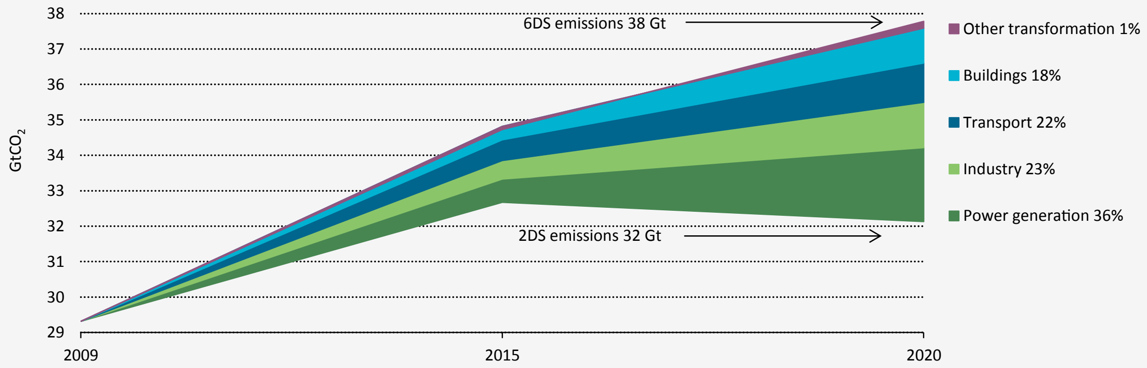
- Enhance investment in RD&D in new clean energy technologies and double its share in public budgets. Public RD&D investment should be supplemented with targeted policies that foster demand for these technologies.
- Improve quality and availability of technology-specific data on public energy RD&D investment. Understanding RD&D gaps requires greater clarity on current spending, both public and private.
- Expand international collaboration on energy RD&D, including sharing lessons on innovative RD&D models, to more effectively leverage limited government resources, avoid duplication and improve efficiency of investments.

Tracking Progress: How and Against What?

- ***Tracking Clean Energy Progress 2013* assesses how effective current policy is at achieving a more sustainable and secure global energy system.** What rates of deployment do recent trends demonstrate for key clean energy technologies? Are emerging technologies likely to be demonstrated and commercially available in time to fully contribute?
- **Tracking against near-term targets but aiming for the long term.** This report uses interim, 2020 2DS benchmarks to provide an overview of whether technologies and energy savings measures are on track to achieve 2DS objectives by 2050. The near-term focus shows whether actions that are necessary for more profound decarbonisation post-2020 are progressing as required. The report highlights how the overall deployment picture has evolved since the 2012 Clean Energy Ministerial (CEM3) and, vitally, key policy and technology measures that energy ministers and their governments can take to scale up deployment for each technology and sector with energy savings potential. Graphical overviews[6] that introduce each section summarise the data behind the section's key findings. The book is structured by technology and sector. This year's edition contains new sections dedicated to natural gas technologies and smart grids, and a special feature on RD&D innovation. As a separate annex to this report there is a publication on CCS applications in industry.
- **Technology penetration, market creation and technology developments are key measures of progress in clean energy deployment.** All three are essential to the success of individual technologies. The 2DS relies on development and deployment of lower-carbon and energy-efficient technologies across the power generation, industry, transport and buildings sectors (Figure I.2). For each sector, this report assesses, on the basis of available quantitative and qualitative data:
  - **Technology penetration.** What is the current rate of technology deployment? What share of the overall energy mix does the technology represent? Is the technology being distributed or diffused globally at the rate required?
  - **Market creation.** What mechanisms are in place to enable and encourage technology deployment, including government policies and regulations? What level of private sector investment can be observed? What efforts are being made to drive public understanding and acceptance of the technology? Are long-term deployment strategies in place?
  - **Technology developments.** Is technology reliability, efficiency and cost evolving and if so, at what rate? What level of public investment is being made into technology RD&D?

6 Enhanced interactive data visualisations are available on www.iea.org/etp/tracking.

Figure I.2 Sector contributions to emissions reductions



Key point *All sectors must contribute to achieve the 2DS.*

Box I.2 *ETP 2012* scenarios

The **6°C Scenario (6DS)** is largely an extension of current trends. By 2050, energy use almost doubles (compared with 2009) and greenhouse gas emissions rise even more. The average global temperature rise is projected to be at least 6°C in the long term.

The **4°C Scenario (4DS)** takes into account recent pledges made by countries to limit emissions and step up efforts to improve energy efficiency. It serves as the primary benchmark when comparisons are made between scenarios. In many respects, this is already an ambitious scenario that requires significant changes in policy and technologies. Moreover, capping the temperature increase at 4°C requires significant additional cuts in emissions in the period after 2050.

The **2°C Scenario (2DS)** is the focus of *ETP 2012*. The 2DS describes an energy system consistent with an emissions trajectory that recent climate science research indicates would give an 80% chance of limiting average global temperature increase to 2°C. It sets the target of cutting energy-related CO_2 emissions by more than half in 2050 (compared with 2009) and ensuring that they continue to fall thereafter. The 2DS acknowledges that transforming the energy sector is vital, but not the sole solution: the goal can only be achieved if CO_2 and greenhouse gas emissions in non-energy sectors are also reduced.

Chapter 1

Power Generation

Renewable Power

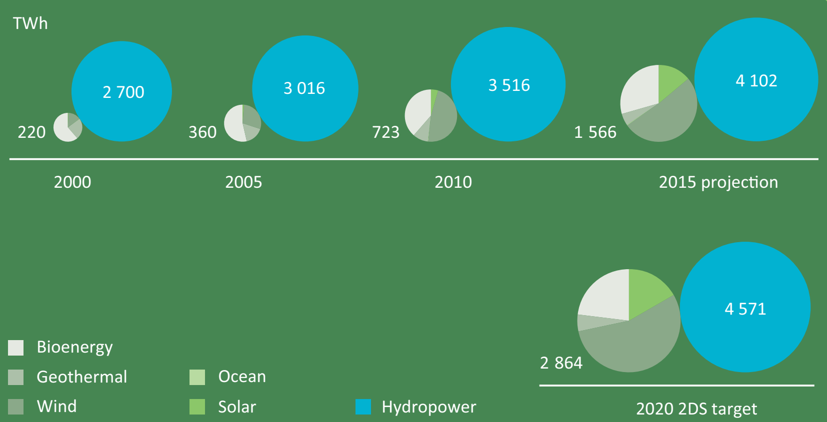
On track

Renewable power technologies are broadly on track to meet 2DS targets by 2020, as performance improves, deployment is scaled up and markets expand globally. Improving economic competitiveness is likely to support robust growth but effective policy support is vital, including market design reforms to facilitate grid integration. Wider deployment of concentrating solar power and offshore wind is needed, as well as enhanced RD&D for promising new technologies, such as ocean power.

Technology penetration

1.1 Renewable power generation by technology

More online

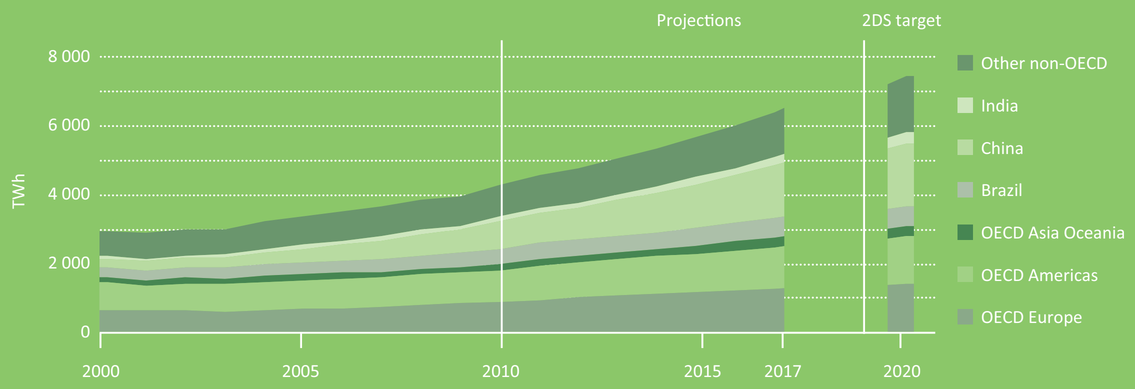


19%

SHARE OF RENEWABLES IN GLOBAL ELECTRICITY GENERATION IN 2011 (25% 2DS TARGET IN 2020)

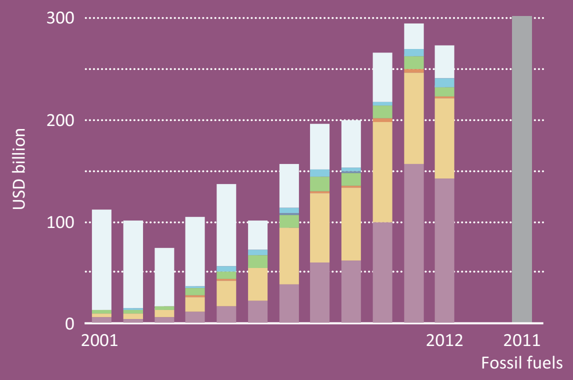
1.2 Renewable power generation by region

More online



Market creation

1.3 Annual capacity investment



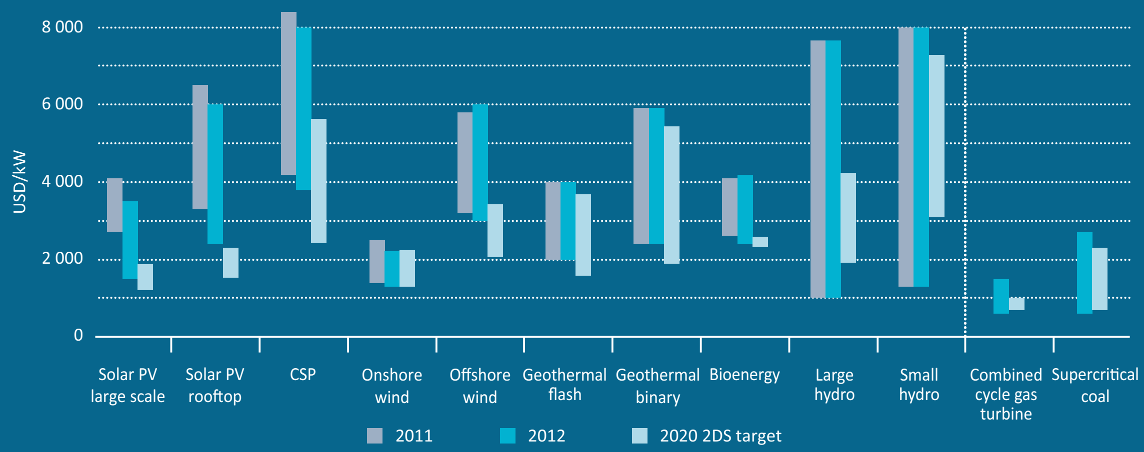
Recent developments

Policy uncertainty contributed to a slowdown in renewable capacity investment in 2012. Clear and predictable policy support is vital to keep deployment on track

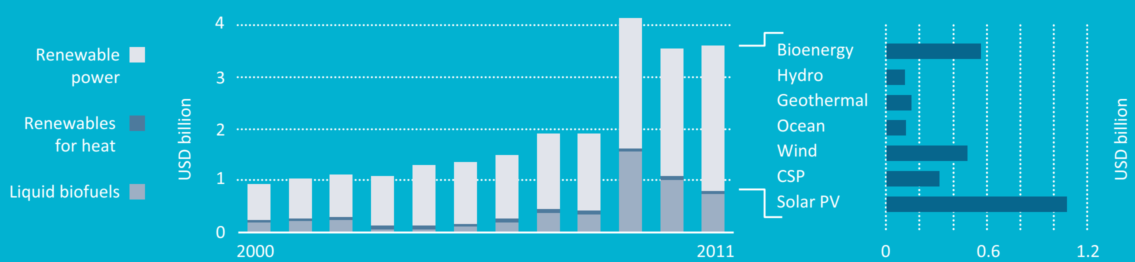
2012 investment was still in line with 2DS objectives, at an estimated USD 270 billion

Technology developments

1.4 Technology investment costs



1.5 IEA public RD&D spending



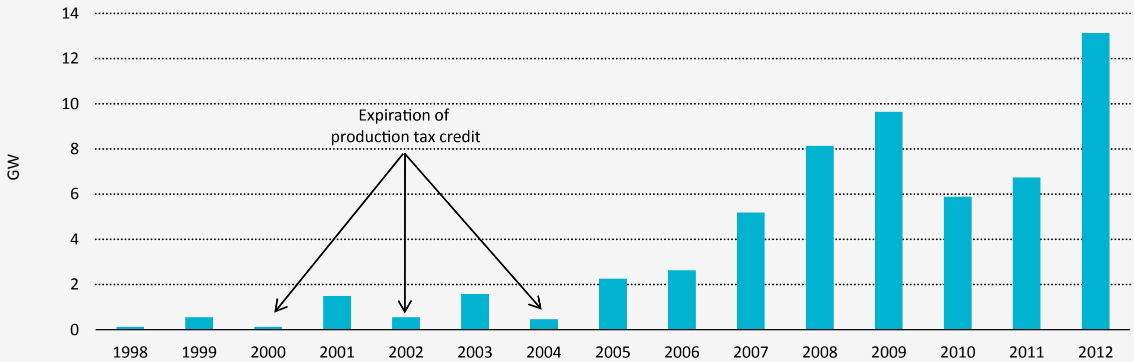
For sources and notes see page 141

Recent developments

- Globally, renewable energy continued to grow strongly in 2012 in both OECD and non-OECD countries. Preliminary analysis suggests that capacity expanded in the most dynamic sectors – solar PV, by an estimated 29-30 GW (+42%), and wind (onshore and offshore), by 44-45 GW (+19%). This builds on robust performance in 2011, when total generation (as well as capacity) showed strong growth. Non-hydropower generation rose by an estimated 142 TWh from 2010 (+19%) and hydropower generation increased by 108 TWh (+3%), to bring total growth in renewable power generation to 250 TWh (+6%). Non-hydropower capacity increased by 77 GW (+19%) in 2011, while hydropower capacity expanded by 35 GW (+3%).
- Global investment in new renewable power plants excluding large hydropower was USD 240 billion in 2012. This is 11% lower than the record USD[1] 270 billion in 2011, but remains in line with 2DS objectives. The slowdown in investment reflects policy uncertainty and "stop-and-go" policy decision-making in key regions, in addition to falling equipment costs – in particular for solar PV and wind – and challenging financing conditions in several markets, including Europe.
- In the United States, for example, uncertainty regarding the potential expiration of a production tax credit for wind generation at the end of 2012 continued to slow investment in future wind capacity (Figure 1.6). A one-year extension enacted at the start of 2013 means that the tax credit, and consequently investment, still lack long-term certainty. Similarly, wind investment fell in India after tax- and generation-based financial incentives expired in 2012, with uncertainty remaining over their reinstatement.
- While several governments reduced economic incentives for renewable technologies as their competitiveness improved, and to control policy costs (*e.g.* Germany, Italy and Spain), others increased or upgraded economic incentive schemes or policy frameworks. Japan introduced a feed-in tariff scheme across a range of renewable technologies, in the face of rising electricity needs. China introduced measures to facilitate the grid connection of distributed solar PV systems and a deployment target of 10 GW of new solar PV for 2013. Korea replaced its feed-in tariff scheme with a renewable portfolio standard, supported by renewable energy certificates and tax incentives.
- The renewable energy industry, largely in solar PV and wind, entered a phase of deeper consolidation, particularly among smaller and higher-cost manufacturers. Increased competition in the manufacturing sector, however, continued to boost other parts of the industry value chain.
- Investment costs for renewable electricity technologies continued to fall in 2012, particularly for solar PV and onshore wind. However, cost reductions are proceeding more slowly for other technologies, such as offshore wind and CSP.

1 Unless otherwise stated, all costs and prices are in real 2010 USD, *i.e.* excluding inflation. Other currencies have been converted into USD using purchasing power parity (PPP) exchange rates.

Figure 1.6 Wind capacity additions in the United States



Note: Figures and data that appear in this report can be downloaded from www.iea.org/etp/tracking.
Source: IEA, 2012c; American Wind Energy Association www.awea.org/learnabout/industry_stats/index.cfm (for 2012 data).

Key point *Policy uncertainty has a direct impact on investments.*

Overall progress assessment

The role of renewable power in the 2DS

Renewables dominate power generation in the 2DS: the scenario assumes an increase in renewable energy's share of world electricity generation from 20% in 2010 to 28% by 2020 and 57% by 2050. In the 2DS, 7 500 TWh of renewable electricity is generated in 2020, versus total generation of 27 165 TWh. Hydropower makes the largest contribution (17% of total electricity generation), followed by wind (6%), biomass and waste (3%), and solar (2%). Renewable energy contributes around 15% to emissions reductions relative to the 4DS by 2020, the second-largest contribution after end-use fuel and electricity efficiency. In the 2DS, the largest proportion of global renewable electricity generation in 2020 comes from China (24%), followed by OECD Europe (19%), the US (11%), Brazil (7%) and India (5%).

Technology penetration

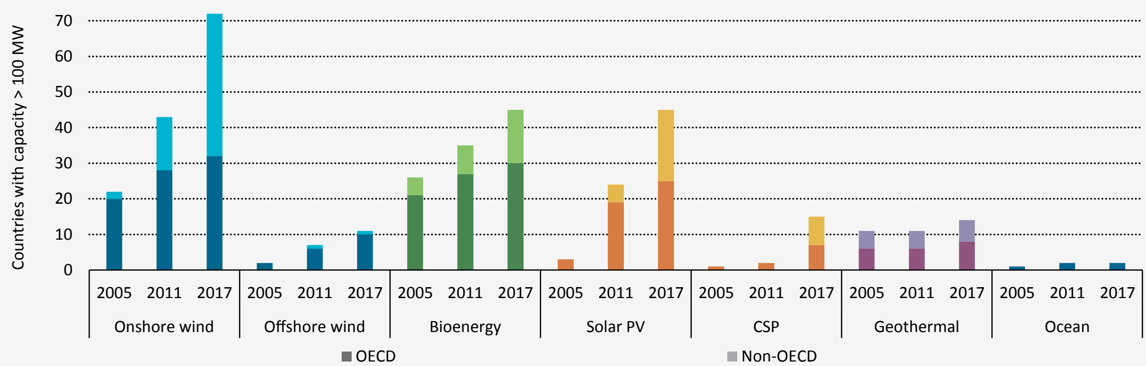
As a portfolio of renewable technologies continues to become more competitive, renewable power is on track to meet 2020 2DS objectives in terms of absolute generation (Figure 1.1). In 2011, renewable generation (including pumped hydro storage) reached an estimated 4 540 TWh, up from 4 290 TWh in 2010 (+5.8%). This follows strong growth over the last decade, with global renewable generation growing by 1 620 TWh from 2000-11 (+4.1% annually). Non-hydropower sources increased by 680 TWh (+13.6% annually) and hydropower by 940 TWh (+2.8% annually) over the period. Robust growth is expected to continue,[2] with renewable generation forecast to increase to almost 6 400 TWh in 2017 (+5.8% per annum from 2011 levels), in line with 2DS goals. Non-hydropower technologies are projected to expand by over 1 100 TWh (+14.3% annually) and hydropower by 730 TWh (+3.1% annually) (IEA, 2012c).

Renewable deployment, particularly non-hydro, is continuing to spread geographically. In 2011, the number of countries with installed capacity above 100 MW rose significantly compared with 2005 levels for several non-hydro technologies, including onshore

2 The IEA *Medium-Term Renewable Energy Market Report 2012* sets out market trends and projections to 2017 for the renewable electricity market.

and offshore wind, bioenergy, and solar PV (Figure 1.7). Such diffusion is vital to meet 2DS objectives across different regions, and is projected to continue and deepen in the medium term. Growth is shifting beyond traditional support markets in Europe to an increasing number of non-OECD areas. Led by Brazil, China and India, in 2011 non-OECD regions accounted for an estimated 2 410 TWh, or around 53%, of renewable electricity production, up from 45% in 2000 (Figure 1.2).

Figure 1.7 Market concentration of non-hydro renewables



Source: unless otherwise noted, all tables and figures in this report derive from IEA data and analysis.

Key point *Deployment of renewable electricity is spreading geographically.*

Solar PV generation is growing fast, expanding from marginal levels in 2000 to an estimated 65 TWh in 2011 (+47% annually), up from 32 TWh in 2010. Despite increased turbulence in the upstream manufacturing industry and incentive cuts in some key markets (*e.g.* Germany and Italy), growth in capacity remained robust in 2012, spurred by falling system prices and stronger policy frameworks in markets such as Japan and China. Preliminary analysis suggests 2012 global solar PV installations near 30 GW, similar to capacity additions in 2011. Generation growth is projected to continue over the medium term, to nearly 280 TWh in 2017, putting solar PV on track to achieve 2020 2DS objectives (380 TWh in 2020). Until recently, deployment was concentrated in countries with strong policy support, such as Germany, Italy and the United States. However, improving competitiveness is helping deployment to spread into Africa, the rest of Asia, Latin America and the Middle East. This trend must continue if 2DS objectives are to be met.

Concentrating solar power (CSP) has not had the same explosive growth as solar PV. In 2000-2011, total growth was just over 3 TWh (+20% annually), reaching an estimated 4 TWh in 2011, from over 2 TWh in 2010. Though it is projected to grow significantly through 2017, to more than 30 TWh, development is likely to fall short of the 2DS 2020 goal of 100 TWh. Competition from lower-cost solar PV is challenging deployment, with some projects in the United States having converted from CSP to solar PV. However, the suitability of CSP for hybridisation (*e.g.* integration with a fossil fuel plant) and storage can enhance its value through dispatchability, which may lead to increased market penetration. Commercial capacity has been concentrated in a few areas, largely Spain and the United States, but numerous projects are being developed in the Middle East and North Africa, as well as in Australia, India, China and South Africa. In Morocco, the first phase (160 MW) of the 500 MW Ouarzazate project secured financing in 2012 and is expected to be operational by 2015.

Onshore wind generation is on track to achieve the 2DS 2020 objective of almost 1 500 TWh generation. One of the most cost-competitive renewable energy sources, onshore wind has been deployed in several countries with good resource areas. From 2000 to 2011, generation increased by 400 TWh (+27% per year), reaching an estimated 435 TWh in 2011, up from 335 TWh in 2010, reflecting sizeable expansions in China and the United States in particular. By 2017, generation is expected to reach almost 1 000 TWh. In some countries with good wind resources, such as Brazil and Turkey, projects are competing well against fossil fuels in wholesale electricity markets without economic incentives. Global growth rates have started to slow, however, because of grid integration challenges, in China for example, and uncertainty over key policy incentives in some areas, such as the United States and India.

Offshore wind generation growth has accelerated in the past few years, but from low levels, reaching an estimated 12 TWh in 2011, up from almost 9 TWh in 2010 (+40%). The technology is still emerging and requires further deployment to bring down costs. The United Kingdom, where exploitation rights to developers have been offered via three tendering rounds over the past decade (47 GW total), and Denmark, with its long-standing wind experience, have led deployment. Most medium-term developments are expected in Northern Europe and China. Still, meeting the 2DS objective of 130 TWh may be difficult; at current expected growth rates, generation should reach 80 TWh in 2017. Progress will depend on securing grid connections and tackling technical and financial difficulties.

Geothermal generation grew by over 19 TWh from 2000 to 2011 (+2.9% annually), to over 70 TWh. Generation costs from high-temperature geothermal resources are competitive with fossil fuels, and medium-term projections see generation rising to 90 TWh in 2017, but development is trailing the 2DS objective of 150 TWh, because of risks associated with well exploration. Geothermal represents a significant portion of electricity production in Iceland (27%), El Salvador (26%), Kenya (19%) and the Philippines (15%). The United States, Indonesia and the Philippines have the largest installed capacity and most medium-term development is expected in these areas. In Japan, the government has approved development in parts of national parks, bringing total exploitable potential to 12 GW.

Electricity from solid biomass, biogas, renewable municipal waste and liquid biofuels grew by over 170 TWh from 2000 to 2011 (+8% per year), to reach an estimated 310 TWh, up from almost 280 TWh in 2010. Deployment is on pace to meet the 2DS goal of 655 TWh. Not every country has great domestic bioenergy potential, but municipal waste can contribute to renewable power production anywhere in the world. Moreover, some bioenergy feedstocks, such as wood pellets, are internationally traded, which is rare among renewable energy sources. Medium-term projections see generation rising to over 530 TWh in 2017. The largest developments are expected in China, Brazil and Japan. Other players include the United States, with the largest current capacity; Nordic countries, with co-generation plants producing both electricity and heat for district heating systems; and the United Kingdom, which is taking a lead in co-firing with coal and the conversion of coal-fired plants. Meeting 2DS objectives will depend heavily on the cost and availability of biomass.

Ocean power generation remains small, at less than 1 TWh in 2011, but has taken important strides towards commercialisation. In 2011, the largest commercial ocean project came on line in Korea; large plants also exist in France and Canada. The potential for ocean technologies is significant and widespread. Still, the technology remains costly and much activity remains at the demonstration level. Further RD&D support is needed to bring deployment in line with 2DS objectives.

Hydropower grew from 2 700 TWh (including pumped hydro storage) in 2000 to an estimated 3 640 TWh in 2011 (+3% annually). China, Brazil, Canada, the United States and Russia have the largest hydro output, with China and Brazil accounting for most growth. Medium-term projections see generation expanding to near 4 380 TWh in 2017, with globally capacity at 1 300 GW, a pace that exceeds the 2DS objective of 4 570 TWh by 2020. Significant global resource potential remains, however, especially in developing countries, where hydropower can provide cheap and reliable electricity. With long project lead times, the on-time commissioning of plants as well as addressing project sustainability issues remain key to achieving the 2DS goal.

Market creation

Investment in new renewable electricity capacity, including in emerging markets, has more than doubled over the last decade and is currently in line with the sizeable levels required to meet the 2DS goals (Figure 1.3). In the 2DS, renewables account for 56% of average annual investment in power generation between 2010 and 2020, or around USD 210 billion per annum. Wind accounts for 20% of average annual investment (USD 75 billion); solar 16% (USD 61 billion); and other renewables 20% (USD 74 billion). Global investment in new renewable energy capacity, excluding large hydropower capacity, increased by USD 230 billion between 2001 and 2012, reaching an estimated USD 240 billion in 2012 (+34% annually), in line with 2DS objectives. In 2012 investment reached USD 143 billion in solar, USD 78 billion in wind, and USD 19 billion in other renewables. Investment is expanding in many emerging markets, including Brazil and other countries in Latin America and in Asia, supported by attractive project economics and rising electricity demand. This progress needs to extend to newer markets, such as the Middle East and Africa, in order to meet 2DS objectives.

Investment slowed in some technologies and regions in 2012 not only because of continued falls in technology costs and increased economic headwinds, but also because of policy uncertainty in key markets. This highlights the importance of clear, predictable and long-term policy support, backed by long-term targets. Government support schemes, including generation and deployment targets, economic incentives (*e.g.* feed-in tariffs, tradable green certificates, tenders, tax incentives and grants) and measures to facilitate the system integration of variable renewables (*e.g.* through increased power system flexibility) have driven the strong growth in renewable energy deployment over the last decade. The challenge for governments is to design policies that achieve several goals at once: help renewables to compete; effectively match the pace of cost reductions for renewable technologies, to avoid excessive policy costs; and maintain investor certainty and confidence, through transparent and predictable frameworks that reduce investment risk and cost, and increase availability of finance.

Some 110 countries had national renewable electricity policies in place at the end of 2012. The extent of revisions to government policy in 2012 demonstrates the complexity in implementing effective policy support. Table 1.1 provides an overview of key policy shifts in national economic incentives for renewable power in 2012. The largest changes in incentives pertained to markets where solar PV deployment had accelerated amid rapid cost reductions, or occurred in countries with deteriorating economic conditions – with some markets experiencing both trends. Many of the decreases in economic incentives were adjustments to feed-in tariffs (FITs) and the implementation of mechanisms for reducing FITs for future projects over time. Even highly developed markets, such as Germany, faced difficulty in reconciling investor certainty with policy flexibility in the adjustment of solar PV feed-in tariffs. Still, changes in economic incentives should not be confused with overall support frameworks. In general, countries have not scaled down renewable electricity deployment targets, with some even increasing them (*e.g.* China, Denmark and Italy).

Table 1.1 Changes in key national economic incentives for the renewable electricity sector in 2012

	Incentive	Countries
Change of regime		Japan: feed-in tariffs (FITs) replaced renewable portfolio standard (RPS). South Korea: RPS system replaced FITs. Sweden and Norway: introduced joint Green Certificates Market.
Increase	FITs	Indonesia: tariffs for geothermal energy implemented. Jordan, Malaysia, Rwanda and Ukraine: FIT systems introduced.
	Other economic incentives	Australia: AUD 2 billion for investments via Clean Energy Finance Corporation. Brazil: introduced discounts on transmission and distribution fees and net metering. China: waived charges for grid connections for small-scale solar PV. Romania: implemented allocation floor for Green Certificates.
Decrease	FITs	Australia:[3] FIT levels for solar PV reduced by 41%. Canada:[4] FIT levels reduced for wind by 15% and and solar PV by 9.6%-31.5%. Germany: under EEG 2012, FIT rates revised down and degression rates increased for several technologies, particularly solar PV. Italy: FIT levels for solar PV lowered by 20% and annual support cap imposed. Portugal: moratorium on FITs for new installations. Spain: moratorium on FITs for new installations.
	FITs and other economic incentives	Bulgaria: FIT cuts of 10%-50%. Biggest decrease of tariffs for solar PV. Retroactive tax for solar PV operators introduced. Greece: FIT levels reduced up to 46% for solar PV, new licenses for solar PV installations were suspended and retroactive tax on renewable systems introduced. United Kingdom: cuts in FIT levels up to 40% for solar PV. Announced future adjustments to Renewable Obligation Certificates (both increases and decreases depending on technology).
	Other economic incentives	Belgium:[5] adoption of a retroactive grid access tariff for the use of the grid for PV systems benefiting from net-metering. United States: expiration of cash grant programme (Section 1603). Uncertainty over the expiration of the production tax credit (extended for one year at the start of 2013). India: expiration of accelerated depreciation and generation-based incentives.

3 Changes refer to FITs in the state of Victoria.
4 Changes refer to decrease of FITs in the province of Ontario.
5 For Flanders only; adoption December 2012.

Technology developments

While renewable electricity remains generally more expensive than conventional wholesale power and economic policy incentives play a large role in sustaining development, leading technologies are becoming increasingly competitive (Figure 1.4). Capital costs for onshore wind, hydropower and geothermal are decreasing in line with assumptions. Capital costs for solar PV continue to fall – in 2012, large-scale systems were at USD 1 500-3 500/kW and small-scale systems were at USD 2 400-6 000/kW – but remain above 2020 2DS levels (USD 1 211-1 880/kW for large systems and USD 1 534-2 303/kW for small systems). Cost reductions are proceeding more slowly for other technologies, however. Turbines and associated equipment suited for an ocean environment make offshore wind costlier than onshore wind. CSP costs are also high, though hybridisation and storage features add value that should enhance attractiveness over time.

These trends in investment costs have translated into increasingly attractive generation economics versus other sources. In Brazil, average onshore wind auction prices fell to USD 42/MWh on average in December 2012 (12% lower than the prior year). There, wind competes well with natural gas and with other historically less expensive renewable sources, such as hydropower and bioenergy, though delivering projects at the most recent low bid prices will be challenging in practice. Onshore wind has been competitive in New Zealand for several years, thanks to excellent wind resource conditions and relatively expensive fossil-based alternatives. Geothermal and most hydropower are already competitive with their fossil alternatives in places with favourable resource conditions. Large-scale bioenergy plants can also be competitive, depending on feedstock prices.

Solar PV generation costs are higher, but are falling rapidly. While utility-scale solar PV costs are still significantly higher than base-load generation from conventional fuels, they approach peak power prices in places with summer peak demand (*e.g.* due to air-conditioning needs) and unsubsidised fossil-fuel alternatives. Small-scale solar PV systems are more expensive, but mini-grid and off-grid applications are already competitive with alternatives in many cases. Grid-connected residential PV systems can achieve lower generation costs than retail electricity prices for households in countries with good solar resource and high retail prices. Still, these generation costs may vary with the allocation of the fixed costs associated with grid connections. With PV expanding in all world regions, the combination of decreasing capital costs and favourable financing is expected to further decrease generation costs.

Increased RD&D investment in emerging technologies, particularly solar CSP, ocean and enhanced geothermal, is needed to enhance competitiveness. OECD government RD&D spending in renewable power technologies has grown over the past decade, from USD 0.9 billion in 2000 to USD 3.9 billion in 2011 (Figure 1.5). Recent spending has remained high, boosted by stimulus packages starting in 2009. However, outlays for renewables remain smaller than those for conventional fuels; in 2011, public RD&D expenditure on fossil fuel and nuclear combined was more than twice that for renewable electricity.

Recommendations for governments

- *Countries should implement transparent and predictable renewable energy strategies that will sustain market deployment of a portfolio of renewable technologies that best fit local market conditions (in terms of costs, resources and technology maturity) over the long term. Policy uncertainty is currently undermining investment in some markets. A transparent process of policy adjustment according to changing market conditions and technology cost development will reinforce investor confidence.*
- *Strengthening the flexibility of the energy system will be key to enabling the grid and system integration of higher penetrations of variable and distributed generation technologies like wind and solar PV. This can first be done through better utilisation of existing infrastructure and optimisation of operations (e.g. generation forecasts). New infrastructure, particularly to strengthen the grid, will also be necessary.*
- *Governments at the forefront of renewable energy deployment should take measures to ensure timely investments in additional flexibility infrastructure such as smart grids, transmission, flexible generation or storage. In this regard, Ireland may provide the best current example of an integrated approach for providing the flexibility needed to support ambitious deployment targets of variable renewables. Taking a regional rather than national approach wherever possible can greatly enhance flexibility.*
- *The expansion of renewables into newer markets with large resource potential and good economic attractiveness is essential to reaching 2DS goals. Many developing areas fall under this category, including countries in the Middle East, Latin America, Africa and Southeast Asia, where renewable deployment for some technologies is still at its inception phase. Governments in these regions should review potential policy measures prior to CEM 5, and commence policy planning and development as soon as possible.*
- *Continued RD&D into emerging technologies, such as offshore wind, CSP and enhanced geothermal, is essential in order to realise the potential that these technologies offer.*

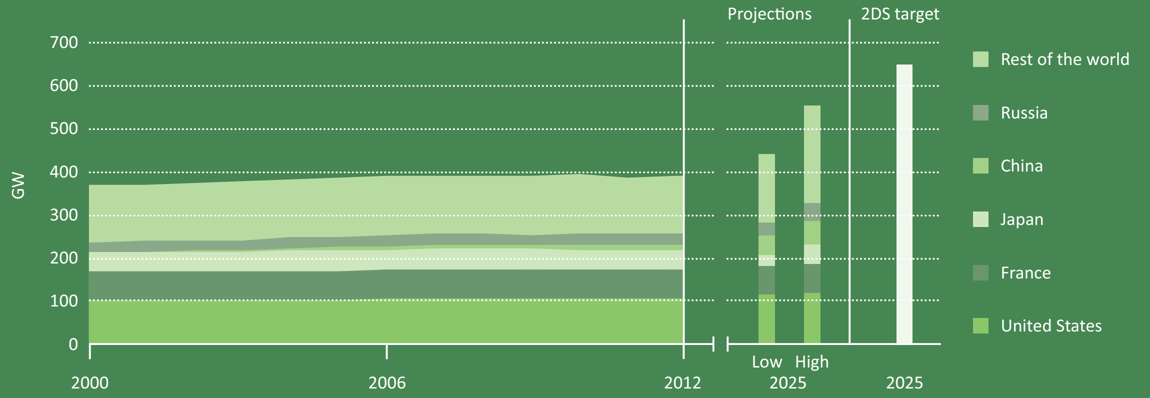
Nuclear Power

Not on track

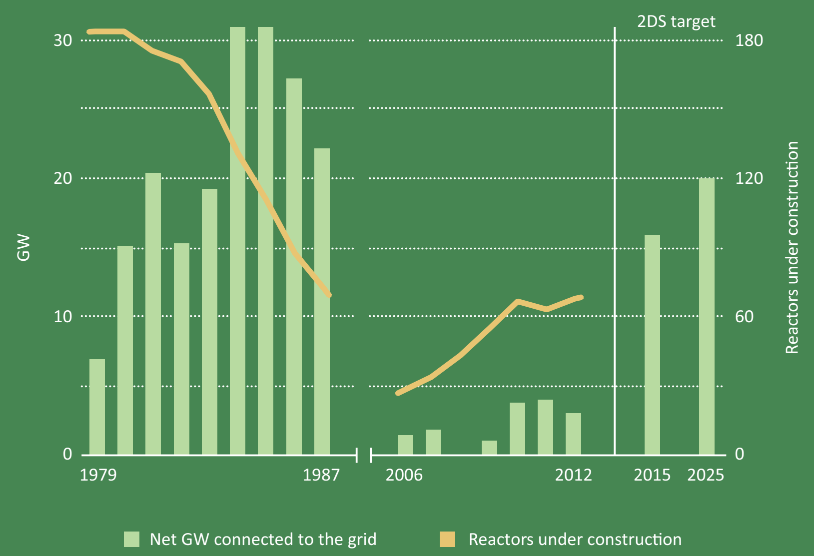
The nuclear policy landscape is stabilising after the Fukushima accident in Japan, but major construction of new reactors is needed in order to meet 2DS targets. Achieving this will require greater public acceptance of nuclear energy, and more favourable electricity market mechanisms and investment conditions.

Technology penetration

1.8 Installed gross nuclear capacity



1.9 Capacity additions and reactors under construction



16

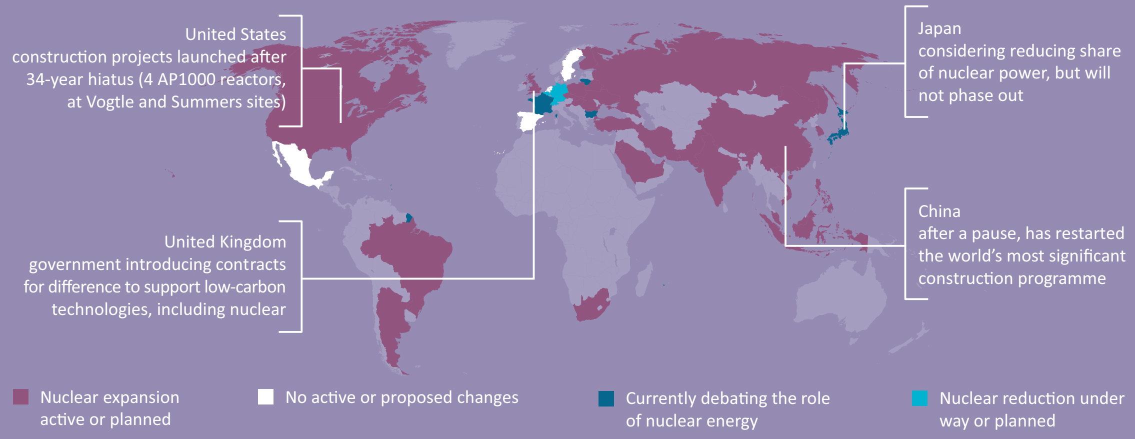
GW REQUIRED CAPACITY ADDITIONS TO 2020

30

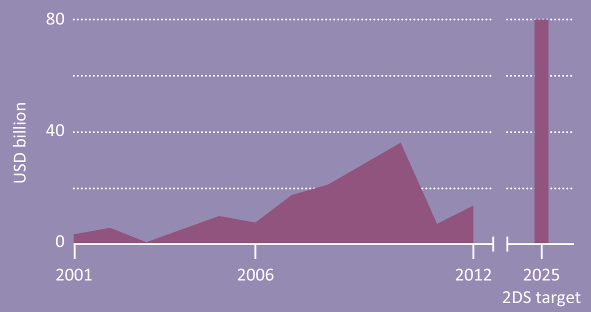
GW HISTORIC HIGH IN CAPACITY ADDITIONS

Market creation

1.10 Nuclear policy status in 2012



1.11 Annual capacity investment



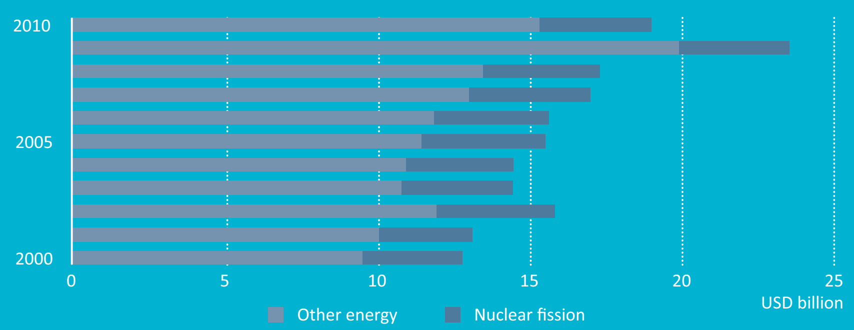
Recent developments

Post-Fukushima safety evaluations concluded in 2012, allowing continued operation of most reactors, but recommending improved resistance to extreme natural events

Germany, Belgium and Switzerland announced a phase-out of nuclear power following the Fukushima accident. Most countries' deployment targets remain unchanged, although debate on nuclear energy policy continues

Technology developments

1.12 IEA government RD&D spending



Key point

IEA government spending on nuclear fission RD&D has declined as a percentage of total RD&D spending; from 34% in 2000 to 24% in 2010.

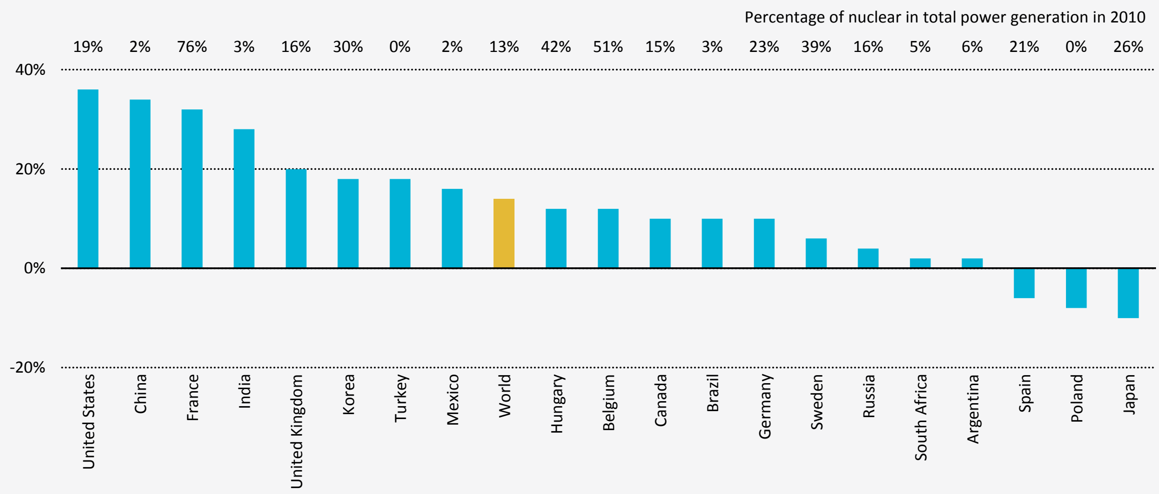
For sources and notes see page 141

Recent developments

- Seven projects globally started construction in 2012, an increase from 2011 when new projects fell to only four after the Fukushima accident. In 2010 there had been 16 new projects.
- Most safety evaluations ordered by governments after the Fukushima accident have found that existing reactors can continue to operate if systems to improve resistance to extreme natural events and loss of off-site power are implemented. Preliminary assessments of the cost of upgrades to ensure resistance to Fukushima-type events range from USD 100 to USD 200/kW for generation II reactors, which make up about 95% of existing reactors (NEA, 2012a).[6] Only minor design changes are anticipated for generation III reactors – which represented 26 of the 68 reactors under construction at the end of 2012 and half of the capacity under construction[7] – so that overnight generation costs for new nuclear construction will probably not increase much as a result of the strengthening of safety regulations related to Fukushima-type events.[8]
- Some countries continue to debate nuclear policy in the wake of the Fukushima accident. Japan is considering reducing its dependency on nuclear power; the new government is to review from scratch the former government's energy strategy. Nuclear power supplied 26% of electricity in 2010 (288 TWh) but this figure fell to just over 18% in 2011 (102 TWh) and only two reactors out of 50 operational reactors had been restarted by the end of 2012. The French government is considering reducing the share of nuclear electricity (79% of generation in 2011) to 50% by 2025, and has scheduled closure of the country's oldest plant in 2016.[9]
- Several countries have active or planned nuclear expansion programmes. In 2012 construction began on four generation III reactors in the United States, after a 34-year hiatus. China, which froze the approval process for new plants after the Fukushima accident, has announced that it will resume its construction programme, although based on generation III designs and on coastal sites only. In the United Kingdom, industry intends to build up to eight units by 2025, representing at least 10 GW, with two projects possibly to be launched in 2013. Russia and India have also confirmed plans to continue to build nuclear plants (15 GW to 20 GW each by 2025).
- A survey comparing attitudes to nuclear energy in April 2011 and September 2012 showed that the level of public support for nuclear energy has increased since the height of the Fukushima accident in most countries (+14% for the global figure, to 45%: see Figure 1.13). This trend most pronounced in the United States, China and France. Strong local opposition to nuclear power has been reported in India, however, notably around the Kudankulam site where the commercial operation of two Russian-built generation III plants has been delayed.

6 These cost additions are modest, compared with investments required for long-term operation of nuclear power plants.
7 Generation III reactors are under construction in China, Finland, France, India, Japan, Korea, Russia and the United Arab Emirates.
8 The cost of construction for nuclear power plants varies significantly by region and reactor type. Average overnight costs of generation III/III+ reactors range from about USD 1 560 to USD 3 000/kW in Asia and USD 3 900 to USD 5 900/kW in Europe.
9 The government continues to support the construction of the first European Pressurised Reactor reactor at Flamanville.

Figure 1.13 Change in net public support for nuclear power since Fukushima



Source: Ipsos Mori, 2012.

Key point *Public support for nuclear seems to be increasing since the height of the Fukushima accident.*

Overall progress assessment

The role of nuclear power in the 2DS

In the 2DS, nuclear power plays a substantial role in the decarbonisation of the electricity sector, reaching around 16% of global generation by 2025[10] (about 4 600 TWh), and contributing around 6% of cumulative emissions reductions relative to the 4DS. To reach 2025 2DS goals, nuclear capacity must increase by over 250 GW from 2012 levels, by about 16 GW a year to 2020, and then by about 20 GW a year in the following decade.

Technology penetration

Gross global nuclear capacity has changed little since 2000, taking into account both grid connections, power uprates[11] **and reactor shut downs. Installed capacity remains well below 2DS objectives** (Figure 1.8). There were 437 operational reactors at the end of 2012, with total capacity of about 392 GW (up 23 GW from 2000 levels). Around 2 518 TWh of nuclear electricity was generated in 2011, making up over 12% of the world's electricity mix. This is more than 2 000 TWh (or 45%) below 2025 generation levels envisaged in the 2DS.

Additional capacity is coming on line, but too slowly. Since the middle of the last decade, an average of 2.4 GW in global capacity has been added each year (Figure 1.9), including 3.8 GW in 2010, 4 GW in 2011 and 3 GW in 2012. These figures are far below the annual capacity additions required to meet 2DS objectives and the annual capacity increases of over 30 GW in the mid-1980s.

10 2025 is taken as the benchmark for nuclear, given timeframes associated with current phase-out plans, and new construction timeframes (see the Technology developments section below).
11 Power uprate is the term used when an existing reactor is modified to generate more power.

The rate of construction starts for new reactors, previously on an upswing from around 2005, has been slowed by the Fukushima accident and the global financial crisis (Figure 1.9). There were 68 reactors under construction globally in 2012, which together have the potential to boost global capacity by 67 GW. Assuming construction times of about five to seven years, major construction is required to reach 2020 2DS goals. Nuclear capacity is projected to grow over the next decade and a half, to between 440 GW and 555 GW in 2025 (Figure 1.8). Even at the high end of the range, projected capacity still falls short of the 2DS target, by almost 100 GW.

Reaching 2DS levels of nuclear deployment will require the long-term operation of existing reactors, in addition to construction of new reactors (NEA, 2012b). Extending the operation of existing nuclear plants beyond their original design lifetime, which requires licence extensions or renewals and significant investments by utilities,[12] can help maintain nuclear capacity until new reactors replace older units. The 2DS assumes a 60-year lifetime for US reactors (at the end of 2012, over 70 reactors had received licence extensions of up to 60 years in the United States), and a 55-year lifetime elsewhere. However, long-term operation is becoming more complex, principally due to changes in safety requirements and government policy after the Fukushima accident. If closure of existing capacity is accelerated, the new rate required to reach 2DS targets will have to increase correspondingly, from 16 to 20 GW/year to 2020, and from 20 to 30 GW/year from 2020 to 2030 (NEA 2012b).

Market creation

Uncertainty in the nuclear policy landscape after the Fukushima accident is starting to dissipate, but the future of nuclear power in some key countries remains undecided. In the second half of the last decade, nuclear energy was increasingly perceived as an important low-emissions energy source. While most countries announced they would not change nuclear deployment targets after the Fukushima accident, others chose to phase-out nuclear power by closing down or not extending the lifetime of existing plants (Germany, Belgium and Switzerland, representing collectively about 30 GW of nuclear capacity); scale back or delay construction of new projects (China, at least for the next five years); or postpone (Thailand) or abandon (Italy) plans to start a nuclear programme (Figure 1.10). Today several governments are still debating the role of nuclear power in their national energy mix. However, others are expanding, or planning to expand, nuclear development.

Reflecting the slowdown in new construction since 2010, annual investment in capacity has cooled off considerably in the last two years (Figure 1.11). Investment was over USD 36 billion in 2010, consistent with the record number of construction starts in that year since 1985. That figure fell to USD 7.3 billion in 2011 (-80%), but grew slightly in 2012, to USD 13.6 billion (still -62% from 2010 levels). This compares with USD 80 billion annual capacity investment envisaged in the 2DS. The slowdown is in part due to safety evaluations undertaken in 2011 and 2012 – which led some governments to suspend or delay decisions on new projects – and postponement of investment decisions as some governments reviewed nuclear policy.

Technology developments

IEA government spending on nuclear fission RD&D reached USD 3.6 billion in 2010 (Figure 1.12). While spending has remained relatively constant since 2000 (rising only 11% from USD 3.3 billion), IEA government spending has declined as a percentage of total RD&D energy spending, to 24% in 2010 from 34% in 2000.

12 The French operator EDF has quoted the sum of EUR 40 billion to operate its fleet of 58 reactors beyond 40 years (French Senate report No. 667, 11 July 2012, www.senat.fr/rap/r11-667-1/r11-667-11.pdf, page 109). The investment is worthwhile if the operator has assurance that it will be able to operate the refurbished reactor for several decades more (typically another 20 years), since construction costs will be fully amortised by then.

Interest in small modular reactors (less than 300 MW net capacity) – known as SMRs – or medium-size reactors (300 MW to 1 000 MW) is increasing. Pre-licensing activities continue in the United States, where the Department of Energy is providing up to USD 450 million to develop and license SMR designs as part of cost-sharing contracts with industry. The target is to construct a first-of-a-kind SMR before 2022. The market for SMRs in the United States is essentially the replacement of small coal-fired power plants that are set to close. Korea's SMART SMR received standard design approval in July 2012; the country is looking to export the technology for combined power and desalination applications. Russia is constructing two small reactors on floating barges (KLT-40S design). In December 2012, construction of two 100 MW units of HTR-PM, a gas-cooled high temperature reactor that represents a first step towards a Generation IV Very High Temperature Reactor, started in Shidaowan, China.

The time required to construct nuclear power plants varies by region and reactor type, but is typically five to seven years. Between 2000 and 2012, China, Japan and Korea completed grid connection of 22 generation II and III units, with typical construction times under five years In contrast, new European generation III projects in Finland and France have encountered delays, with estimated construction times of about nine years; lessons learned from these first-of-a-kind projects should reduce construction times in the future.

Finland, Sweden and France are leading the way for establishing programmes for geological disposal of nuclear waste. Finland's POSIVA company, a subsidiary of the two nuclear power utilities, submitted an application to the government in January 2013 to build a geological repository and waste encapsulation plant, to start operating around 2020. A similar application was submitted in 2011 in Sweden by the Swedish nuclear fuel and waste management company. France's nuclear waste agency intends to submit its application to build a geological repository in 2015, to start operating in 2025. The United States has just announced a new nuclear waste management strategy designed to lead to the construction of a geological repository by 2048, combined with the construction of regional interim storage facilities.

Recommendations for governments

- *More favourable electricity market mechanisms and investment conditions are needed to ensure that new reactors can be constructed at the necessary rate. For new projects, the high upfront investment cost of nuclear technology is a challenge, especially in liberalised markets and markets with low prices for competing fuels or technologies. In liberalised markets where feed-in tariffs have been used to promote the deployment of renewable technologies, the profitability of dispatchable technologies has been degraded to the point where new investments are unlikely. A more equitable system that favours all low-carbon technologies, such as the Contract for Difference mechanism of the UK Electricity Market Reform, would make investments in nuclear technologies more attractive. Governments that have decided to move ahead with nuclear power should work to improve electricity market mechanisms to boost prospects for investment.*
- *To improve public acceptance of nuclear power, governments should work with all stakeholders to ensure that factual, reliable and scientifically credible information is available on the advantages and risks of nuclear power, and to emphasise the role of nuclear power in meeting energy and environmental policy objectives. Governments, regulators and utilities should also work quickly to implement the post-Fukushima safety upgrades in existing nuclear power plants, to address public concern about extreme external events.*
- *Governments should also enhance support for RD&D for advanced fission reactors, to ensure that more economical and even safer technologies are available for deployment before 2050.*

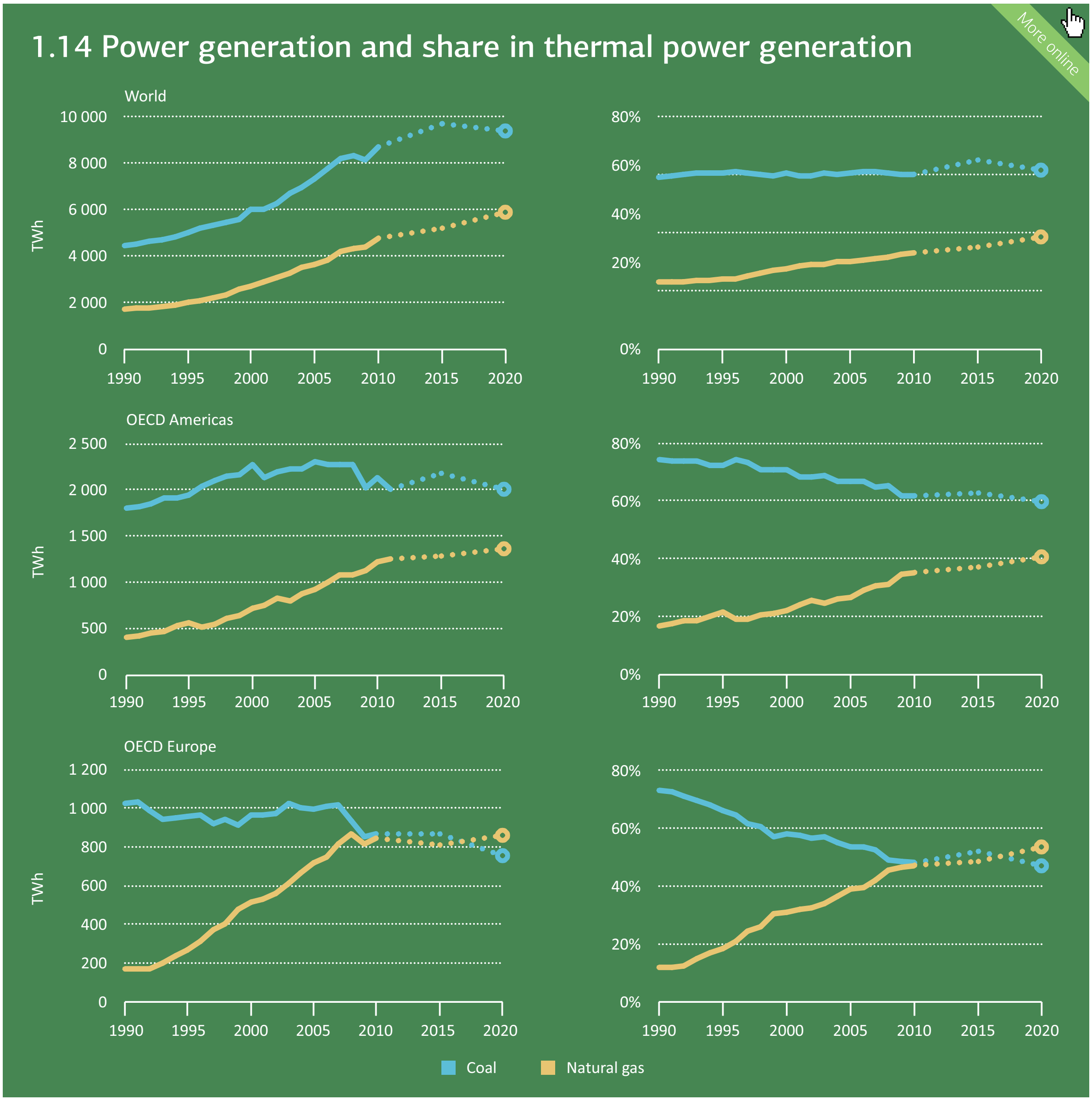
Natural Gas-Fired Power

Improvement needed

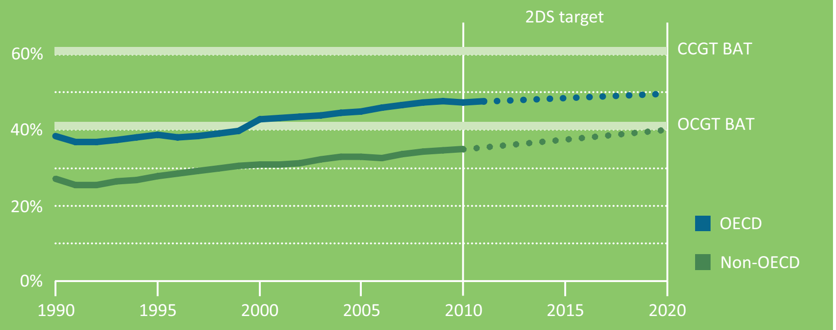
The use of natural gas can reduce CO_2 emissions from the electricity sector primarily by displacing coal, but this tends to occur only if gas prices are lower than coal prices. Regional market dynamics are currently driving divergent trends. In regions where gas prices are high, high carbon prices are needed to stimulate coal-to-gas switching.

Technology penetration

1.14 Power generation and share in thermal power generation



1.15 Gas-fired power plant fleet efficiency



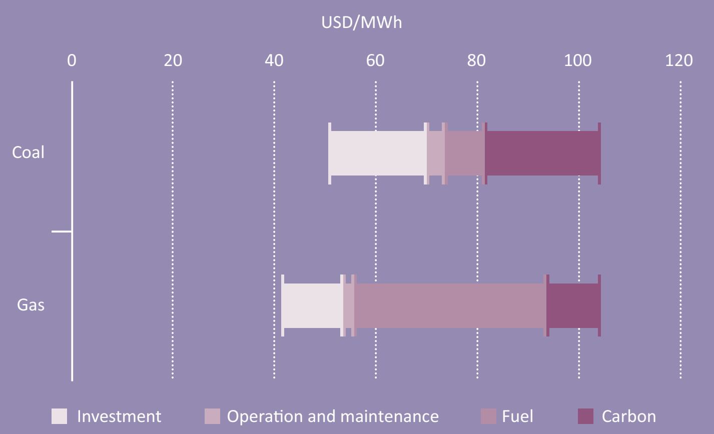
Coal-to-gas or gas-to-coal?

Regional market dynamics are producing divergent trends in coal-to-gas fuel switching

Switching is ongoing in the US, driven by the shale gas revolution; the opposite trend occurred in Europe in 2012

Market creation

1.16 Impact of CO_2 pricing on cost-competitiveness



EU CO_2 PRICE

50 €/tCO_2

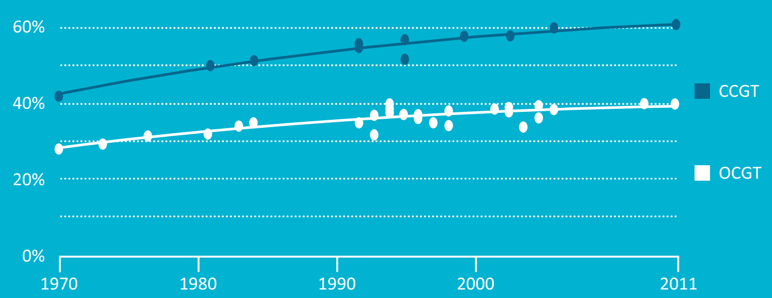
FOR SHORT TERM COAL TO GAS GENERATION SWITCH

25 €/tCO_2

FOR LONG TERM CAPACITY INVESTMENT SWITCH

Technology developments

1.17 BAT efficiency



Technology trends

BAT efficiency has risen to around 40% (OCGT) and in excess of 60% (CCGT)

Moderate improvements are expected before 2020

For sources and notes see page 141

Recent developments

- Global natural gas-fired power generation is estimated to have increased by over 5% between 2010 and 2012, building on strong growth over the past few years. Generation increased by 9% from 2009 to 2010, to 4768 TWh (IEA, 2012d).
- The extent to which increased gas-fired generation is displacing coal for baseload power – an important medium-term role for natural gas in the 2DS – is less clear. Globally, coal-fired power generation was at 8 660 TWh in 2010, up 7% on 2009 levels; this growth is projected to have continued in 2011 and 2012. It is also difficult to determine to what extent gas could be displacing renewable sources of energy. Preliminary analysis suggests that access to investment capital for renewables may be tighter due to competition from gas.
- The competitiveness of natural gas relative to coal in day-to-day system operation is highly dependent on regional market conditions, in particular fuel prices. Coal-to-gas fuel switching is continuing in the United States, as the boom in unconventional gas extraction keeps gas prices low. In the first 11 months of 2012, gas-powered electricity generation increased 24% compared with the same period in 2011 (to 1 146 TWh). Coal-fired power generation decreased by 14% (to 1 382 TWh), while total power generation remained essentially constant.
- In OECD Europe, however, gas remained less competitive than coal in 2012. The collapse in US gas prices led to increased coal exports from the United States to Europe, where there was a corresponding dramatic increase in coal generation. From January to June 2012, gas-fired power generation dropped by 15% in Germany, 12% in Spain and 33% in the United Kingdom, while coal-generation grew by 8% (Germany), 65% (Spain) and 35% (United Kingdom).[13]

Overall progress assessment

The role of natural gas in the 2DS

In the 2DS, natural gas plays an important role in the transition to lower-carbon electricity generation before 2020, principally by displacing coal power plants. Global gas-fired power generation increases to over 5 800 TWh in 2020, up 1 100 TWh (23%) on 2010 levels, and contributes emissions reductions of almost 1 200 Mt CO_2 relative to the 4DS (24% of total cumulative emissions reductions in the power sector). Around 80% of the reductions result from coal-to-gas switching. Plant efficiency improvements provide most of the remainder.[14]

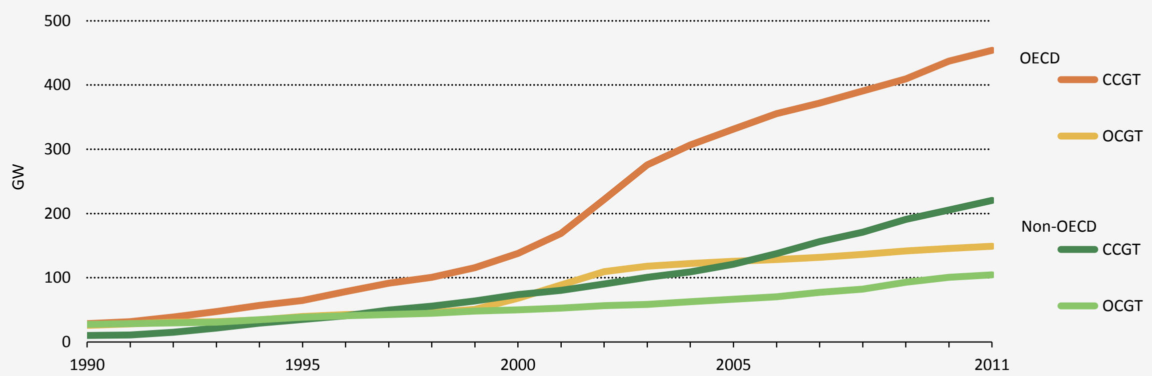
The role of natural gas in the 2DS shifts after 2025. Although electricity produced with gas is less carbon-intensive than that from coal, by 2025 the average CO_2 intensity of electricity generation in the 2DS needs to fall below what gas can provide. Gas-fired power generation therefore peaks in 2030 in the 2DS, at around 6 800 TWh, as the transition to a low-carbon energy system intensifies. By 2050, generation from natural gas decreases to around 4 800 TWh (down 30% on 2030 levels); roughly a third of power generated comes from CCS-equipped gas-fired plants. Natural gas retains a role in providing back-up capacity, to balance variability from renewable energy sources.

13 Low electricity prices and increasing renewable power penetration has also dampened gas capacity investment in Europe.
14 CCS plays a role in the post-2020 period, together with biogas (39% and 14% of CO_2 emission savings from gas out to 2050). See the CCS chapter.

Technology penetration

Gas power capacity has risen rapidly over the last two decades, as high-efficiency combined cycle gas turbine (CCGT) plants have enabled gas to compete with traditional base-load power plants. Between 1990 and 2011, 930 GW of gas-fired capacity (674 GW of combined cycle gas turbine [CCGT], 250 GW of open cycle gas turbines [OCGT]) was built (Figure 1.18), mostly in the United States and the European Union. Just from 2000 to 2005, 315 GW of capacity (240 GW CCGT, 75 GW OCGT) was added, most of it in the United States. Around 4 770 TWh of gas-fired electricity was generated globally in 2010, up 170% from 1990 levels (Figure 1.14). Global gas-fired generation is expected to increase by 3% annually until 2017, which is broadly consistent with 2DS assumptions before 2020 (IEA, 2012d).

Figure 1.18 Cumulative CCGT and OCGT capacity



Source: Platts Database.

Key point *Gas fired power capacity, particularly CCGT, has increased rapidly since 2000.*

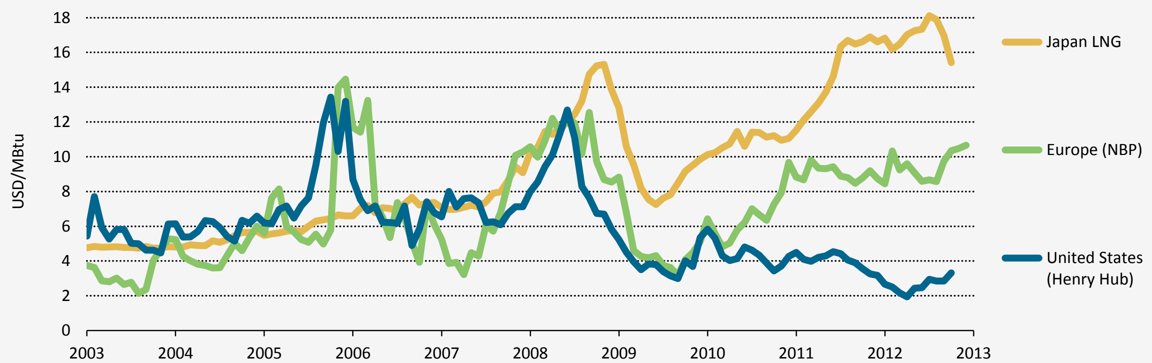
Coal-to-gas switching is a complex mechanism to assess. Coal-to-gas switching can be understood both on a short-term, fuel-switching basis (*i.e.* where gas is dispatched in preference to coal based on short-run marginal production cost), and on a longer-term basis (*i.e.* a shift from coal to gas capacity through new investment and decommissioning). For short-term fuel switching, fuel price and other market forces have a direct impact. Market conditions differ widely between regions. For example, in April 2012 United States gas prices[15] fell below USD 2/MBtu, the lowest prices in a decade; European spot and contract gas prices stabilised at USD 8 to USD 10/MBtu; LNG import prices in Japan were about USD 17/MBtu throughout 2012 (Figure 1.19). Long-term investment decisions on coal or gas deployment will depend on expected fuel prices as well as other operational, technological, financial and energy security considerations.[16] These factors add to the complexity of assessing progress in coal-to-gas switching.

The rise in generation from gas has been more than matched by strong growth in coal generation (Figure 1.14). From 2000 to 2010, coal-fired power generation rose almost 45% to reach 8 650 TWh, while coal's share in global thermal electricity generation increased from 38% to 40%. By comparison, gas-fired power generation's share rose from

15 Henry Hub.

16 Including, for example, construction, operation and maintenance costs; start-up and ramp-up rates; existing infrastructure; and emissions performance.

Figure 1.19 Natural gas spot prices



Note: NBP = National Balancing Point (United Kingdom), representative of European gas prices.
Sources: Henry Hub: IntercontinentalExchange; NBP: GasTerra; Japan LNG: Japan Customs.

Key point *Geographical price differences in natural gas have increased in recent years, following the revolution in unconventional gas extraction.*

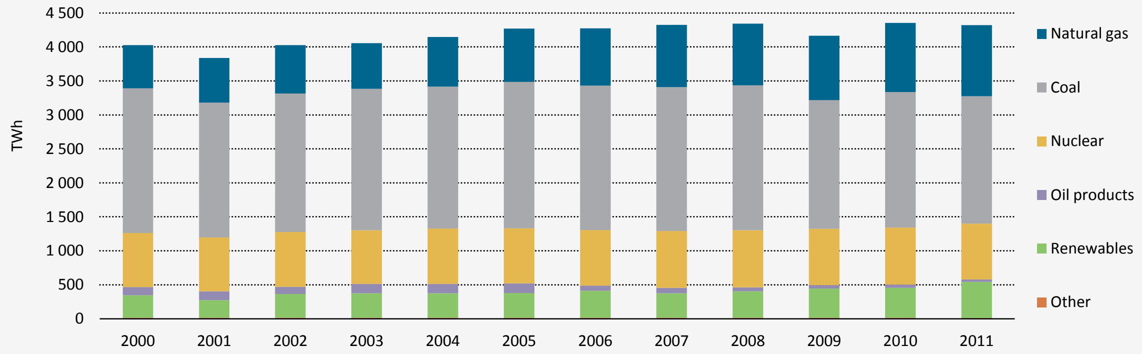
18% to 22%. Only in OECD Americas and OECD Europe has the share of gas in thermal electricity generation increased markedly at the expense of coal. A real coal-to-gas switch in absolute numbers cannot be observed even in these regions, however, as coal generation decreased only moderately compared with the strong gas growth in both regions. In OECD Americas, coal generation fell 266 TWh from 2000 to 2011, while gas-fired electricity generation rose by 529 TWh. In OECD Europe, coal generation decreased 60 TWh from 2000 to 2011, while generation from natural gas rose by 260 TWh. This suggests that gas has limited the role of additional coal capacity in meeting incremental demand, rather than displacing existing plants.

Regional market dynamics are producing divergent trends in coal-to-gas fuel switching, including low prices in the United States that are driving strong growth in gas-fired power generation. The US shale gas revolution that gained momentum in 2006 has pushed gas prices lower, increasing the market share of gas-fired power plants at the expense of coal (Figure 1.20). From 2006 to 2011, gas-fired generation rose by 24% to more than 1 000 TWh, while coal generation receded by 12% to less than 1 900 TWh. This has occurred against a backdrop of stagnating power demand. Coal consumption in the US power sector is projected to further decrease over the medium term, from almost 19 exajoules (EJ) in 2011 to just over 16 EJ in 2017 (-13%) (IEA, 2012e).

By contrast, European gas-fired plants have had increasing difficulty competing against coal-fired plants, partly because gas prices have been relatively high. Between 2010 and 2011, gas-fired generation decreased by 9% in OECD Europe, while coal-fired generation rose 4%. Gas-fired power generation as a share of total generation fell from 23.5% to 21.6% in this period while coal's share rose from 24% to 25.3%.[17] This trend deepened in 2012, as noted above, and gas consumption in the European power sector is set to further decline by 13% from 2011 to 2017 (IEA, 2012d).

17 Total generation in OECD Europe decreased by 1.6%.

Figure 1.20 Power generation by fuel in the United States



Key point *In the United States, the share of gas in power generation has increased at the expense of coal.*

Global average gas-fired power efficiency, now above 40%, is improving and is broadly on track to meet 2DS 2020 objectives (Figure 1.15). Increased deployment of efficient CCGTs is the primary factor behind this positive trend. Average fleet efficiency in OECD regions increased to 47% in 2012, up from 38% in 1990, and has exceeded OCGT BAT efficiency since 2000. In non-OECD regions, average efficiency is just under 35%, up from 27% in 1990. The 2DS assumes global fleet efficiency of almost 44% in 2020; just over 49% in OECD regions, and almost 40% in non-OECD regions. Efficiency improvements are on pace with these objectives. The slowdown in the rate of efficiency improvement in the 2DS reflects that OCGTs remain the best available peak-load power plants in terms of flexibility; this means that the share of CCGTs in the gas power fleet may have a saturation point.[18]

Market creation

In addition to fuel price and other market and technological forces, carbon policy can influence competition between gas and coal (Figure 1.16). Where coal is more competitive than gas, government policy can favour a switch to lower-emitting gas-fired generation. There has been some progress globally in implementing prices or limits on CO_2 emissions that could encourage coal-to-gas switching (*i.e.* Australia's new carbon price, the Californian emissions trading system that started in 2013, the United Kingdom's proposed Emissions Performance Standard and the EU Emissions Trading Scheme).

Current carbon prices are not high enough to drive coal-to-gas switching, however. In Europe, for example, where it is currently cheaper to generate electricity from coal based on relative fuel price, the carbon price was about EUR 4 (USD 5.4) in early February 2013, but a price of about EUR 50 (around USD 67) would be required to effect a switch from coal to gas in the short run.[19] Given relative capital, operation and maintenance costs, prices required to influence long-term capacity switching are likely to be lower – around EUR 25 (USD 34) in Europe based on current conditions, for example.[20]

18 CCGTs are becoming more flexible, however, and are likely to be designed for fast ramp-up times in the future.
19 This price assumes an efficiency of 0.36 for coal and 0.5 for gas, a coal price of USD 90/metric tonne and a gas price of EUR 27/MWh. The required carbon price will be higher or lower, depending on regional gas and coal prices.
20 This price assumes an efficiency of 0.45 for coal and 0.57 for gas, a coal price of USD 88 to 117/metric tonne, a gas price of USD 8 to 11/MBtu and investment costs as illustrated in Figure 1.16.

Other measures that limit emissions from coal-fired power generation or address local pollutants can also play a significant role in coal-to-gas switching. Governments are starting to adopt more stringent policies that are likely to play an increasing role in coal and gas competition. In the United States, the Environmental Protection Agency (EPA) proposed several new regulations in 2011 that, if adopted, would affect the economics of coal-based power generation. Examples include the Cross State Air Pollution Rule, the Ozone Rule, the Coal Combustion Residuals Rule or the Maximum Achievable Control Technology Rule. Uncertainty regarding the adoption of these regulations contributes to the fact that coal-fired power generation plant investment in the United States is currently unattractive.[21]

Technology developments

Both OCGTs and CCGTs are advanced technologies, but moderate efficiency improvements at full load BAT are expected before 2020. BAT OCGT efficiency has risen to around 40% from around 35% in 1990. BAT CCGT efficiency now exceeds 60%, up from about 55% in 1990 (Figure 1.17). A demonstration project supported by the Japanese government aims to have an operational CCGT with 63% efficiency by 2016, by increasing turbine inlet temperature to 1 700°C. The development of hybrid gas power plants that include, for example, a solar concentrator and a fuel cell before the gas turbine, is another technological option, with potential efficiencies up to 70%. Integrated solar combined cycle plants are under construction or in the planning stage in Algeria, Egypt, India, Iran, Italy, Mexico, Tunisia and the United States. Private sector development is under way on a so-called triple-cycle power plant that places solid oxide fuel cells before a CCGT.

Improving the performance of plants required to operate at part load or cyclically is important to meeting 2DS objectives, due to the peak-load/ back-up capacity role envisaged for natural gas over the longer term. Increasing operation flexibility for CCGT and OCGT both for installed and new plants is a key priority, and there has been some progress over recent years. Over the longer term, humid air turbines with potential efficiencies of 55% are envisioned. Such turbines are expected to have higher part-load efficiency than CCGTs, and shorter start-up times.

Technology to capture CO_2 from gas-fired generation has still not been demonstrated at large scale, and no such projects are under construction or in advanced stages of planning. Given that around one-fifth of gas-fired power generation needs to be equipped with CCS by 2050 in the 2DS, CCS must be demonstrated at large scale in the near future.[22]

21 The coal section sets out key policies impacting on coal deployment and, therefore, competition between coal and gas.
22 See the CCS chapter.

Recommendations for governments

- *It is vital to enhance carbon pricing and other regulatory mandates in order to encourage a coal-to-gas switch in regions where gas is uncompetitive with coal. Current carbon prices will not drive switching in the near-term.*
- *Development of unconventional gas resources would help bring down gas prices and potentially trigger coal-to-gas switching in regions that currently rely heavily on coal. In the absence of additional gas resources, price differentials between regions are likely to remain high. Scaling up unconventional gas extraction requires careful regulation and monitoring, in order to avoid adverse effects on the environment.*
- *Governments should assess the role of natural gas in their energy futures, including estimating the needs for flexible generation capacity. The strategic increase in gas infrastructure required to meet 2DS goals means that government policy and infrastructure planning must be carefully undertaken. Strategies for deploying gas-fired power generation should be designed so that the benefits of gas can be realised while not over-investing in infrastructure that may be under-utilised in the longer term.*

Coal-Fired Power

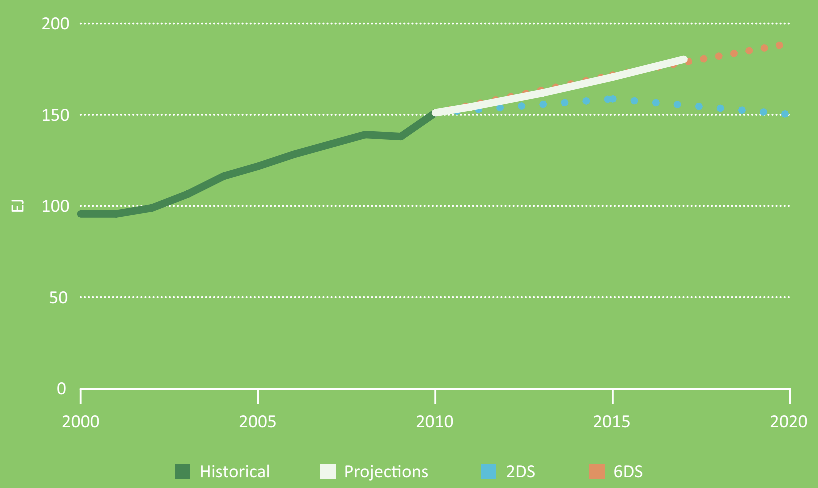
● Not on track

Growing reliance on coal to meet rising energy demand presents a major threat to a low-carbon future. To meet 2DS targets, governments must act decisively to counter growth in emissions from coal-fired power generation and the deployment of inefficient coal technology.

Technology penetration

1.21 Shifts in coal-fired power generation

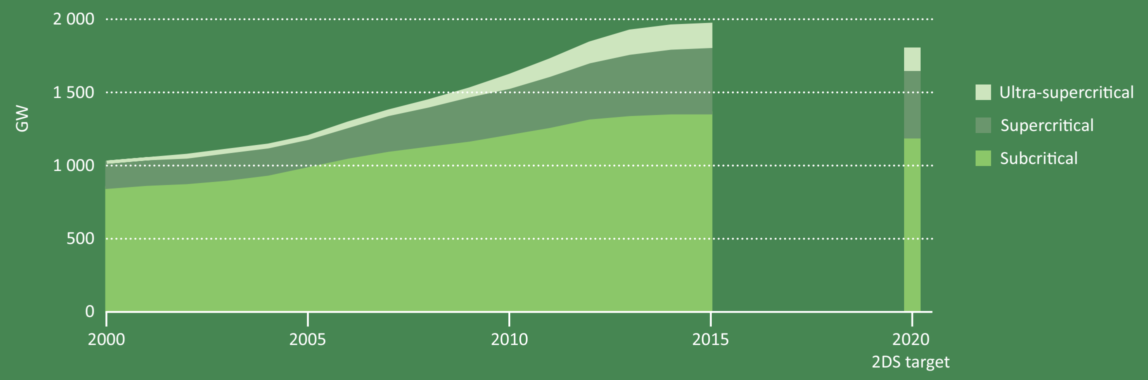
1.22 Global coal demand



Key trends

- Growth in coal-fired generation (+45% between 2000 and 2010) is far outpacing growth in generation from non-fossil energy sources (+25% in same period)
- Global coal demand is projected to increase to 180 EJ in 2017, 17% above 2DS levels
- Around half of new power plants in 2011 use inefficient, subcritical technologies

1.23 Coal capacity deployment



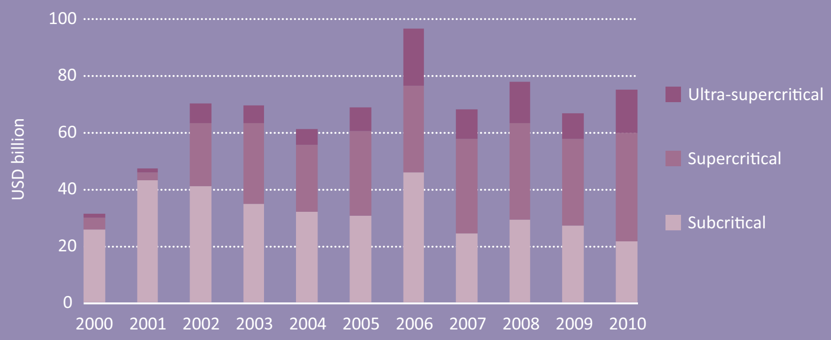
Market creation

Market developments

Current policy is failing to halt and reverse growth in emissions from coal-fired generation

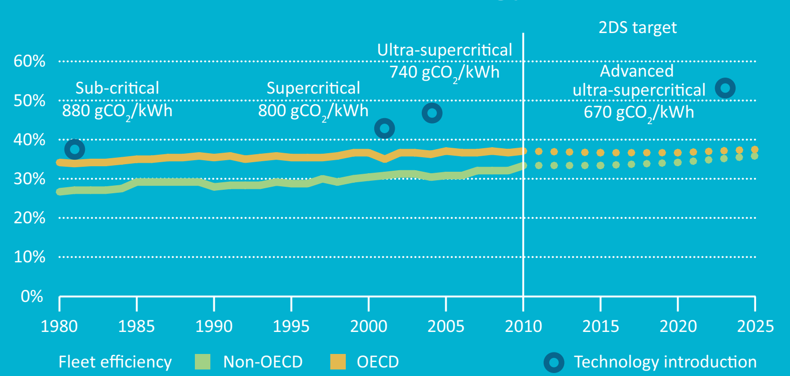
Capacity investment was 140% on 2000 levels in 2010

1.24 Annual capacity investment



Technology developments

1.25 Coal-fired power technology introduction



33%

GLOBAL FLEET AVERAGE EFFICIENCY, COMPARED TO 46% WITH ULTRA-SUPERCRITICAL

For sources and notes see page 141

Recent developments

- The unremitting rise in global coal demand for power generation continued in 2012. Global coal-fired power generation is estimated to have increased by around 6% between 2010 and 2012, building on strong growth over the past few years. Generation increased by about 7% from 2009 to 2010, to almost 8 700 TWh, leaving coal as the main source of electricity generation by far.
- China and, to a lesser extent, India continue to play a key role in driving demand growth. China's coal consumption represented 46.2% of global coal demand in 2011; India's share was 10.8%, up 7% and 9% respectively on 2010 levels. In 2011 alone, coal plant with a capacity of 55 GW was installed in China, more than the total installed capacity of Turkey.
- Demand for coal also rose in OECD Europe in 2012 (Table 1.2). The unparalleled expansion of shale gas in the United States led to an increase in coal exports from the country. This created an excess of coal on the market, with coal prices plummeting from USD 130/t in March 2011, to a low of USD 85/t in May 2012. Consequently, generation from coal in Europe showed a marked increase, particularly from late 2011 through 2012, essentially taking share from gas whose price in Europe remains largely tied to oil – and leading to higher CO_2 emissions. This phenomenon has been most notable in Germany, Spain and the United Kingdom, and has put a strain on emissions reductions targets in Europe.

Table 1.2 Gas- and coal-based electricity generation in select European countries

	Gas			Coal		
Electricity generation	**Jan-Jun 2011**	**Jan-Jun 2012**	**Relative growth**	**Jan-Jun 2011**	**Jan-Jun 2012**	**Relative growth**
Germany	40 984	34 749	-15%	129 399	140 008	8%
Spain	40 696	35 790	-12%	16 803	27 656	65%
United Kingdom	71 894	48 109	-33%	52 422	70 991	35%

Source: IEA, 2012e.

- Annual capacity investment in coal-fired power generation reached 75 billion in 2010, up 12% on 2009 figures. Strong government policy action is required to stem the growth of emissions from coal-fired power generation. Developments in 2012 underscore the fact that, despite some advances, current government policy efforts remain grossly insufficient.
- Older, less efficient coal plants were closed in some regions, however. The United States, for example, closed 9 GW of capacity in 2012 (around 3% of its total coal capacity). China's mandated closure of small, inefficient units continued in 2012, consistent with its 12th Five-Year Plan. China had shut down 85 GW of small, inefficient plants by the end of 2011.

Overall progress assessment

The role of coal in the 2DS

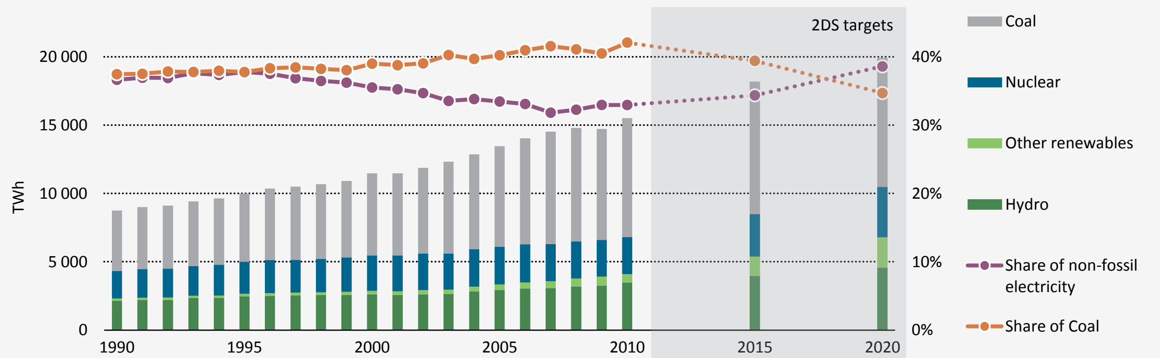
Global primary coal demand must peak before 2020 in the 2DS, and total around 150 EJ in 2020. Coal-fired electricity generation, which represents almost two-thirds of energy-sector coal demand, is at 9 351 TWh in 2020, compared with 10 534 TWh in the 4DS (down 11%), after peaking in 2015 at 9 701 TWh.

Cutting emissions from coal is a major factor in the transition to the 2DS. CO_2 emitted from coal-fired power generation declines from 2015, to reach around 9 $GtCO_2$ in 2020, 16% below 4DS levels. By 2050, emissions are almost 90% less than 4DS levels, down to 0.92 $GtCO_2$. The 2DS relies on a combination of measures to achieve this reduction, principally switching from coal to lower-carbon alternatives, greater use of more efficient coal technologies and deployment of CCS.[23]

Technology penetration

Global coal deployment has risen steeply over the past two decades. Coal met the lion's share of incremental growth in electricity generation between 2000 and 2010, with coal-fired electricity generation increasing by almost 2700 TWh, or 45%, to 8 700 TWh in 2010 (Figure 1.26). The growth of coal-fired electricity generation has far outpaced the significant increase in generation from all other non-fossil energy sources: nuclear, hydro renewables and non-hydro renewables increased by 1 300 TWh cumulatively over the same period (25%) to reach 6 800 TWh. In 2010, coal's share of electricity generation reached 42%, up from 39% in 2000, compared with a 33% share for non-fossil electricity (down from over 35% in 2000). As a consequence, coal-fired power generation contributed over 70% of total power-sector CO_2 emissions in 2010 (8.9 $GtCO_2$). The extent to which fast-growing economies depend on coal is substantial. China and India accounted for almost 95% of global coal demand growth between 2000 and 2011; despite the global recession, in 2009 consumption increased in China by 6 EJ and in India by 1 EJ.

Figure 1.26 Coal and non-fossil power generation



Key point *Coal is increasing its share of global power generation, and in 2010 generation from coal was 28% higher than all non-fossil sources combined.*

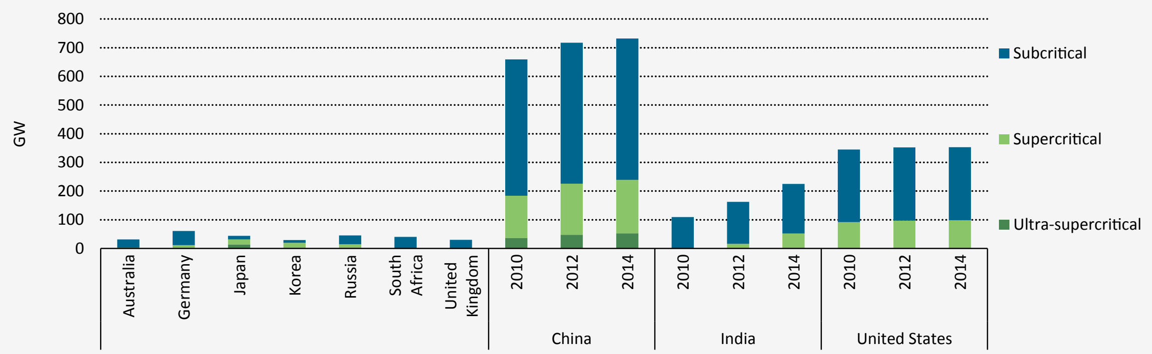
The current trajectory for coal is fundamentally inconsistent with a low-carbon future. Global coal demand is set to increase from an estimated 155 EJ in 2011, to 180 EJ in 2017 (+2.6% per annum), still driven predominantly by emerging economies, in particular China and India (Figure 1.22). Chinese coal demand alone is projected to increase from an estimated 75 EJ in 2011 to 93 EJ in 2017 (3.7% per annum). It is currently difficult to envisage a future in which coal is not used to meet growing power demand – not only in non-OECD regions, but also in many OECD countries. In regions where the demand for electricity is rising, availability and cost of alternative fuels or other low-carbon sources of power will affect the decision to reduce generation from coal-fired plants. In a truly low-carbon future, however, coal cannot be the dominant energy source (Figure 1.21).

23 CCS plays more of a role in the post-2020 period, and is therefore not addressed in this section. Over 60% of coal-fired power generation is CCS equipped in 2050 in the 2DS, as compared to less than 1% in 2020. See the CCS chapter.

There is a wide gulf between the average efficiency of global coal-fired power generation and state-of-the-art efficiency. In addition to switching from coal to lower-carbon alternatives, minimising generation from older, less efficient coal plants is essential to reach 2DS goals. The average efficiency of the global coal fleet is around 33% (LHV, net).[24] By contrast, current state-of-the-art technology operating under ultra-supercritical (USC) steam conditions can achieve efficiencies up to 46% (LHV, net). While a unit operating at the global average efficiency would emit more than 1 000 g CO_2/kWh, the best USC units reduce this to closer to 740 g CO_2/kWh.

Around 75% of current coal-based power generation capacity deploys subcritical technology, capable of achieving maximum net efficiencies of about 38% (Figure 1.23). In practice, this level of efficiency is not achieved on the majority of units, due to factors such as unit size and age, the type of coal used, ambient temperature, standard of maintenance and mode of operation. More than half of current capacity is over 25 years old and comprises units of less than 300 MW. The share of higher-efficiency, lower-emissions (HELE) coal-fired power generation (*i.e.* from supercritical, ultra-supercritical and integrated gasification combined cycle technology plants) remains far too low. The Chinese fleet has the highest percentage of supercritical coal-fired and ultra-supercritical units, at 28% of total capacity (Figure 1.27). After the first 1 000 MW ultra-supercritical unit entered operation in only 2007, more than 40 of them were in operation in China in 2011. The 12th Five-Year Plan (2011-2015) caps coal production at 3.8 billion tonnes by 2015; all plants of 600 MW or more must be supercritical (SC) or USC technology. Units are also becoming larger and more efficient in India; since 2008, supercritical units of 600, 700 and 800 MW have been constructed.

Figure 1.27 Supercritical and ultra-supercritical capacity in major coal-using countries



Key point *75% of installed coal capacity in 2012 used inefficient subcritical technology.*

Far too many inefficient, subcritical units are still being constructed. Around half of new coal-fired power plants in 2011 used subcritical technologies. Coal plants are large point sources of CO_2 emissions, so concerted efforts to improve their efficiency can significantly reduce coal consumption and lower emissions. If the 550 GW of new coal-fired generating capacity added between 2000 and 2011 had been ultra-supercritical, for example, cumulative emissions of CO_2 over that period would have been reduced by almost 2 Gt (8%) (CIAB, 2013).

24 Lower heating value of the fuel and net output.

Market creation

Governments need to implement stronger CO_2 emissions reduction policies, pollution control measures and policies to reduce generation from less efficient units, in order to halt and reverse the steep upwards trend in coal deployment and emissions from coal-fired generation. Some countries have made progress implementing such policies, but there is still a long way to go (Table 1.3).

Table 1.3 Key policies affecting coal deployment in select countries

Country or region	Policy	Impacts and goals of policy
Australia	Generator efficiency standards defined best practice efficiency guidelines for new plants: hard coal plant (42%) and brown coal (31%). Both based on higher heating value net output. Emissions trading will begin in 2015. Carbon tax introduced in 2012.	New plants are likely to be SC or USC technology.
China	11th Five-Year Plan (2006-10) mandated closure of small, inefficient coal-fired power generation. 12th Five-Year Plan (2011-15) caps coal production at 3.8 billion tonnes by 2015; all plants of 600 MW or more must be SC or USC technology. Ongoing, mandated closure of small, inefficient units. Stringent emissions control for SO_2, NO_X and particulates are mandated on new units from 2012 (SO_2 = 50 mg/m^3; NO_X = 100 mg/m^3; PM = 20 mg/m^3). New standards, including limits on mercury emissions, are applicable from 2014 for existing plants.	Between 2006 and 2011, 85 GW of small, inefficient generation was shut down. 17% reduction (compared with 2010) in carbon intensity targeted by 2015 (across all power generation) and a 40% to 45% reduction by 2020.
European Union	Power generation covered by the EU ETS. In the first two phases, over 90% of emissions credits were "grandfathered" or allocated to power producers without cost, based on historical emissions. Beginning with Phase 3 in 2013, 100% of credits will be auctioned. European legislation required coal-fired power plants to meet more stringent limits on air pollution by 1 January 2008. Units that do not meet the requirement must close by 2016. Emission limit values according to the Industrial Emission Directive 2010/75/EU for new power plants are: SO_2, 100-300 MW = 200 mg/m^3, > 300 MW = 150 mg/m^3; NO_X, 100-300 MW = 200 mg/m^3, > 300 MW = 150 mg/m^3; PM, 100-300 MW = 20 mg/m^3, > 300 MW= 10 mg/m^3.	GHG emissions reduction of 21% in 2013 compared with 2005 levels under the EU ETS. Credit auctioning aims to provide further incentive to curb emissions from coal plants. Countries across Europe have opted to close part of their coal generating capacity rather than meeting the cost of compliance. In the United Kingdom alone, more than a quarter of coal capacity will close by 2016.
India	The 12th Five-Year Plan (2012 to 2017) states 50% to 60% of new coal-fired capacity added should be SC. In the 13th Five-Year Plan (2017-22), all new coal plants should be at least SC; energy audits at coal-fired plants must monitor and improve energy efficiency.	The 12th and future Five-Year Plans will feature large increases in construction of SC and USC capacity.
Indonesia	Began indexing Indonesian coal prices to international market rates (2011); put emissions monitoring system in place.	Likely to increase coal prices paid by importers of Indonesian coal.
United Kingdom	White Paper on Energy Market Reform recommends an Emissions Performance Standard of 450 g CO_2/kWh for new coal and gas. Stricter limits on air pollutant emissions imposed by EU legislation.	From 2014, no new coal-fired capacity will be built without CCS. Of the current 25 GW of coal-fired generating capacity, over 7 GW will close before 2016.
United States	The US EPA proposed a number of rules in 2011, including the Maximum Achievable Control Technology rule, the Cross State Air Pollution rule, the Ozone rule and the Air Combustion Residuals rule.	New plants are all likely to have SC or USC technology. The impact of pending EPA regulation on the economics of coal generation, combined with low natural gas prices, suggest limited coal capacity additions in the future.

Current policies have failed to stem growth in emissions from coal-fired power generation. The annual investment figures for coal-fired generation capacity reflect the strong upwards trend in coal deployment (Figure 1.24). The USD 75 billion spent on coal-fired capacity in 2010 represents a 140% increase on 2000 levels.

Current CO_2 emissions reduction policies – where they are in place – are not sufficient to drive a switch from coal to lower-carbon generation technologies. Europe's CO_2 price, for example, has failed to halt the gas-to-coal generation switch that is currently being observed on the continent, driven by low coal prices.

Pollution control measures and policies to reduce generation from less-efficient units are having greater success, but must nevertheless be strengthened. In the United States, for example, policies combined with very low gas prices are contributing to reduction in coal-fired power generation. Coal-fired generation dropped by 6% from 2010 to 2011, to 1 994 TWh. Coal consumption from 2012 to 2017 is projected to fall still further. Emissions regulations relating to air pollutants in the European Union are leading some countries to close part of their coal generating capacity, rather than meet the cost of compliance. Globally, however, current policy measures are insufficient to make a significant impact on the rise in coal-based power generation, or substantially phase out generation from old, inefficient plants.

Technology developments

Advanced ultra-supercritical technology is being developed in many parts of the world. Coal plant efficiencies approaching or even surpassing 50% are possible if materials can be developed that withstand the necessary high pressures and temperatures within the boiler and steam turbine. Programmes to develop the technology have been under way in Europe, Japan and the United States for many years, and more recently in India and Russia. China set up a consortium approach in July 2010 to meet the challenge.

Units are not only increasing in efficiency, but also in capacity. Larger units offer economies of scale, providing higher efficiencies. Single pulverised coal combustion (PC) units of 1 000 MW capacity have been constructed in China. Following commissioning in 2009 of a 470 MW circulating fluidised bed combustion (CFB) unit in Poland, even larger CFB units are being designed and constructed.

Following a spate of IGCC construction in the 1990s, little has been built since, because costs remain high. However, development of the technology has continued, focused mainly on improving reliability and reducing costs. This is because it is thought that IGCC may be more cost-competitive than pulverised coal combustion where CCS is fitted to units. More recently, some IGCC plants have been modified to test the potential for CO_2 capture. Interest in the technology remains predominantly in those countries with existing units. China, with its wealth of experience with coal gasification, has joined the club with a recently constructed 250 MW IGCC unit in Tianjin. Commissioning began in late 2012. If it proves successful, by demonstrating high thermal efficiency and a facility for lower cost, effective CO_2 capture, it may lead to greater interest in the technology.

Biomass co-firing can effectively reduce CO_2 emissions from coal-fired power plants. This has been demonstrated in a number of countries, *e.g.* Denmark and the United Kingdom, to good effect. As biomass is commonly regarded as a carbon-neutral fuel, emissions can be directly reduced according to the scale adopted. Biomass can be high in moisture and also contain chemicals that give rise to fouling and corrosion in boilers. However, co-firing 10% to 15% has been extensively trialled with little adverse effect. Logistical costs and the potential for competition with food crops for land may inhibit large-scale adoption.

CCS offers the potential to reduce CO_2 emissions to less than 100 g/kWh, but must be developed and demonstrated rapidly if it is to be deployed after 2020 at a scale sufficient to meet the 2DS. Given the recent increase in construction of new coal-fired power plants, meeting the 2DS will mean adding CCS to a significant proportion of operating plants if they are to remain operational. In the 2DS, 63% of coal-fired power generation is equipped with CCS in 2050. CCS is yet to be demonstrated at commercial scale on a coal power plant.[25]

Recommendations for governments

- *Governments must explicitly recognise the impact of increasing coal-fired power generation, and put in place the initiatives necessary to stem the increase in energy-related CO_2 emissions. At present there are insufficient or no commercial or regulatory imperatives to slow the rise in emissions from coal-based power generation and to phase out subcritical plant in favour of supercritical technology or better.*
- *To reduce the impact of increasing coal use, it is essential to deploy best practice technology and to accelerate development of more efficient technology. Ultra-supercritical units should be installed unless there are strong reasons not to do so. Further demonstration of IGCC is needed to reduce cost and lower risk. The development of more advanced combustion and gasification technologies needs to be accelerated, including through increased RD&D spending.*
- *CCS must be developed and demonstrated rapidly if it is to be deployed after 2020 at the scale required to meet the 2DS.*

25 See the CCS chapter.

Chapter 2

Carbon Capture and Storage

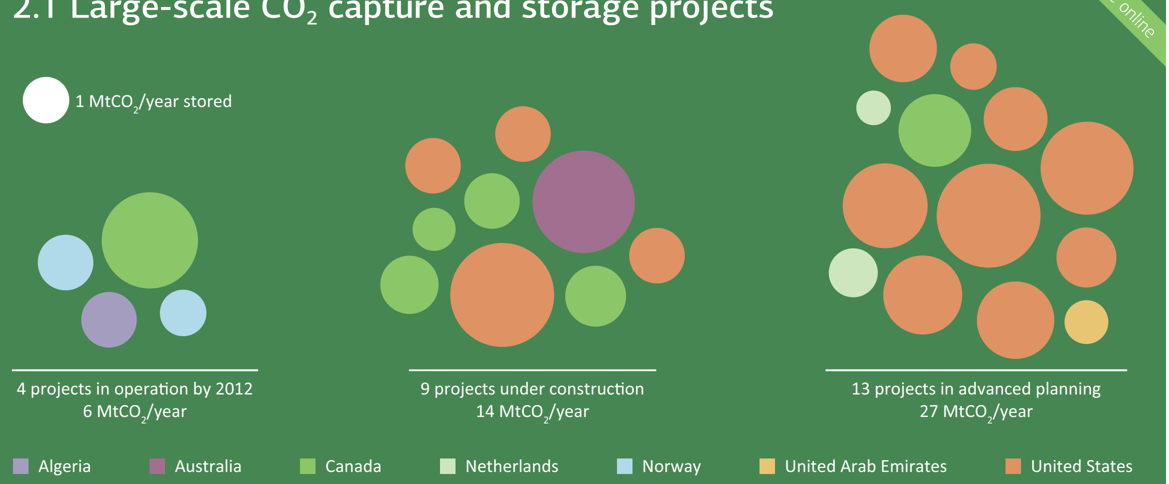
Carbon Capture and Storage

Not on track

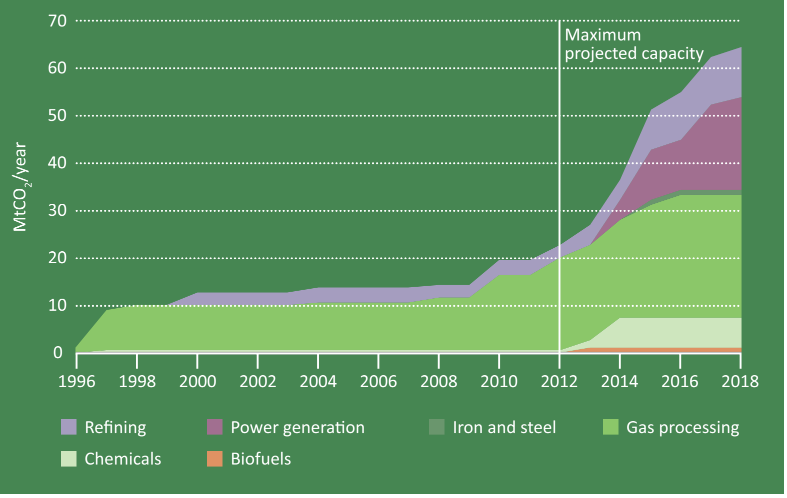
While 13 large-scale carbon capture and storage (CCS) demonstration projects are in operation or under construction, progress is far too slow to achieve the widespread commercial deployment envisioned in the 2DS. Governments must make real commitment to demonstration and increase financial and policy support for deployment, including strong, credible emissions reduction policies.

Technology penetration

2.1 Large-scale CO_2 capture and storage projects



2.2 Large-scale CO_2 capture projects

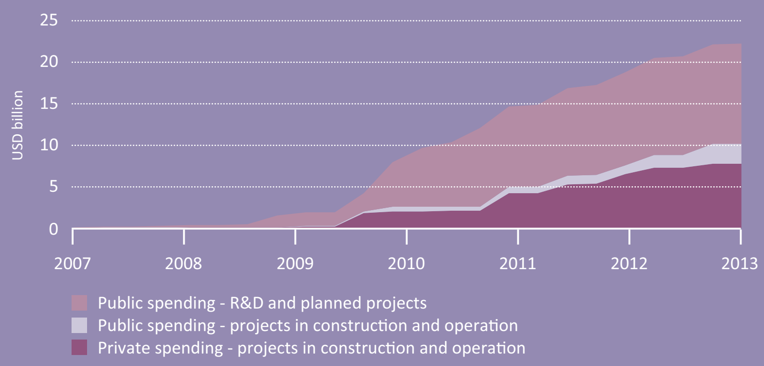


Key developments

- CCS technologies are mature in many applications and have been operating for decades
- 50 $MtCO_2$ have been stored to date through CCS projects, with monitoring to provide confidence that CO_2 is permanently stored
- 9 projects are under construction, but projected storage rates in 2020 are well below 2DS target

Market creation

2.3 Cumulative spending on CCS projects

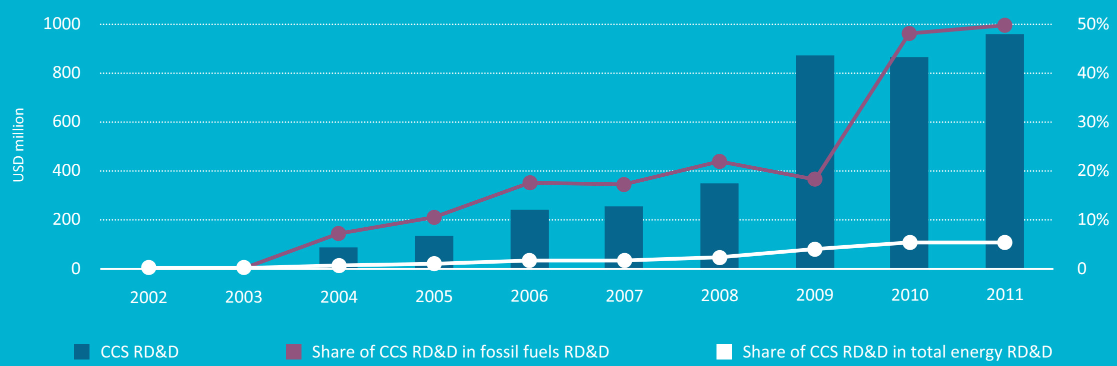


UK

ONLY COUNTRY GLOBALLY IMPLEMENTING CCS-SPECIFIC DEPLOYMENT INCENTIVES

Technology developments

2.4 IEA public RD&D spending

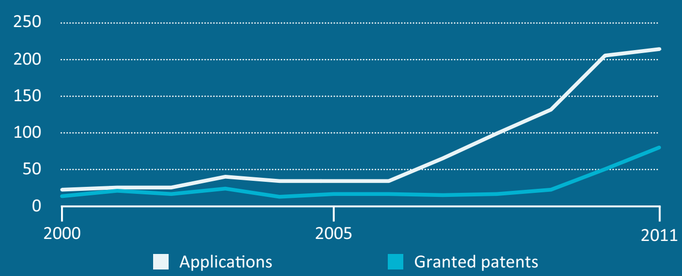


Key technology trends

There are signs of commercial interest in CCS technology, with a compound annual growth rate of 46% in patent applications between 2006 and 2011

IEA member governments spent 5% of total energy RD&D budget on CCS in 2011

2.5 Patenting activity in CCS related technologies



For sources and notes see page 142

Recent developments

- In 2012, construction began on two[1] integrated CCS demonstration projects in North America, bringing the total number of projects under construction to nine. Together, the two projects have the potential to store 2.3 $MtCO_2$ per year. All nine projects are expected to be in operation by 2016.
- While construction is due to begin on several additional projects in coming years, the number of planned projects decreased in 2012 because eight projects were publicly cancelled. The number of planned commercial projects remains drastically below the numbers required to achieve the emissions reductions envisaged in the 2DS.
- The two new projects that began construction in Canada raised public and private spending on CCS demonstration significantly in 2012, by USD[2] 2.6 billion, one-third higher than 2011 levels. Scaling up CCS to the commercial deployment stage – and boosting investment prospects for project developers – will require further government support, in the form of appropriate incentive policies, along with strong, credible and long-term commitments to reducing emissions across the economy. There was limited movement in this regard in 2012.
- In 2012, several important pilot and demonstration projects began operation. The Technology Centre Mongstad in Norway, for example – a public-private USD 1 billion facility geared to testing and improving CO_2 capture – is expected to drive CO_2 capture technology forward for gas-fired power generation and refining. The Plant Barry CCS project in Alabama is the largest integrated CCS project to be operated on a coal power plant.

Overall progress assessment

The role of CCS in the 2DS

CCS plays a major role in reducing global emissions in the 2DS, which envisages capture and storage of around 260 $MtCO_2$ in 2020, across power generation and industrial sectors (6% of emissions reductions in that year). CCS deployment increases exponentially between 2015 and 2050 in the 2DS, primarily driven by CO_2 pricing (or other comparable emissions reduction policies), resulting in 7.8 $GtCO_2$ captured in 2050. Thus, CCS deployment provides around one-fifth of emissions reductions globally through 2050 (around 123 $GtCO_2$ captured and stored between 2015 and 2050), relative to the 4DS.

Technology penetration

To date, four large-scale CCS projects have carried out sufficient monitoring to provide confidence that injected CO_2 is permanently retained (Figure 2.1). Collectively, these projects have stored approximately 50 $MtCO_2$.[3] Nine further projects under construction together have the potential to capture and store an additional 14 $MtCO_2$ a year. All nine projects should be operational by 2016. Operation of more than a dozen CCS demonstration projects will greatly bolster confidence in the ability of CCS to safely deliver emissions reductions and form a solid foundation for commercial deployment of CCS.

1 Shell's Quest project near Edmonton, Alberta (Canada), and the North West Red Water (NWR) Partnership project at the Sturgeon refinery, near Edmonton, Alberta (Canada).

2 Unless otherwise stated, all costs and prices are in real 2010 USD, *i.e.* excluding inflation. Other currencies have been converted into USD using purchasing power parity (PPP) exchange rates.

3 Injection at the In Salah project was suspended in June 2011. The future injection strategy is under review; a comprehensive monitoring programme continues. The IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project ended in 2011, although Cenovus and Apache continue to operate the Weyburn and Midale fields, respectively, as CO_2-flood EOR projects.

The amount of CO_2 that could be captured and stored from projects that are likely to be operating in 2020 is well below that envisaged in the 2DS. If all projects currently operational, in construction, or at an advanced stage of planning are operational in 2020, total capture and storage rates would be around 65 $MtCO_2$/year (Figure 2.2). However, this would appear unlikely given that 10% to 20% of projects in planning have been cancelled every year for the past several years. Due to the long lead-times required to develop a CCS project, which can easily approach a decade, government and industry must take urgent action to boost the number of projects under development to reach 2020 2DS targets.

Of the projects under construction or at an advanced stage of planning, 70% (16 of 22) intend to use captured CO_2 to improve recovery of oil in mature fields (enhanced oil recovery, or CO_2-EOR). CO_2-EOR projects merit cautious treatment as an indicator of progress in CCS deployment. To ensure the integrity of CO_2 storage as a climate mitigation option, projects that store captured CO_2 through EOR must comply with regulatory standards for monitoring, measurement and verification and long-term storage equivalent to those applied for projects that store CO_2 purely to prevent its release to the atmosphere. Currently, CO_2-EOR projects are generally not required to undertake monitoring in a way that is sufficient to provide confidence that injected CO_2 is permanently retained (IEA, 2012f).

Developments in some industrial sectors – important to reaching 2DS goals – are notably absent. Although all four operating projects are capturing CO_2 from industrial applications – natural gas processing and hydrogen production – there is a dearth of projects in the iron and steel, cement, oil refining, biofuels and pulp and paper sectors, which have struggled to develop projects in the current economic and climate policy landscape. Only two possible demonstration projects at iron and steel plants and two at coal-to-chemicals/liquids plants are at early stages of planning (GCCSI, 2012).

Market creation

Progress in CCS deployment depends entirely on strong financial and policy action by government. There is currently no commercial benefit to undertaking CCS, unless there is a sufficiently high charge or fee on CO_2 emissions, or a commercial market for captured CO_2 for CO_2-EOR. To drive private investment in CCS-equipped facilities, governments must provide demonstration funding and policy incentives for deployment beyond demonstration – including strong and credible emission reduction policies (IEA, 2012g). Further research on possible uses of CO_2 is also needed.

Cumulative spending between 2007 and 2012 on projects that demonstrate CCS reached almost USD 10.2 billion (Figure 2.3). This total includes spending on CCS-equipped power generation with a capacity greater than 100 MW (and at all scales for industrial applications of CCS) between 2007 and the end of 2012 that is under construction or operating. Government grants contributed USD 2.4 billion of this total. USD 7.7 billion came from private finance, although the private total reflects, in most cases, more than just the cost of CCS components. Moreover, the private finance total includes significant spending on capture projects that supply CO_2 for EOR, some of which may not carry out sufficient monitoring to provide confidence that injected CO_2 is permanently retained. Almost the entire USD 2.4 billion in public funding is from governments in the United States and Canada (federal and state or provincial). In addition, over the same period, a further USD 12.1 billion of public funds was awarded to other demonstration projects (as well as R&D) worldwide.[4]

4 Some of these government grants are to CCS-equipped power generation with a capacity of less than 100 MW, while others may be to large projects in power or industry that have not yet reached construction, or, in some cases, have been cancelled.

While the significant growth in cumulative spending that has occurred over the past five years is a positive sign, the current amount is far below the estimated USD 100 billion required to deliver CCS levels envisaged in the 2DS. Thus, additional public financial support is required, particularly for projects in industrial sectors where capture processes have yet to be demonstrated, and where trade exposure reduces the private sector's ability to invest. Private investment must also increase, but this will depend on clear, long-term policy signals from government.

There has been progress in implementing broader emissions reductions initiatives that could provide incentives for CCS installations, but these initiatives are generally not currently sufficient in themselves to drive CCS deployment (Table 2.1). For example, Australia's new carbon price is expected to encourage investment in lower-emissions generation technologies, but at AUD 23 (which at the end of 2012 was roughly equivalent to USD 23), it is far lower than the amount required to make power plant demonstration projects competitive with other lower-carbon generation options, such as natural gas or certain renewables (DCCEE, 2012; IEA, 2011a). This amount is likely to be in excess of USD 100 per tonne of CO_2 avoided. Norway is the only country in which a technology-neutral carbon price (a tax on CO_2 emissions from offshore oil and gas activities) has driven commercial CCS deployment to date.[5]

A lack of coherent incentive policies that link near-term demonstration of CCS with a long-term need for emissions reductions represents the most critical barrier to further penetration of CCS technologies (Table 2.1). The Electricity Market Reform process under way in the United Kingdom is the only comprehensive attempt globally to set policy to drive CCS deployment beyond the first wave of demonstration facilities, as part of the broader reform package to decarbonise the electricity sector.[6]

Table 2.1 CEM government policy support for CCS deployment

R&D programme	Australia, Canada, China, European Union, Finland, France, Germany, India, Indonesia, Italy, Japan, Korea, Norway, South Africa, Spain, Sweden, United Arab Emirates, United Kingdom, United States.
Demonstration programme	Australia, Canada, European Union, France, Japan, Korea, Norway, United Arab Emirates, United Kingdom, United States.
CCS-specific financial incentives	United Kingdom (under development).
Limits or price on carbon emissions	Australia, Canada (Alberta, British Columbia, Quebec; federal level from 2015), China (under development), Denmark, European Union, Finland, France, Germany, Italy, Korea (2015), Norway, Spain, Sweden, United Kingdom, United States (some states).
National CCS roadmaps or visions in place or under development	Australia, China, Korea, Norway, South Africa, United Kingdom.

5 The Sleipner and Snohvit projects. Both of these projects are in the gas processing sector, in which the incremental costs of capture are low compared with other sectors.

6 The proposed reforms include feed-in tariffs combined with contracts for difference, to provide stable revenue streams to generators of low-carbon electricity; a carbon price floor, to strengthen the incentive to invest in low-carbon electricity generation and reduce investment uncertainty; and an emissions performance standard, intended to ensure that no new coal-fired plants are built without CCS.

Technology developments

IEA member governments spent an estimated USD 960 million on RD&D for CCS in 2011, about 5% of their total energy RD&D expenditure, up 10% from 2010 (Figure 2.4). The share of CCS in fossil fuel RD&D expenditure has increased significantly since 2008, from 22% to almost 50%. Government-funded fundamental research continues to be important to advance novel CO_2 capture technologies and tools for storage monitoring and modelling, and thus reduce costs and risks associated with CCS technologies.

Over the past five years, the number of patent applications that relate to CCS has sharply increased, signalling commercial interest in the technology (Figure 2.5). Applications increased at a compound annual growth rate of 23% over the period 2000-11, and by 45% between 2006 and 2011. This was followed by a significant increase in the number of granted patents from around 2009. These results provide strong evidence that R&D activity has grown strongly in response to greater policy focus on CCS since the middle of last decade.

The slow progress in deploying large-scale CCS demonstration projects is, however, restraining technological learning. CCS technologies only operate at the large scales necessary to abate CO_2 from the biggest emissions sources, which means that fewer individual installations are relied upon for the transfer of cumulative experience and cost reduction compared with other mitigation options. While sophisticated pilot projects, such as those at Mongstad (Norway) and Plant Barry (USA), are contributing to this learning process, the commercial drivers for exploring and proving sufficient CO_2 storage capacity globally are absent and public initiatives remain crucial (IEA/GCCSI, 2012).

Recommendations for governments

- *To scale up CCS deployment, governments need to explicitly recognise the role that CCS will play in their energy futures through clear, long-term deployment strategies. In addition to adequate financial support for CCS demonstration, these strategies must include appropriate incentives to drive commercialisation, and be supported by credible long-term climate mitigation commitments. They must also recognise the large investments and long-lead time required to discover and develop viable storage capacity.*
- *The recommended actions on CCS financing developed by the CEM Carbon Capture, Use and Storage Action Group (CCUS AG) for CEM2 – related to identifying shortfalls in existing CCS or climate change policies and assessing appropriate policies to reduce the financial gap – remain relevant (CCUSAG, 2011). They require real commitment by governments to drive progress. Work undertaken by the IEA (IEA, 2012g) and the Program Managers' Network of governments that manage large-scale demonstration programmes, as presented to CEM4 by GCCSI, may guide governments in this process.*
- *CEM3 identified CCS in non-power sectors as a crucial area for policy action, because some of these sectors have not yet approached the demonstration phase that power plants are currently entering (IEA/ GCCSI, 2012). Governments should implement the recommendations on actions to advance CCS in industrial applications presented by the IEA to CEM4 on behalf of the CCUS Action Group (IEA, 2013a).*

- *Important near-term actions include:*
  - *Support regional and international consortiums to develop and demonstrate CCS technologies through collaborative efforts across industry sectors. The iron and steel and cement sectors are of particular relevance to this action and should seek to develop replicable solutions.*
  - *National policy plans should be expanded to address CO_2 emissions from industrial applications and introduce CCS as a necessary solution, while being sensitive to competitiveness concerns. The immediate low-cost opportunities for CCS in gas processing and hydrogen manufacture – in refining and chemicals production – are of particular relevance to this action.*
  - *Engage all sectors in strategic CCS activities, including CO_2 transport and storage needs. The goal is to raise the level of knowledge among all companies, inspire local endorsement of CCS and share costs across clusters of industrial sites. To support wider stakeholder engagement and knowledge sharing, IEA will soon release an update of its CCS technology roadmap.*

Chapter 3

End Use Sectors

Industry

Improvement needed

Using best available technologies (BAT) could reduce industrial energy consumption by around 20% in the medium- to long-term. To meet 2DS goals, it will also be necessary to optimise production and process techniques, and achieve technological advances. There has been reasonable progress in implementing these changes across industrial sectors, but governments must step up implementation of energy and emissions reduction policies.

Recent developments

- Several regions significantly scaled up policy support for energy efficiency in industrial sectors in 2012. The European Commission, for example, launched a public-private partnership, Factories of the Future, consisting of a research programme of USD[1] 1.6 billion (EUR 1.2 billion) to help the manufacturing industry in the European Union develop sustainable technologies.
- The South African Department of Trade and Industry's Manufacturing Competitive Enhancement Programme announced a new project in 2012 to encourage and support companies to invest in clean technology, among other areas of investment. USD 640 million is being made available over five years, from 2012.
- Australia's Clean Energy Future plan commenced in 2012. The plan includes a carbon price and complementary programmes to support energy efficiency measures in industry, including a USD 10.3 billion Clean Energy Finance Corporation and a USD 1.24 billion Clean Technology programme.
- Several institutions released low-carbon technology roadmaps relevant to industry in 2011. The European Union, for example, released a roadmap for moving to a low-carbon economy in 2050 (EC, 2011). The Confederation of European Paper Industries released its 2050 Roadmap to a low-carbon bioeconomy (CEPI, 2011). Other European sectors, such as iron and steel, chemicals and cement, are following suit. The IEA together with the International Chemical Council Association and DECHEMA will soon release a roadmap for the Chemical sector. These roadmaps should assist in driving energy efficiency progress in industry.

Overall progress assessment

The role of industry in the 2DS

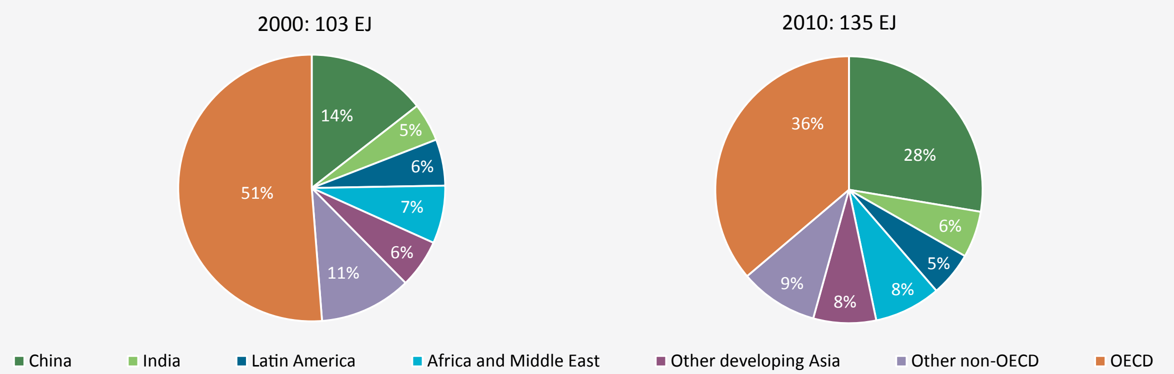
Industry must rein in growth in its energy consumption to 162 EJ[2] by 2020. In the 2DS, direct industrial CO_2 emissions peak by 2020, at around 9 $GtCO_2$, with industry contributing one-fourth of emissions reductions in 2020 relative to the 4DS. By 2020, the majority of required reductions come from chemicals and petrochemicals (42%), iron and steel (30%) and cement (7%). Energy efficiency improvements represent 49% of industrial emissions reductions requirements, through widespread adoption of BATs and improved production techniques; new technology deployment provides the bulk of the remainder.

1 Unless otherwise stated, all costs and prices are in real 2010 USD, *i.e.* excluding inflation. Other currencies have been converted into USD using purchasing power parity (PPP) exchange rates.
2 Energy consumption numbers in this section represent final energy consumption.

Technology penetration and technology developments

Total industrial final energy use increased by 31% between 2000 and 2010,[3] to 135 EJ – around one-third of total final energy consumption – with 8 $GtCO_2$ associated direct emissions (Figure 3.1). Non-OECD countries, particularly China and India, drove this growth, consistent with increase in demand and production of industrial materials in those regions. OECD regions' share of global industrial energy use declined, from over 50% in 2000, to 36% in 2010, reflecting a major downturn in production. Industry has also observed a structural change: energy consumption of the five energy-intensive industrial sectors increased relative to other industrial sectors between 2000 and 2010 (Figure 3.2). The five main energy-intensive sectors accounted for more than 67% of total

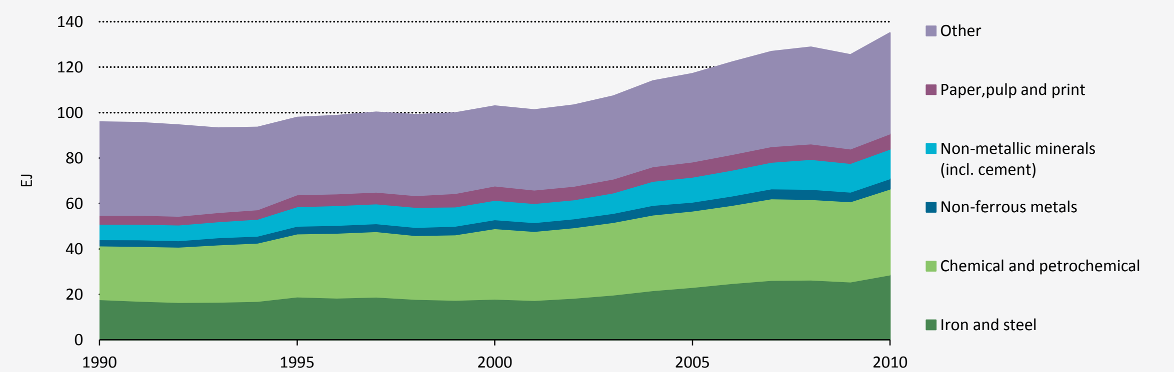
Figure 3.1 Global industrial energy consumption by region



Notes: Unless otherwise noted, all tables and figures in this report derive from IEA data and analysis.
Figures and data that appear in this report can be downloaded from www.iea.org/etp/tracking.

Key point *Industrial energy consumption is shifting to non-OECD countries.*

Figure 3.2 Global industrial energy consumption by sector



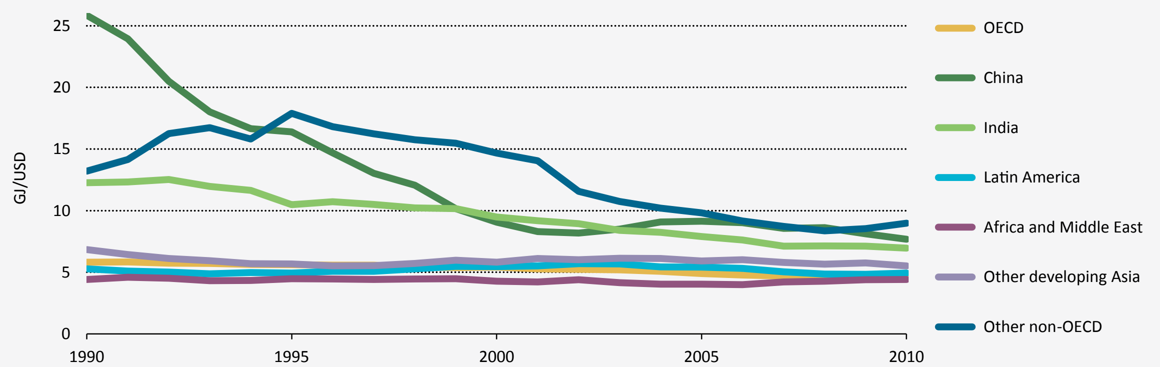
Key point *The five most energy intensive industry sectors are increasing their share of global industry energy consumption.*

3 Includes energy used as feedstock in the chemicals and petrochemicals sector, as well as energy use in coke ovens and blast furnaces.

final industrial energy use in 2010, compared with 58% in 1990. This has had an upward impact on overall industrial energy intensity, but has been offset mainly by energy efficiency improvements in many regions of the world, especially in developing countries, where high production growth rates have allowed addition of new and efficient production capacity.

Despite industry reducing its energy intensity[4] since 1990 (Figure 3.3), energy consumption has continued to grow due to increases in global industrial material demand, with a resulting increase of total energy use and CO_2 emissions. The greatest improvement in energy intensity was in China (70%), India (43%) and other developing Asian countries (32%). OECD regions improved their energy intensity by 20%. Energy intensity improvement does not necessarily imply direct increases in energy efficiency: other factors can play a role, such as structural changes that base a higher share of the economy on less energy-intensive industry, and fluctuating materials prices.

Figure 3.3 Aggregate industrial energy intensity



Note: Industrial value-added from IEA, 2012h.

Key point *The rate of improvement in industrial energy intensity has slowed in recent years.*

Iron and steel

To meet 2020 2DS targets, the iron and steel sector must limit growth in energy consumption to reach 32 EJ in 2020 (+12% from 2010 levels), and reduce CO_2 emissions by 247 $MtCO_2$ relative to the 4DS. The iron and steel sector consumed over 28 EJ in 2010 – the second-largest share of industrial energy use, up almost 60% on 2000 levels – and produced the most emissions from industry (2.5 $GtCO_2$). Between 2000 and 2011 production grew 76% to 1 490 Mt, an average annual growth rate of 5.3%, despite a drop in global steel production by 9% between 2007 and 2009 due to the global economic downturn, primarily in OECD countries. Crude steel production increased in China by 432% between 2000 and 2011 (Worldsteel, 2011). Growth in crude steel production is expected to slow down; projected production in 2020 is 1 775 Mt, still an increase of about 20% from 2011 levels.

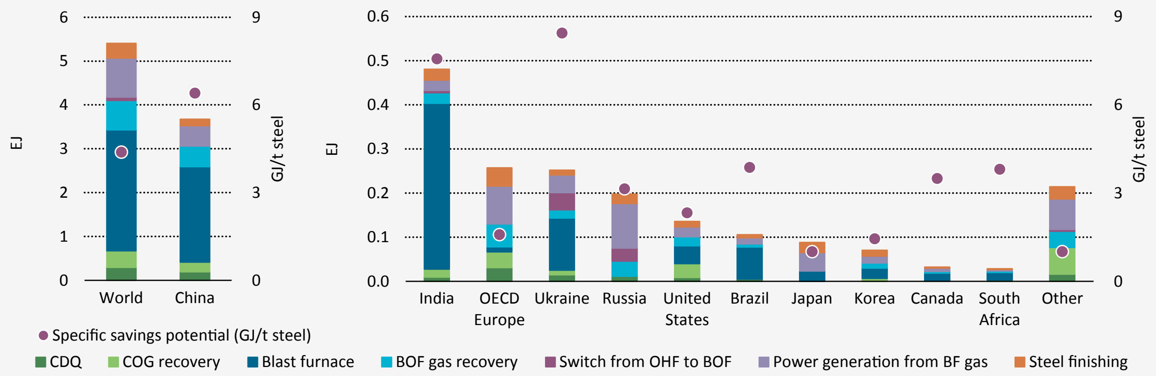
Worldwide energy intensity remained relatively static in the steel industry over the last ten years, decreasing from 21.2 GJ/t in 2000 to 20.2 GJ/t in 2010.The 2DS envisages energy intensity of about 18 GJ/t crude steel in 2020. Additional capacity has reduced the average age of the capital stock; newer plants tend to be more energy-efficient than older plants, although they do not all apply BAT. In parallel, however, recycling as a proportion

4 Energy use by unit of industrial value-added.

of total crude steel production has declined, from 47% in 2000 to around 31% in 2010. This is primarily due to the rapid increasing use in China of blast furnace/basic oxygen furnace technology as opposed to scrap-intensive electric furnace technology: the share of crude steel produced in electric furnaces decreased from 34% in 2000 to 29% in 2010. This also reflects the inability of available scrap levels to meet rapidly growing production.

Large potential exists to reduce energy consumption and emissions from iron and steel. The sector has technical potential to reduce energy consumption by 5.4 EJ – about 19% of the sector energy consumption in 2010 – through application of BAT (Figure 3.4). Around 67% of this potential is in China. These savings cannot be fully tapped by 2020 as the rate of implementation of BAT depends on several factors, including capital stock turnover, raw material availability and rates of return on investment. The 2DS also relies on a shift in production and process routes to reduce energy and CO_2 intensity by 2020, including the phase-out of open-hearth furnaces, reduction in coal-based direct reduced iron (DRI) production – the 2DS envisages a decrease from an estimated 19.2 Mt in 2010 to 15.1 Mt in 2020 – and increased use of scrap steel and electric furnaces. These measures have the potential to limit growth in CO_2 emissions by 3% between 2010 and 2020 (Table 3.1). Other important emissions reduction options will not be fully commercialised by 2020, including smelting reduction and CCS, but start to play a role in reducing emissions after 2020.

Figure 3.4 Energy savings potential for iron and steel, based on BAT[5]



Note: BF = blast furnace; OHF = open-hearth furnace; BOF = basic oxygen furnace; COG = coke-oven gas; CDQ = coke dry quenching (also includes advanced dry quenching); GJ/t = gigajoule per tonne.

Key point *About 19% of the energy consumption in 2010 in iron and steel could be saved through application of best available technologies.*

5 Depending on the specific status of the relevant process or plant, not all the indicated energy savings potentials may be relevant or able to be cumulatively tapped.

Table 3.1 Priority actions and milestones in the iron and steel sector

- Share best practice policies for the promotion of energy efficiency and CO_2 emission reduction measures.
- Phase-out open-hearth furnaces and start phasing-out coal-based DRI.
- Provide support and infrastructure to maximise the recycling of obsolete scrap.
- Provide policy incentives for the demonstration of CCS in the iron and steel sector.

Low-demand case	2010	2015	2020
Energy intensity (GJ/t crude steel)	21	19	18
Production from coal-based DRI (Mt)	19	17	15
Production from recycled materials	31%	35%	38%
CCS ($MtCO_2$ captured)	0	0	29

Cement

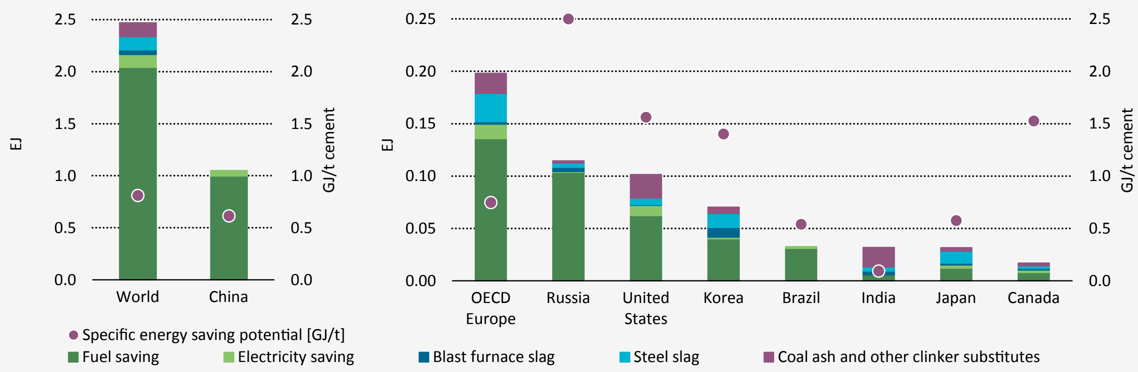
The 2DS envisages emissions from the cement sector in 2020 lower than 4DS levels by around 60 $MtCO_2$, a reduction equivalent to about 3% from 2010 emission levels. The cement sector is the third-largest energy consumer in industry, consuming 13 EJ in 2010 (+52% from 2000), and the second-largest CO_2 emitter (2 094 $MtCO_2$ in 2010). The sector accounted for about 25% of direct CO_2 emissions from industry in 2010. Average annual growth in cement production, which was 2.6% from 1980 to 2000, was 7% between 2000 and 2010, driven by the rapid economic growth in developing countries. Cement production reached 3 125 Mt in 2010; China accounted for about 50% of this production. Production growth is expected to slow by 2020, to see production of 3 708 Mt in 2020, as the peak in China cement production is expected to occur before 2020. This represents an increase of global cement production of 1.9% per year from 2010 levels between 2010 and 2020.

The rising number of dry-process kilns with pre-heaters and pre-calciners (current BAT for the cement industry) has improved thermal energy consumption per tonne of clinker[6] produced in the last decade, to 3.9 GJ/t clinker in 2010. The 2DS target is 3.7 GJ/tonne in 2020. Thermal energy efficiency in the cement industry is strongly linked to the production process used. There are two basic types, "wet" and "dry". The wet process consumes more energy, as it is necessary to evaporate slurry water before heating raw materials for calcination (5.9 to 6.7 GJ/t clinker of fuel consumption). The dry process is more efficient, as it avoids this step (3.0 to 4.2 GJ/t clinker of fuel consumption, depending on the configuration of the pre-heater and pre-calciner). The more efficient dry process with pre-heaters and pre-calciners is the technology of choice for new plants. The use of dry technologies rose from 49% of operating plants in 2000 to 68% in 2010 (CSI, 2010).

To reach 2020 2DS targets, the cement industry will have to use alternative fuels in production, clinker substitutes and CCS, as well as raising thermal and electric efficiency (IEA/WBCSD, 2009). Due to progress over the last decade, the cement industry is on track to reach 2DS goals in terms of thermal energy consumption per tonne of clinker produced, although there is still potential to improve energy savings by around 2.5 EJ (around 25% of 2010 levels) by applying BAT globally (Figure 3.5). Further progress is needed to overcome challenges associated with increased use of alternative fuels (*e.g.* potential energy penalties, public acceptance) and using clinker substitution materials (*e.g.* economic barriers). Demonstrating CCS will also be essential to reach 2DS goals.

6 A core component of cement, made by mixing ground limestone and clay at a temperature of about 1 400°C to 1 500°C.

Figure 3.5 Energy savings potential for cement, based on BAT



Key point *Some 19% of the energy consumption in 2010 in cement could be saved through application of BAT.*

Table 3.2 Priority actions and milestones in the cement sector

- Share best practice policies for the promotion of energy efficiency and CO_2 emission reduction measures.
- Phase out all wet and vertical shaft kilns.
- Promote R&D to improve BAT and long-term energy efficient technologies.
- Ensure national waste disposal policies enable the full potential of co-processing in the cement industry (i.e. use of alternative fuels).
- Develop new or revise existing cement standards and codes to allow more widespread use of blended cement and facilitate the use of a new generation of emerging cements.
- Governments should provide policy incentives for the demonstration of CCS in the cement sector.

Low-demand case	2010	2015	2020
Thermal energy per tonne of clinker (GJ/tonne)	3.9	3.8	3.7
Electricity per tonne of cement (kWh/tonne)	107	106	104
Share of alternative fuel and biomass use	4%	10%	12%
Clinker to cement ratio	0.80	0.78	0.77
Number of CCS pilot plants	0	0	11
$MtCO_2$ captured	0	0	13
tCO_2/t cement	0.73	0.71	0.68

Box 3.1 Indian cement industry targets emissions and efficiency

The Indian cement industry is one of the most efficient in the world and has made strong efforts to reduce its carbon footprint. Yet opportunities for improvements still exist. *Technology Roadmap: Low-Carbon Technology for the Indian Cement Industry* (IEA/ WBCSD, 2013) sets out milestones that would enhance the country's energy security by limiting growth in energy consumption, and further reduce direct CO_2 emissions intensity by about 45% by 2050. This transition would also have energy benefits, reducing consumption by at least 275 PJ.

Decisive action by all stakeholders is critical to realise the roadmap's vision, which is achievable but ambitious. To reach the proposed levels of efficiency and emissions, government and industry must collaborate to create an investment climate that will generate the financing required.

In the short term, the specific intensity of thermal heat requirements needs to be reduced from 3.04 MJ/t clinker in 2010 to 2.97 MJ/t clinker in 2020. The clinker-to cement ratio needs to be lowered from 0.74 to 0.70 and the specific intensity of electrical requirements (excluding the potential from waste heat recovery) should decline from 80 kWh/t cement to 75 kWh/t cement.

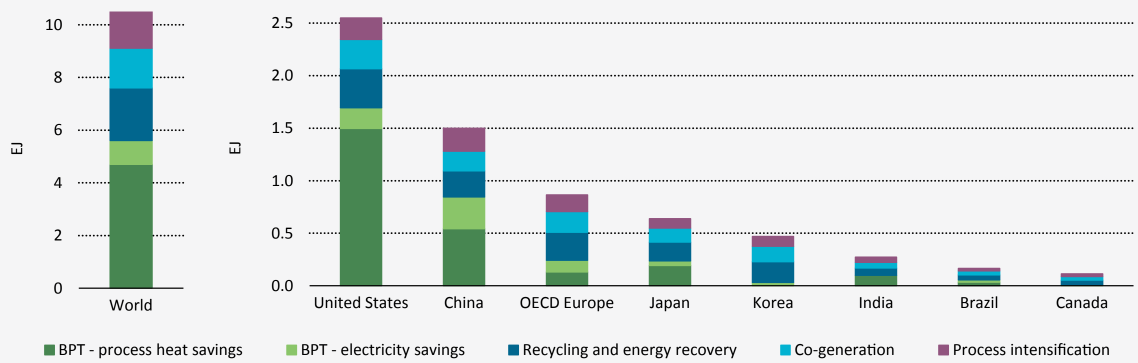
Chemicals and petrochemicals

In the 2DS, emissions from the chemicals and petrochemicals sector in 2020 are around 350 $MtCO_2$ lower than 4DS levels. The required reductions represent over 27% of 2010 emissions from the sector. Chemicals and petrochemicals is the largest industrial sector in energy consumption terms, with almost 38 EJ[7] of final energy use in 2010 (up 20% on 2000 levels). This represents 28% of total 2010 industrial final energy consumption. The sector accounted for 16% of total direct industrial CO_2 emissions in 2010 (1 292 $MtCO_2$ in 2010). The sector is complex and diverse, covering many products that can each be produced through several routes and technologies. There are five major products in terms of level of production and energy intensity: ethylene, propylene and BTX[8] (high-value chemicals or HVCs), as well as ammonia and methanol. Energy use by the sector has been steadily increasing over the past decade, from around 30 EJ in 2000 to almost 38 EJ in 2010 (+27%), driven by growing demand for chemical products. Global production of HVCs is expected to increase from 44 kg/capita in 2010 to 59 kg/capita in 2020, with the largest growth in the Middle East. Global ammonia production is projected to increase by 21% by 2020 (from 159 Mt in 2010 to 193 Mt in 2020), and global methanol production is anticipated to increase by 126% by 2020 (from 49 Mt in 2010 to 110 Mt in 2020). Improving energy efficiency would contribute to partially decouple materials production from energy consumption.

Based on the main production routes for the five main chemical and petrochemical products, implementing economically viable best practice technologies (BPT) could reduce final energy consumption by an estimated 10 EJ, together with process integration, co-generation,[9] recycling and energy recovery. This represents around 28% of energy use in the sector in 2010. Production of olefins (synthetic hydrocarbons such as ethylene and propylene) through steam cracking, for example, was estimated to perform in 2010 at levels of around 16 GJ/t olefin in China, India and the United States, and 14 GJ/t olefin in the Middle East, Germany and France, compared with12 GJ/t olefin based on BPT[10] (excluding feedstocks). Ammonia production from natural gas is estimated to require around 19 GJ/t ammonia in Russia, 17 GJ/t ammonia in the United States, and 15 GJ/t ammonia in Brazil and the Middle East, against a BPT benchmark of 11 GJ/t ammonia (excluding feedstocks). The energy requirement for methanol production from natural gas is estimated at around 14 GJ/t in most regions, significantly above the corresponding BPT threshold of 9 GJ/t (excluding feedstocks). Several emerging technologies could also significantly reduce energy consumption of key production processes. Producing olefins through catalytic cracking of naphtha, for example, rather than the widespread steam cracking technology, can use 10% to 20% less energy (Ren, Patel and Blok, 2006). To accelerate its efforts to reduce CO_2 emissions, the sector will also need to use advanced membrane technologies, introduce biomass as a feedstock via gasification or fermentation, deploy CCS, and take other measures.

7 Including feedstock (*i.e.* energy locked into the products). Feedstock energy consumption values are assumed as follows: 45 GJ/t olefin, 20.7 GJ/t ammonia, 20 GJ/t methanol.
8 Benzene, toluene and xylene.
9 The combined production of heat and power.
10 BPT specific energy consumption values from IEA/ICCA/DECHEMA, 2013.

Figure 3.6 Energy savings potential for chemicals and petrochemicals, based on best practice technologies



Key point *Some 28% of the energy consumption in 2010 in the chemical and petrochemical sector could be saved through application of BAT.*

To 2020, priority actions for governments globally in the chemicals and petrochemicals sector include:

- increase incentives and reduce barriers for energy efficiency improvements, and introduce policies facilitating the use of best practices where new facilities will be built;
- develop a long-term policy framework that invigorates R&D in chemical and petrochemical energy-intensive processes;
- provide financial incentives for the demonstration of CO_2 capture technologies;
- share best practice policies for the promotion of energy efficiency and CO_2 emission reduction measures;

Industry and research bodies should:

- work to improve performance of catalytic process toward thermodynamically optimal limits;
- develop novel separation technologies and bio-based polymers;
- improve and develop processes for hydrogen production from renewable sources.

Box 3.2 Cross-sectoral energy efficiency potential in industry

Most enhancements that improve energy efficiency are specific to particular industries, but some cut across several sectors, so they deserve special attention from policy makers. Examples include high-efficiency motors and variable-speed drives, heat recovery technologies, sensors and controls, and co-generation. Electric motor systems, for example, consume about 70% of all power used in the industrial sector, so optimising them (*i.e.* ensuring appropriate motor size and type, and suitable configuration of systems) could lead to energy savings of 20% to 40%. Broad policy packages to promote motor system optimisation globally could save 2 800 TWh/year by 2030.

Policy makers can use market transformation packages to tap this potential, including stringent minimum energy performance requirements, effective labelling schemes, energy performance test procedures for all motor types and components of electric motor-driven systems, energy management systems, and system-wide assessment standards. Non-regulatory policy measures, including large-scale awareness programmes and capacity building efforts, are also relevant (IEA, 2011b).

Market creation

Government policies can promote the implementation of cost-effective energy efficiency measures in industry, including by helping to overcome barriers related to the market (such as required upfront capital investments and long life-spans of infrastructure), knowledge barriers (lack of information and technical know-how, and difficulty in calculating costs and benefits of energy-efficient technologies and practices), as well as other impediments.

Many government policies have advanced energy efficiency, but more aggressive measures and guidelines for industry implementation are required to fully realise energy efficiency potential in industry. Key policies and measures include energy management policies, energy efficiency services for small- and medium-sized enterprises, minimum performance requirements for industrial equipment (*e.g.* motors) and systems, and complementary policies (Table 3.3)

Table 3.3 Key policy action to enhance industrial energy efficiency

Policy options	Progress
Energy management in industry	
■ Measurement of energy consumption; identification of energy savings potential; setting benchmarks for industry energy performance; mandating energy audits and energy managers; publicly reporting progress.	Voluntary agreements for large energy-intensive industries (including regular audits, reporting, target-setting, and capacity building): Sweden, Denmark, Ireland, Finland, Belgium (Flanders), and the Netherlands. Voluntary agreements (general industry): Austria, Japan. Voluntary certification programmes: United States, Canada. Mandatory energy management and assessment requirements for large energy-intensive industry (including audits, reporting, target-setting): Australia, China, South Korea. Audits: India, Japan, and Russia (mandated periodic energy audits for large industries), European Union (EU Directive 2012/27/EU on energy efficiency calls for periodic energy audits in large energy-intensive industry). Mandated certified energy managers: Japan. Mandatory energy efficiency targets: Japan. ISO standards for energy management in industry (ISO 50001): 1 100 certifications by the end of 2012 (600 in Germany).
Energy efficiency services for SMEs	
■ Support for energy audits, including by providing information on proven energy efficiency practices; energy performance benchmarking.	Subsidised audits: New Zealand (50% of cost), Chile (70%), South Korea (70%), Germany (including technical advice), South Africa, Ireland. Energy management programmes: Australia (voluntary for medium energy users), Austria (voluntary agreement). Industry networks and energy management tools: Germany, Switzerland, Austria. Information programmes: Australia (Energy Efficiency Information Grants and Energy Efficiency Exchange website). EU Directive 2012/27/EU on energy efficiency calls for measures to promote energy efficiency in SMEs.

High-efficiency industrial equipment and systems	
■ Implement mandatory minimum energy performance standards for electric motors and other categories of industrial equipment, such as distribution transformers, compressors, pumps and boilers. ■ Measures to address barriers to optimisation of energy efficiency in design and operation of industrial processes (e.g. providing information on equipment energy performance, training initiatives, audits, technical advice and documentation, and system-assessment protocols).	Minimum energy performance requirements for 3-phase induction motors: IE1 Standard (Standard efficiency): Taiwan, Israel, Costa Rica. IE2 Standard (High efficiency): Australia, Brazil, China, South Korea, New Zealand, Switzerland, Mexico. IE3 Standard (Premium efficiency): European Union (<7.5kW by 2015; all IE3 by 2017), United States, Canada, Japan (will add motors to its Top Runner Programme). Incentive schemes: Netherlands (tax relief programme), Japan (special depreciation rate and tax deduction). Market transformation programmes: China (motors), Switzerland (motors), United Kingdom. Standards for systems optimisation: China. In 2012, the International Electrotechnical Commission and the US National Electrical Manufacturers Association launched an initiative to establish a Global Motor Labelling Programme.
Complementary policies to support industrial energy efficiency	
■ Remove energy subsidies and internalise the external costs of energy through policies such as carbon pricing. ■ Encourage investment in energy-efficient industrial equipment and processes through targeted financial incentives such as tax incentives, risk-sharing or loan guarantees with private financial institutions, and facilitating the market for energy performance contracting.	Dedicated industrial energy efficiency funding: Germany, China, South Africa. Low interest loans or innovative financing mechanisms: Germany, United Kingdom (equipment replacement for SMEs), South Korea, Australia. Revolving funds: South Africa, Thailand. Accelerated depreciation rates for energy efficient equipment: Canada, Ireland, United Kingdom, United States. Subsidies for energy efficient equipment: China, Japan, Thailand. Market-based schemes: India (Perform, Achieve & Trade programme). GHG emission trading schemes: established in European Union and California (United States), considered or pending in Australia, South Korea, China. EU Directive 2012/27/EU on energy efficiency calls for measures to facilitate national financing facilities for energy efficiency measures.

Notes: This table does not set out an exhaustive list of policies globally; rather, it highlights key policies and approaches. SME: small- and medium-sized enterprises.

Recommendations for governments

- *Growing markets for industrial materials provide an opportunity to deploy BAT, optimise energy use in industrial processes and promote the development of a range of new technologies. Governments should implement appropriate policies to ensure that new capacity is developed at best practice energy efficiency performance level and that industrial plant refurbishment projects are promoted to meet energy efficiency targets.*
- *Programmes that more effectively address barriers to industrial energy efficiency and investment create momentum and mainstream the integration of energy management into standard business operation practices and are essential for progress. Particular attention should be placed on measures to facilitate access to financing.*
- *Notwithstanding new programmes to stimulate energy management and energy efficiency, further government efforts are needed to improve energy efficiency, in particular in light industry and SMEs.*
- *To avoid technological lock-in of inefficient production systems in developing countries, technology transfer efforts must be enhanced, by sharing knowledge, know-how, capacity and experience in effective policy development.*
- *To be sustainable, future industrial processes will need advanced technologies with significantly reduced energy consumption requirements and CO_2 emissions. Government and industry must jointly support R&D and demonstration projects for such advanced and novel technologies in industry.*

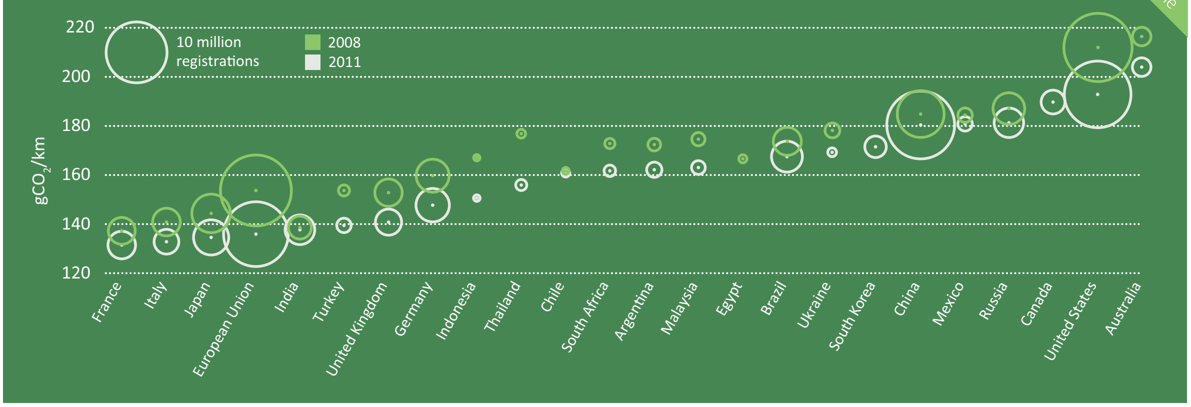
Fuel Economy

Improvement needed

New vehicle fuel economy is increasing more quickly, mainly because OECD governments have accelerated policy measures, but further work is required globally to meet 2DS targets. For new passenger light-duty vehicles (PLDV), fuel economy varies by up to 55% between countries, suggesting significant potential to improve fuel economy worldwide. Policies to promote existing technologies should continue, particularly in non-OECD regions.

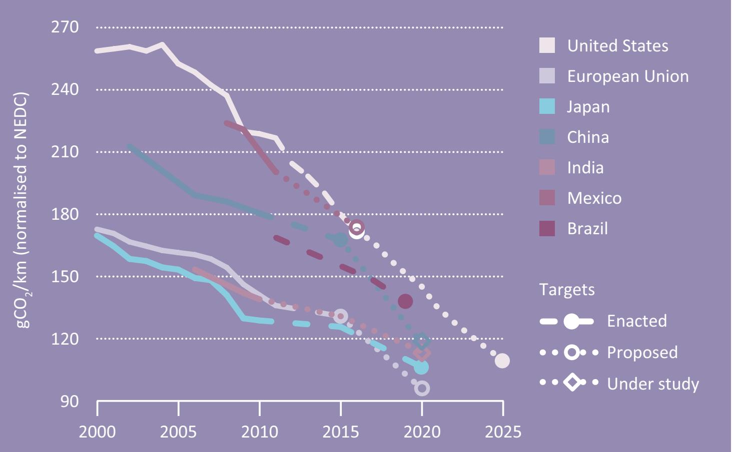
Technology penetration

3.7 New LDV fuel economy performance



Market creation

3.8 New LDV fuel economy standards



1.8%

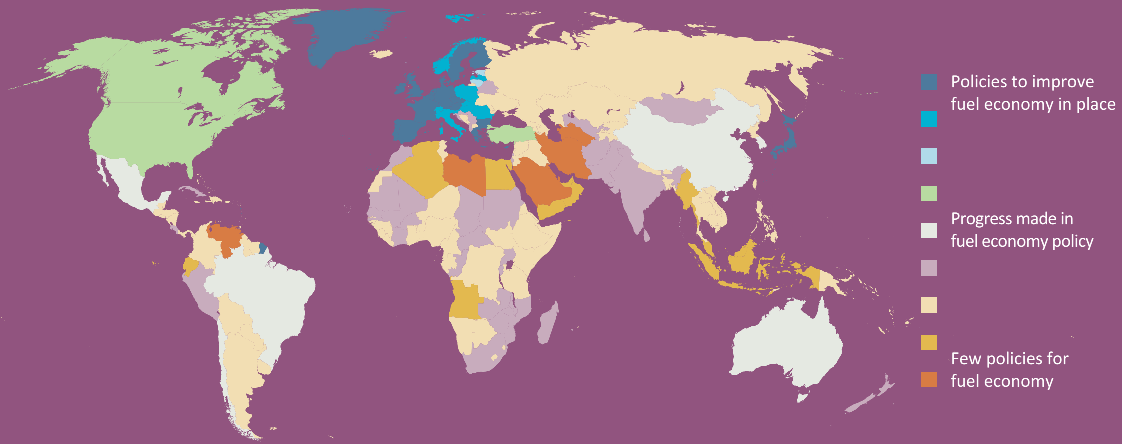
AVERAGE ANNUAL IMPROVEMENT IN GLOBAL FUEL ECONOMY 2008-2011

2.7%

NECESSARY TO REACH THE 2DS TARGET

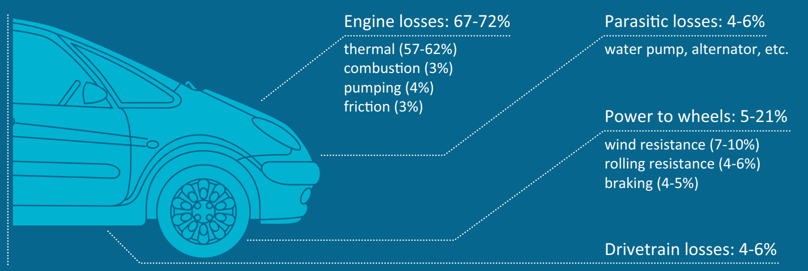
3.9 Fuel economy readiness index status, 2012

More online



Technology developments

3.10 Average LDV energy losses

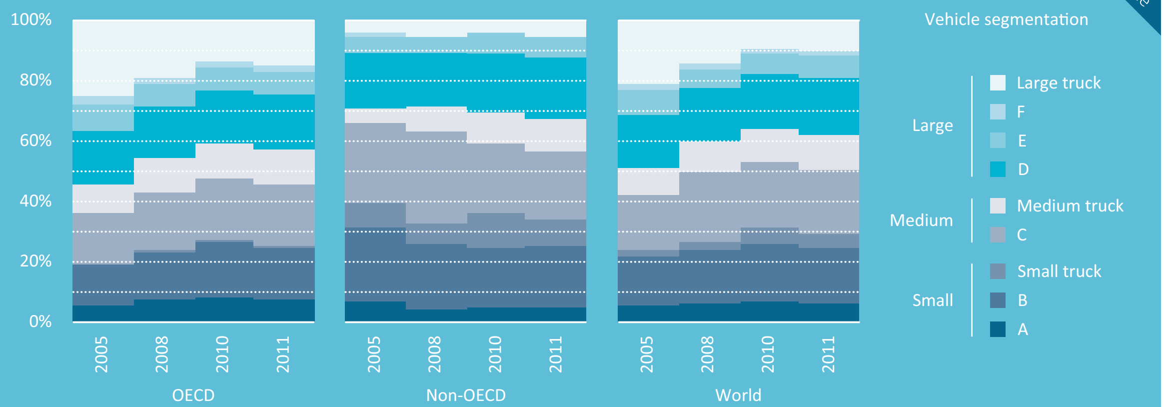


20%

OF FUEL ENERGY IS USED TO PROPEL THE AVERAGE LDV

3.11 New LDV registrations

More online



For sources and notes see page 142

Recent developments

- The rate of improvement of average global fuel economy of light-duty vehicles (LDVs) – reported as lagging behind at CEM3 – accelerated between 2008 and 2011. From 2010 to 2011 the annual rate of improvement slowed, however, reflecting market evolution in some key countries. The US market, which has relatively weak fuel economy, grew significantly between 2010 and 2011, whereas the more efficient Japanese and EU markets shrank, tilting the OECD average upward.
- The overall improvement between 2008 and 2011 has been driven predominantly by OECD regions, where implementation of fuel economy standards and other policy measures has been scaled up. The pace of improvement demonstrates the strong potential to bring improved fuel-saving technologies – which are already widely commercially available – into the market through policy action.
- The IEA fuel economy readiness index, launched in 2012 (IEA, 2012i), assesses and scores progress in implementing policies in OECD and non-OECD regions. The index shows that much potential remains in all regions, but particularly non-OECD regions. Australia, Brazil, India and Mexico are taking important steps towards implementing fuel economy policies.
- Worldwide Harmonised Light Vehicles Test Procedures, an initiative of the United Nations Economic Commission for Europe, has made progress since CEM3. This is significant since better design of fuel economy test cycles is important to address the gap between tested new car fuel economy and in-use vehicle performance, which can be up to 20%. If multiple countries adopt the test cycle, harmonisation will enable better comparison of performance in new car fuel economy between regions.

Overall progress assessment

The role of fuel economy in the 2DS

Improving the fuel economy of conventional vehicles fitted with internal combustion engines (ICEs) holds the greatest potential to reduce fuel consumption and CO_2 emissions in the road transport sector over the next decade. Conventional ICEs are expected to represent more than 90% of LDVs sold between 2010 and 2020, making efficiency gains in these vehicles critical to achieving 2DS targets. Fuel economy accounts for 0.6 $GtCO_2$ reduction in 2020 in the 2DS, or around 60% of total emissions reductions from the road transport sector. This represents a reduction in oil demand of approximately 2.4 million barrels per day in 2020, excluding savings from increased penetration of hybrid-electric engine systems, which are included among technologies to improve ICE efficiency (see section on electric and hybrid-electric vehicles).

The 2DS assumes average new passenger LDV fuel economy of 5.6 litres of gasoline equivalent (Lge) per 100 kilometres (km) in 2020, down from 8 Lge/100 km in 2005. This represents fuel economy improvement in 2020 of around one-third from 2005 levels, with an average annual percentage improvement of 2.7% between 2011 and 2020. The 2DS goals match the Global Fuel Economy Initiative[11] objective of halving new car fuel consumption between 2005 and 2030, to 4 Lge/100 km. The aim is to reduce the average fuel economy of all cars on the road by 50% in 2050, from the 2005 base figure of 10.2 Lge/100 km, as global vehicle stocks turn over. While passenger LDVs represent the majority of fuel use (60% of road transport sector fuel use in 2010), the 2DS also relies on annual fuel economy improvements of 1.5% in HDVs and 0.8% in two-wheelers.[12]

11 www.globalfueleconomy.org/Pages/Homepage.aspx.

12 Little information is available globally on the average fuel economy of HDVs and two-wheelers. This section therefore focuses on progress in LDV fuel economy improvement.

Technology penetration

Globally, the new vehicle fuel economy improvement rate has accelerated since 2008, but more effort is required if 2DS objectives are to be met. The global average fuel economy for LDVs was approximately 7.6 Lge/100 km in 2008, a 1.7% annual improvement rate on 2005 levels of 8 Lge/100 km. This rate of change, significantly less than needed to meet 2DS targets, accelerated slightly between 2008 and 2011 to 1.8% per annum, bringing average fuel consumption for new passenger LDVs globally to around 7.2 Lge/100 km (Table 3.4). The global improvement has been driven by OECD countries, where the average annual improvement rate was 2.7% between 2008 and 2011, up from 2.2% between 2005 and 2008. OECD countries were therefore at approximately 7 Lge/100 km on average in 2011, down from around 7.6 Lge/100 km in 2008 and 8.1 Lge/100 km in 2005. Non-OECD regions also saw improvement between 2008 and 2011, though at a lesser rate (0.6%). This trend seems to indicate, however, a positive turnaround from the rate of annual change between 2005 and 2008 (0.4% worsening in fuel economy). Current enacted and proposed standards need to be strengthened to bring fuel economy improvement rates into line with the 2DS (Figure 3.8), and accompanied by appropriate complementary policy (see below).

Table 3.4 Fuel economy status worldwide against the 2DS target

	Fuel economy (lge/100km)					Annual change		
	2005	2008	2010	2011	2030 target	2005-08	2008-11	Required 2011-30
OECD	8.1	7.6	7.0	7.0		-2.2%	-2.7%	
Non-OECD	7.5	7.6	7.5	7.5		0.4%	-0.6%	
World	8.0	7.6	7.2	7.2	4.0	-1.7%	-1.8%	-3.0%

Note: the 2030 number and required change refer to 2DS and Global Fuel Economy Initiative targets.

The variance in average new passenger LDV fuel economy between countries suggests considerable potential for additional improvement globally. There is greater than 55% variation between France, at one end of the fuel economy spectrum with 5.4 Lge/100 km, (127 gCO_2/km) and Australia, at the other end, with 8.6 Lge/100 km (204 gCO_2/km) (Figure 3.7). Between 2005 and 2011, countries' annual changes in average new vehicle fuel economy ranged from a 3.5% improvement to a 0.8% worsening. Factors that influence differences between countries and fluctuation in fuel economy include vehicle size, weight and power; cultural factors; income levels; technology; and, most significantly, fuel economy policy. The challenge now is to ensure all major economies are deploying appropriate policies to further improve average LDV fuel economy globally.

Average stock on-road fuel-economy has improved across different types of road vehicles in the last two decades (IEA, 2012i). Average fuel economy of the entire stock of LDVs was at 10.8 lge/100 km in 1990. By 2010, that figure reached an estimated 8.8 Lge/100 km (improvement of 20% over 20 years).[13] If average new passenger LDV fuel economy reaches 5.6 Lge/100 km by 2020, in line with the 2DS, stock average fuel economy could increase by around 25% as against 2005 levels in that year, reflecting vehicle stock turnover (to 8 Lge/100 km).[14]

Market creation

Many fuel-saving vehicle technologies are already commercially available and cost-effective, but face a number of market barriers, or are used to enable changes in vehicle characteristics other than improving fuel economy. Fuel prices provide significant incentives for fuel efficiency. When they are low, including due to low fuel taxation

13 There is limited data available regarding on-road fuel economy.
14 This assumes LDV use patterns do not substantially change out to 2020, and the ongoing increase in vehicle sales rates.

rates or outright subsidies, there is less incentive to pay more for a fuel-efficient vehicle. Oil price uncertainty also affects the ability of manufacturers and consumers to judge the importance of fuel economy in the longer term. Lack of information on fuel economy can make it difficult for consumers to choose more fuel-efficient vehicles. In addition, high discount rates in vehicle purchasing mean that purchasers may give low priority to fuel economy, even though fuel-efficient vehicles benefit consumers through reduced spending on fuel consumption. Competition with other vehicle attributes can also reduce incentives to improve vehicle fuel economy: uptake of fuel-saving technologies can be used to reconfigure vehicles to enhance performance, safety or increase vehicle size, for example, rather than improve overall fuel economy.

Fuel economy standards, fuel taxes, CO_2-based vehicle tax and labelling can correct market failures and accelerate the uptake of fuel economy technologies. Fuel economy standards require vehicle manufacturers to meet a minimum level of fuel efficiency per vehicle or across a particular class of vehicles. They encourage technology uptake, while ensuring that it is used to improve fuel economy rather than to enable increased vehicle size, weight or engine power. Other measures that encourage consumers to consider fuel economy when purchasing vehicles are sufficiently high fuel taxes, taxes aligned with vehicle fuel economy or CO_2 emissions at the point of vehicle purchase, and labelling that informs consumers about tested and expected fuel economy (Table 3.5). The IEA has developed guidance for policy makers on effective implementation of fuel economy policies (IEA, 2012j).

Table 3.5 Fuel economy barriers versus expected impact of policies

	Policy options to address market failure			
Barriers	Information and labelling	Fuel economy standards	Fuel taxes	CO_2-based vehicle taxes/feebates
Low and volatile fuel prices; price risk aversion	Provides key information to consumers; more helpful when annual fuel spending are also displayed.	Delivers improved fuel economy regardless of market prices or buyer risk aversion.	Helpful since it raises the fuel cost of driving; can include a price floor mechanism.	Can send strong market signals to buyers; but does not address variable (per km) cost of travel.
High discount rates	Same as above.	Overcomes the market failure by improving the vehicle supply (OEMs) side; requirements across whole fleet can guarantee an outcome.	Can help, but if discount rates are very high, a high tax might be needed to compensate.	Largely overcomes the discount rate issue by reducing cost differential up-front.
Lack of information	Directly addresses this problem but may not fully overcome counter perceptions that fuel economy is unimportant.	Helps improve fuel economy even when consumers are less informed, but should be easier to implement with informed consumers.	Does not address information problem; may be more readily accepted and have bigger impact when more information is available.	Must be linked to labelling system so consumers know and understand the basis for the relative taxes.

Despite progress in some regions, the fuel economy readiness index shows that policies have significant potential globally to improve fuel economy (Figure 3.9). Progress is being made in most OECD regions, including the major European Union and United States markets, as well as in China. All parts of the world could accelerate policy efforts to improve fuel economy, however. Most OECD countries score five or above in the fuel economy readiness index (out of a possible score of eight), having adopted more stringent fuel economy measures in recent years; these can be used as guides for other countries seeking to improve fuel economy. Other parts of world, including most major emerging economies, still lack fuel economy standards, fiscal measures and even fuel economy labelling programmes. A handful of countries do not score in the fuel economy readiness index at all, principally oil-producing countries that heavily subsidise gasoline prices. Even countries with strong policies could tighten them and raise targets to maintain progress in improving fuel economy, and expand coverage to include all road-vehicle types, including heavy-duty vehicles (HDVs).

HDVs are currently a neglected area of fuel economy policy. After LDVs, HDVs account for the most energy use in transport (21% in 2010, at 21 EJ). Only the United States and Japan have implemented standards for HDVs, although they are also under development in Canada, China and the European Union. Lack of HDV standards is a key contributor to the significant potential attributed to fuel economy improvements in the 2DS. Development of HDV standards can be complex, given the wide range of truck types, and that fuel consumption depends on many factors apart from sheer truck weight class, including transported payload and mission profiles (IEA, 2012i).

Technology developments

Engine losses make up 67% to 72% of energy loss in an average LDV (Figure 3.10). While the efficiency of both gasoline and diesel engines has increased in the past decade, the IEA estimated in 2009 that further improvement of around 25% as against 2005 average performance could be achieved with technologies already commercially available. By the end of 2012, some of this improvement had already occurred, but around 35%-50% of the potential for improvement still remains, depending on the country. Engine downsizing and weight reduction represent around 30% of that potential collectively (IEA, 2012i). Vehicle downsizing has enabled considerable efficiency improvements, particularly in OECD regions and since 2005 (Figure 3.11). Reduced friction losses and the use of advanced combustion systems and diesel engines have also improved fuel economy in OECD countries. In non-OECD regions, progress through technology improvement has been hampered by a shift towards bigger vehicles, leading to little fuel economy progress on average (IEA, 2013).

Even though most key fuel economy technologies are available today, some LDV technologies need additional breakthroughs and cost reductions to become commercially viable, including waste heat recovery devices. Thermal losses make up most engine energy loss in average LDVs (Figure 3.10). Although widely used in the power generation industry, the Rankine cycle, which converts heat to power, is still at prototype stage in the automotive industry (GCC, 2011), with first applications for the HDV industry. Lightweight designs using materials such as high-strength steel, aluminium and fibre-reinforced polymers will be crucial to improving fuel economy significantly by the end of the decade.

Recommendations for governments

- *OECD countries should implement fuel economy standards as part of comprehensive fuel-economy policy packages in the near term (i.e. by 2015), where they have not already done so. For non-OECD regions, introducing labelling measures in major markets is a key near-term priority, and full LDV policy packages should be in place by 2015 to 2020.*
- *Stronger economic incentives for consumers are critical in both OECD and non-OECD for the uptake of more efficient vehicles. Available policies include vehicle-specific measures such as CO_2-based vehicle taxes or fee/rebate systems (feebates), or fuel-based instruments such as fuel taxes.*
- *Countries that already have strong policies should maintain progress by tightening targets, extend them out to 2030 to provide policy certainty, and ensure all types of road vehicles are covered, particularly HDVs.*
- *The fuel economy readiness index provides energy ministers with an effective tool to gauge progress in fuel economy policy implementation, and likely fuel economy improvement in the near term. To accelerate fuel economy improvement prior to CEM5, ministers should assess policy gaps as highlighted by the index, and start policy planning and development where improvement is required.*

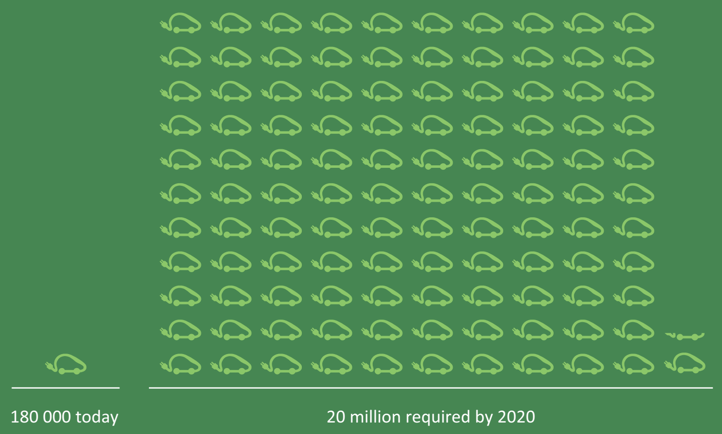
Electric and Hybrid Electric Vehicles

On track

Sales of electric vehicles (EVs) more than doubled from 2011 to 2012. To reach the 2DS goal of 20 million EVs by 2020, sales must increase by 80% per year. This will require longer-term policies, more infrastructure and lower battery development costs. Sales of non-plug-in hybrid-electric vehicles (HEVs) also grew strongly in 2011 and 2012. To build on this momentum, governments must continue and expand policies such as vehicle price incentives.

Technology penetration

3.12 Electric vehicles stock



REQUIRED ANNUAL SALES GROWTH RATE TO 2020

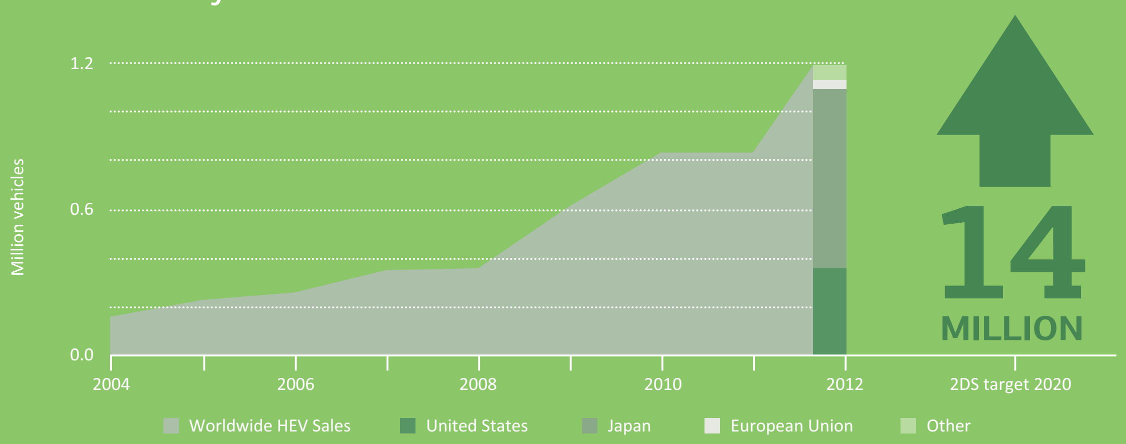
80%

FOR EVs

130%

SALES GROWTH IN 2012

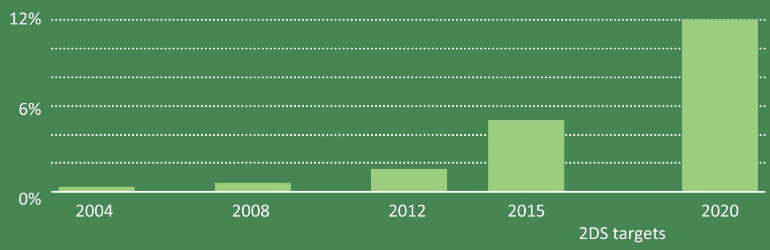
3.13 Global hybrid-electric vehicles sales



30%

AVERAGE GROWTH RATE IN ANNUAL HEV SALES 2005-2012

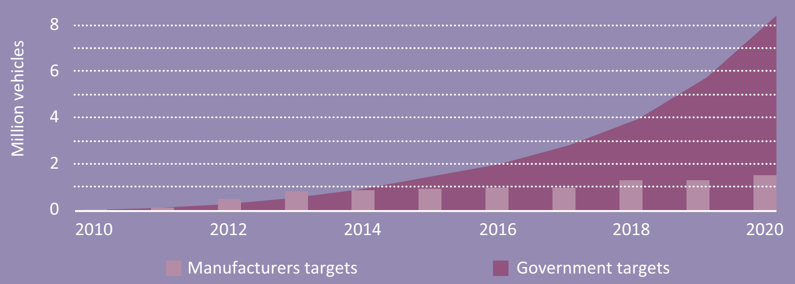
3.14 Hybrid electric vehicles market share



Market creation

3.15 Government and manufacturer EV targets

More online



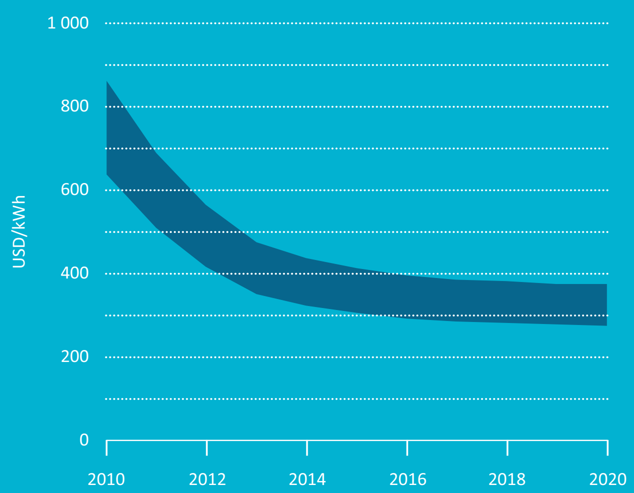
Key points

Government 2020 sales targets match 2DS deployment objectives, at 7-9 million

Longer-term policies are required to ensure production matches government targets out to 2020

Technology developments

3.16 Estimated battery cost reductions



300

USD/kWh ESTIMATED TARGET PRICE FOR EVS TO BE COST COMPETITIVE WITH INTERNAL COMBUS-TION ENGINE VEHICLES

Recent trends

Battery costs are on track to meet competitive levels by or before 2020

50% cost reduction in the past 3 years

For sources and notes see page 143

Recent developments

- Around 100 000 plug-in hybrid-electric vehicles (PHEVs) and full-battery electric vehicles (BEVs)[15] were sold globally in 2012, more than double the number sold in 2011, the first year of widespread market introduction. This rate of sales growth puts EV deployment on track to meet 2DS targets.
- Non-plug-in hybrid-electric vehicles (HEVs) enjoyed a banner year, breaking the 1 million mark in annual sales (1.2 million sales, up 43% from 2011 sales of 830 000). Japan and the United States continue to lead the market, accounting for 62% and 29% of global sales in 2012 (740 000 and 355 000 vehicles sold). Hybrids accounted for 15% of Toyota's global sales and 40% of its sales in Japan. The Prius is now the third best-selling brand worldwide.
- Cumulative government targets for EV sales increased in 2012, with India announcing a target of six million EVs on the road by 2020, together with HEVs. The target is to be backed by government funding of USD 3.6 billion to USD 4.2 billion, representing over half of total required investment.
- Ongoing cost reductions in battery development were dramatic in 2012, with costs down to around USD 500-600/kWh by the end of the year. The US Department of Energy estimates that battery development costs are now at USD 485/kWh of useable energy (not including profit or warranty costs), which will take three to four years to translate into market prices, but indicates what is to come.[16]
- In 2012 there was a breakthrough in charging technology for EVs – a vital measure to boost consumer confidence and lessen anxiety over vehicle range – with the development of a three-phase, on-board, fast EV charger by Volvo Car Corporation. With a charge time of 1.5 hours, the charger operates six times as fast as current on-board devices. It will be on the market in 2013. In a further milestone for public confidence, the Tesla Model S was named 2013 Car of the Year by the American magazine Motor Trend, the first time a non-gasoline powered vehicle has received the award. The Chevy Volt/Ampera also succeeded the BEV Nissan LEAF as the European Car of the Year.

Overall progress assessment

The role of EVs and HEVs in the 2DS

The 2DS assumes strong market penetration of vehicles with zero tailpipe emissions, including PHEVs and BEVs, as a fundamental part of efforts to cut oil use and CO_2 emissions on a per kilometre basis. While fuel economy is the key technology pathway to decarbonising the transport sector by 2020, the 2DS also envisages 20 million EVs on the road by 2020, with yearly sales reaching seven million vehicles. This represents a rapid market introduction for EVs, at 10% of total light-duty vehicle sales by 2020. This progress to 2020 is essential to set EV deployment on course for a more substantial role in the post-2025 period: the 2DS assumes stronger displacement of conventional internal combustion engine (ICE) vehicles from the mid-2020s, with the EV share increasing sharply to half of new vehicles sales by 2050, together with fuel-cell vehicles.

HEVs, as a technology for fuel economy improvement, play an important transitional role in the 2DS. The scenario sees annual HEV sales at 10 million by 2020, or 12% of global market share; this peaks at 40 million in 2040 (30% of market share), as EV and fuel-cell vehicle deployment increases.

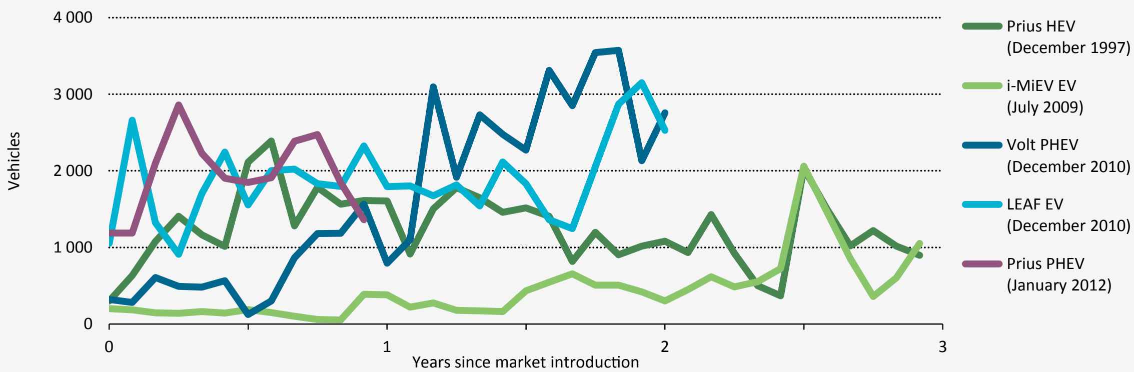
15 Together, electric vehicles (EVs) for the purposes of this section.
16 Correspondence with US Department of Energy.

Technology penetration

To hit the 2DS target for 2020, EV sales have to grow by around 80% each year. (Figure 3.12) Major producers sold around 45 000 EVs in 2011. There were around 100 000 EVs sold in 2012, putting vehicle electrification on track to meet 2DS objectives based on 2011 and 2012 figures, the first two data points enabling progress tracking in EV market penetration. The rate of sales was below that anticipated by automakers and analysts, but remains significant, given both the importance of early sales in establishing the future course of the nascent EV market, and ongoing economic turmoil in global markets. EVs represented 0.13% of total vehicle sales in 2012.

Based on sales growth since date of market introduction, the best-selling PHEVs and BEVs are performing on average better than the Toyota Prius – the first HEV introduced to market and current market lead – was at a corresponding point in time (Figure 3.17). In terms of outlook for ongoing progress in electrification of the vehicle fleet, this indicates that EVs have made a good start in scaling the market development curve; policy support will be essential to maintain this momentum.

Figure 3.17 HEV and EV sales following market introduction



Sources: EVI, MarkLines Database, Nissan, Toyota, hybridcars.com.

Key point *Plug-in hybrids and battery electric vehicles are performing better than the hybrid Toyota Prius did at the corresponding point in time after market introduction.*

HEV market penetration must grow steadily and globally. Growth in the global market share for HEVs has been slow and incremental (Figure 3.13). The 1.2 million sales in 2012 puts HEVs' market share at 1.5%, up from 0.3% in 2004 (Figure 3.14). Market share almost tripled from 2008 to 2012, reflecting an increase in annual sales levels of 230%, from 360 000 to 1.2 million. This momentum must continue in order to reach the 12% market share envisaged by the 2DS in 2020. To reach 10 million sales by 2020, HEV sales growth must increase to 50% per year for the next seven years, from an average growth rate of 30% between 2005 and 2012.

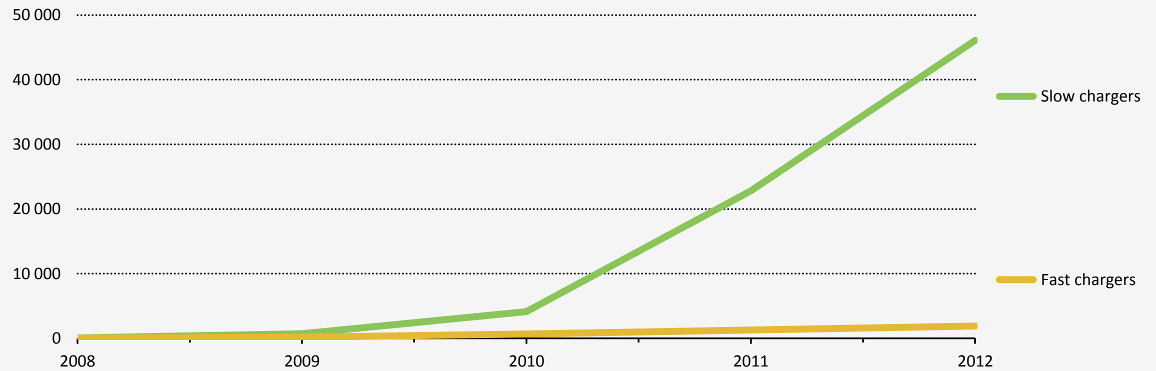
Market creation

Many countries have set ambitious targets for EV deployment by 2015-20; cumulatively, these targets now match or exceed 2DS deployment objectives (Figure 3.15). Government sales targets for 2020 total 7 million to 9 million, compared with the 2DS goal of 7 million. These targets, while not determinative of or a prerequisite for successful EV market deployment, are an indication of government ambition levels.

Based on reported manufacturer production targets, however, it is unclear whether EV vehicle production will continue at levels required to meet government targets after 2014 (Figure 3.15). To raise production rates in the near to medium term, manufacturers require clear and stable incentive frameworks with a timeframe long enough to ensure adequate return on investment. Governments participating in the CEM Electric Vehicles Initiative (EVI)[17] spent a total of USD 3.8 billion between 2008 and 2012 on policy measures such as rebates or tax credits on vehicles, purchase subsidies, or exemptions from vehicle registration taxes or license fees.[18] But current policy measures and programmes generally have timeframes of only one or two years, which is not long enough to give industry confidence that market demand will continue to grow.[19] The public and private sector need to work together to manage expectations of EV supply and demand.

Globally, slow- and fast-charging infrastructure installation has rapidly increased since 2010 (Figure 3.18). By the end of 2012, just below 50 000 chargers had been installed globally. Slow chargers, which complete charging in 6-8 hours, are predominantly being deployed in the United States, where a focus on home-based recharging is developing. Fast chargers, which are considerably more expensive than slow chargers but complete a charge in 0.5-2 hours, are principally being deployed in Japan, where there are fewer single-family dwellings. This development is essential to facilitate market introduction of EVs. EVI governments are aiming to install 2.4 million slow chargers by 2020 and 5 700 fast chargers. Between 2008 and 2012, EVI government spending on EV infrastructure totalled approximately USD 0.8 billion.

Figure 3.18 EV recharging infrastructure development in EVI countries



Key point *The number of charging stations have increased fivefold since 2010.*

17 CEM EVI participating governments, including China, Denmark, Finland, France, Germany, India, Italy, Japan, the Netherlands, Portugal, South Africa, Spain, Sweden, the United Kingdom and the United States: www.cleanenergyministerial.org/our_work/electric_vehicles.

18 Excluding infrastructure spending.

19 Further detail on the current status of government policy support for EVs, including non-fiscal measures, is included in the CEM Electric Vehicles Initiative report to CEM 4, IEA (2013), *Global EV Outlook*, OECD/IEA, Paris and the *EVI EV City Casebook: A Look At The Global Electric Vehicle Movement*, published May 2012.

Favourable policy environments have driven strong HEV deployment in Japan and the United States. HEV passenger light-duty vehicle sales-share was at 19% in Japan and 4% in the United States in 2012, up from 11% and 3% in 2010. HEV deployment in the United States has been in part driven by government procurement of HEVs. In Japan, two sets of financial incentives, which expired in September 2010 and 2012, helped increase sales of fuel efficient cars, including HEVs. Where such policies do not exist, the penetration of hybrids is growing slowly; indeed, few HEVs have been sold outside Japan and the United States. Fiscal levers such as subsidies or more stringent fuel economy policy appear to be essential to promote the continuous penetration of hybrids. Other measures such as reduced price or free parking, and specific targets for public and private vehicle fleets, can also promote the purchase and use of HEVs.

Technology developments

Battery cost is critical for EVs. If current rates of progress continue, battery costs are on track to reach competitive levels by or before 2020 (Figure 3.16). Traditionally, batteries have been the single most costly component of EVs and the biggest obstacle to EVs reaching cost parity – and hence market competitiveness – with ICE vehicles. Battery costs stood at about USD 800-1 000/kWh in 2010. Costs dropped significantly in 2011, to USD 750/kWh; this progress has continued with the reduction of battery prices to around USD 500-600/kWh in 2012. This cost reduction – more than 50% in around three years – is substantial.

Battery costs must be further reduced to an estimated USD 300/kWh to reach cost parity with ICEs (IEA, 2011c). Reductions to below USD 300/kWh would assist immensely in bringing total cost of ownership for EVs to an attractive level for consumers, and hence in boosting EV market penetration. This last part of the cost curve is likely to be the hardest to scale.

Box 3.3 The growing importance of understanding urban mobility

More than half of the world's people now live in cities. By 2050, about 75% of the population will live in urban areas (UN DESA, 2011). This has widespread implications for transport, especially in rapidly growing cities, where rising vehicle ownership has led to considerable shifts away from non-motorised transport and public transport.

Between 2000 and 2010, total global passenger and freight travel increased by an average of 4% per year. As a result, global transport energy use increased 30% in the last decade, while annual global transport emissions grew by nearly 2 billion tonnes of CO_2 equivalent.

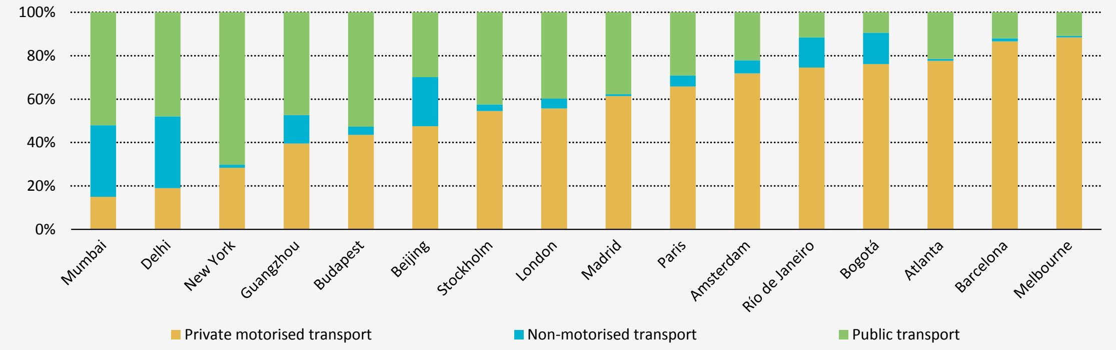
Private motorised transport in cities such as Beijing and Shanghai increased by 20% or more over the past 20 years (Darido et al., 2010). Such shifts to motorised transport, paired with overall growth in travel demand, have had considerable impact on how efficiently people and goods are moved. Many cities worldwide are already experiencing severe and increasing congestion, along with deteriorating local air quality and increasing noise pollution.

To combat these trends and to reach 2DS objectives, understanding of urban mobility needs to improve. Although urban transport plays an increasingly important role in transport and energy discussions, data on urban mobility and transport energy use remain limited. Dedicated policy support for analysis of urban mobility is required, including funding for studies of travel behaviour and choices.

Mobility surveys can be expensive and time-consuming, however, and their design and scope can limit their value in helping to understand the impact of travel choices on energy use and emissions. Surveys often define a trip according to the principal means of transport taken from the starting point to a final destination, without considering other means used to get to and from the principal travel mode. Mobility surveys also often express the share of trips performed by travellers using a given transport mode. However, 25% of trips by bicycle or walking does not equate to 25% of total distance travelled or 25% of energy consumed. To give a better idea of urban mobility, surveys need to be based on energy use and emissions, origin, destination and distances covered.

In 2005, the IEA in partnership with the International Association of Public Transport (UITP) collected data that reveal considerable global variance in urban mobility, especially with regard to non-motorised transport (Figure 3.19). More recent data is limited, however. It is vital that reliable data be collected more often, especially in developing cities, to improve understanding of an increasingly motorised world and help decision-makers encourage greater use of public and non-motorised transport.

Figure 3.19 Urban modal shares for select cities in 2005-06



Recommendations for governments

- *Further policy support for EVs, including measures designed to enhance cost-competitiveness with conventional ICEs, is required to boost manufacturer and consumer confidence and achieve government targets and 2DS goals. Governments should maintain and build on existing financial incentives, ensuring stable frameworks are in place with timeframes at least to 2020.*
- *Successful longer-term strategies are likely to include standards for charging stations, integration of EVs in city mobility programmes (e.g. car sharing schemes) and underscoring the broader value proposition of EVs, including lessened local air pollution. Governments will need to work closely with city leaders, EV supply equipment providers, automakers and other stakeholders. Consumer information and non-financial incentives, such as priority access to parking and restricted highway lanes, and accelerated licensing and installation of electric vehicle supply equipment, are likely to be important complementary policies.*
- *Installation of recharging infrastructure should continue and be carefully coordinated by government to ensure full local access and mobility.*
- *RD&D support for battery cost reductions should continue.*
- *The Global EV Outlook provided by the EVI to CEM4 provides a tool for energy ministers to assess national progress in EV deployment. Ministers should aim to assess national status before CEM5, and initiate policy action to address gaps as appropriate.*
- *To broaden the global market for HEVs, more countries should follow Japan and the United States in providing targeted incentives for deployment.*
- *Public and private fleet acquisitions will be important to bringing down market costs of EVs and HEVs, through economies of scale.*

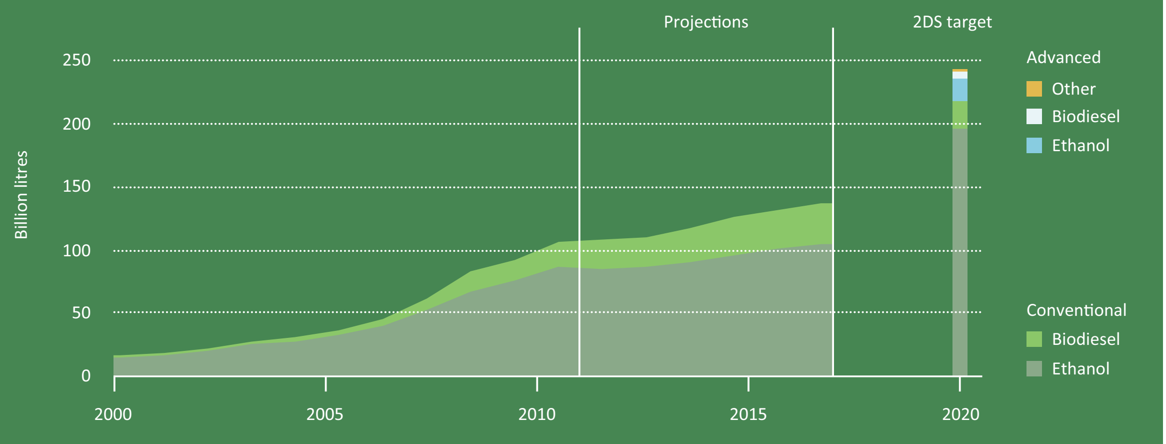
Biofuels

Not on track

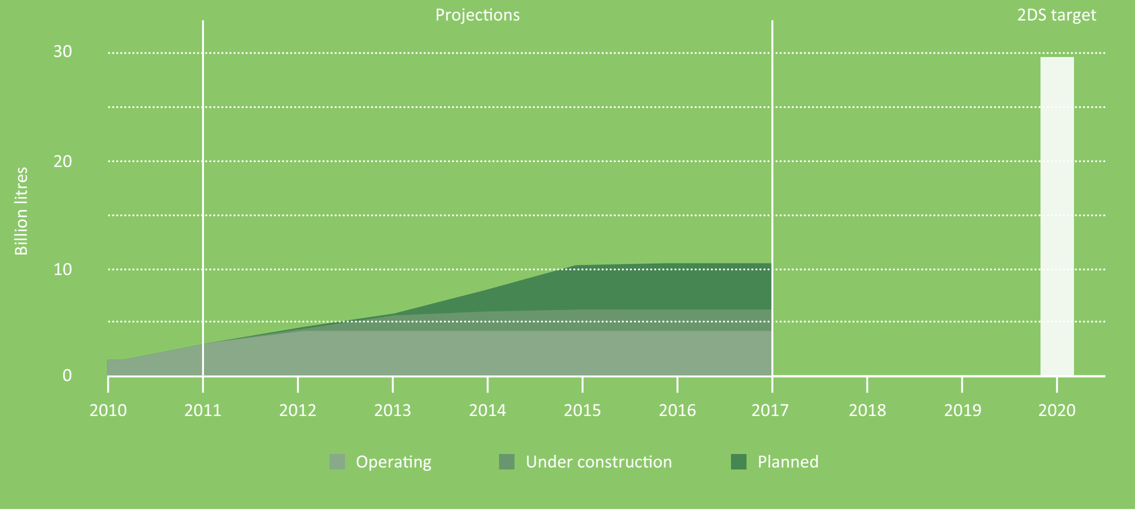
Growth in biofuels production stalled in 2012 because of high feedstock prices. Advanced biofuels capacity increased by around one-third from 2011 levels, however. To reach 2DS targets, biofuels production must more than double by 2020. This will require dedicated policy support for advanced biofuels and additional government funding for research and production.

Technology penetration

3.20 Global biofuels production



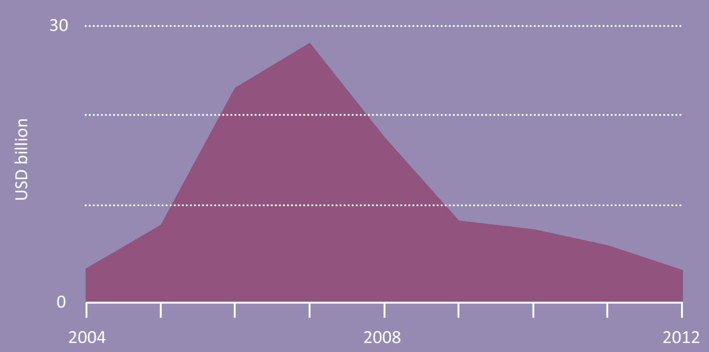
3.21 Global advanced biofuel capacity



Market creation

3.22 Blending mandates and targets in key countries

3.23 Production capacity investment



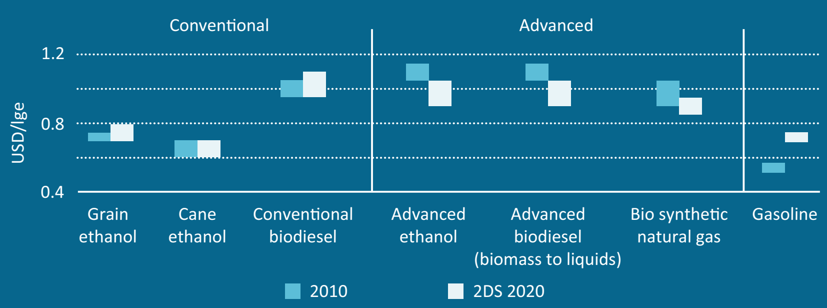
Recent developments

The United States is the only country with a specific quota for cellulosic biofuels, 53 million litres in 2013.

The EU Renewable Energy Directive promotes ligno-cellulosic biofuels, as well as biofuels from algae, wastes and residues, by counting their contribution twice towards the 2020 target in transport.

Technology developments

3.24 Biofuel production costs



1.7

USD BILLION SPENT ON BIOFUELS R&D IN 2012, 1/3 FROM PRIVATE INVESTORS

For sources and notes see page 143

Recent developments

- Global biofuels production – including bioethanol and biodiesel – remained static year-on-year in 2012 in absolute volumes at roughly 110 billion litres, despite strong growth of 7% in biodiesel output in the United States (to 4 billion litres) and Latin America (to 7 billion litres). The slowdown in production growth reflects higher feedstock prices and lower production volumes in key producing regions, principally due to extreme weather conditions.
- Ethanol output declined in the United States, for example – the world's largest biofuels producer[20] – as a severe drought compromised 2012 corn harvest prospects (output down 5% from 2011 levels, at an estimated 50 billion litres). Corn futures rose steeply to around USD 8 per bushel[21] in August 2012, up from around USD 6 in June, leading to a number of temporary plant closures by the end of 2012, as producer margins for ethanol slipped into the negative (IEA, 2012k). The developments in the United States and other regions in 2012 highlight the vulnerability of conventional biofuels production to high feedstock prices, since feedstock costs account for 50% to 80% of total production costs.
- The advanced biofuels[22] sector saw solid capacity additions in 2012, however, with global capacity at 4.5 billion litres by end-2012 (up around one-third from 2011 levels). More than 100 plants are now operating, including first commercial-scale projects. Yet some large-scale projects were cancelled or shelved in 2012;[23] in part, this reflects a lack of adequate policy mechanisms for advanced biofuel deployment in most regions.
- In 2012, new investments in the biofuels sector globally dropped 50% from 2011 levels, to USD 2.8 billion (BNEF, 2013), principally because of overcapacity in some markets (*e.g.* the European biodiesel sector), the review of biofuels support policies in some regions (*e.g.* the European Union) and higher feedstock prices.

Overall progress assessment

The role of biofuels in the 2DS

In the 2DS, a portfolio of low-carbon alternative fuels (electricity, hydrogen and biofuels) meets over 6% of global transport fuel demand in 2020. Almost 80% of this demand is satisfied by 240 billion litres of biofuels, or 5.5 EJ, which would deliver approximately 100 $MtCO_2$ emissions reductions, provided that feedstocks and fuels are produced sustainably.

Technology penetration

World biofuel production has increased sevenfold since 2000, but still meets only 2.3% of final liquid fuel demand. Production of biofuels globally grew from 16 billion litres in 2000, to an estimated 110 billion litres in 2012 (Figure 3.20). Biofuels accounted for around 2.3% of total transport fuel demand in 2011; Brazil, the United States and the European Union have considerably higher shares, at 20.1%, 4.4%, and 4.2% respectively in 2010.

20 The United States accounted for 60% and 15% of global ethanol and biodiesel output respectively in 2011.
21 This is equal to USD 315 per tonne.
22 Conversion technologies that are still in the R&D, pilot or demonstration phases.
23 For instance, the BP Biofuels 135 Ml/yr cellulosic-ethanol project in Florida, United States and the NSE Biofuels 115 Ml/yr BtL project in Finland.

Production must more than double from today's levels to meet 2DS goals. Global biofuel production is set to increase by 25% by 2017, to around 140 billion litres (IEA, 2012k). Despite this growth, a considerable gap of 100 billion litres remains between projected 2017 production volumes and volumes required in the 2DS.

Advanced biofuel production capacity[24] continues to expand, reaching 4.5 billion litres in 2012, up 1.3 billion litres from 2011, and 2.9 billion litres from 2010 (Figure 3.21). This progress, while significant, must be accelerated. Commercial deployment of advanced biofuel conversion technologies will be required to reach 2DS objectives, while improving conversion efficiency, cost and sustainability of conventional biofuels. The 2DS assumes just under 30 billion litres of advanced biofuel capacity in 2020. The advanced biofuel sector is projected to see solid capacity additions out to 2017, with installed production capacity forecast at 10 billion litres in 2017 (IEA, 2012k). This is only one-third of the capacity required to meet the 2DS, however, so significantly more investment in commercial production units is required.

Market creation

Over 50 countries have implemented biofuel blending mandates and targets (Figure 3.22). This includes important producing countries in Latin America, South East Asia and Africa. This policy support, often accompanied by financial support measures such as tax incentives, has driven the steady pace of growth in world biofuel production over the last decade.

By contrast, few countries have put in place targeted policy support in favour of advanced biofuels. The European Union and the United States are among the few regions to have provided financial support for advanced biofuel production facilities. This has helped to promote demonstration and some commercial facilities, but further investments into commercial-scale plants are required to lower costs, raise efficiency and establish a viable advanced biofuel market.

Blending mandates and targets do not in themselves promote deployment of technologies that perform best in terms of land use, greenhouse gas (GHG) reductions, and social and economic impacts. Government policy measures must be geared to promote sustainable performance, for example through mandated minimum GHG savings or financial support linked to life-cycle CO_2 emission reductions. At a national and regional level, such policies are currently limited. The EU Renewable Energy Directive imposes minimum sustainability criteria that must be met for biofuels to contribute to binding national targets for renewable energy deployment (currently 35% GHG emissions saving compared with fossil fuels). These sustainability criteria do not currently include emissions from indirect land-use change, but discussions are under way to include such emissions. Similarly, the US Renewable Fuel Standard 2 imposes GHG reduction standards for biofuels other than corn ethanol[25] (50%) and cellulosic-ethanol in particular (60%); these include emissions from indirect land-use change. Efforts are under

24 Conventional biofuels (commonly referred to as first generation biofuels) include sugar- and starch-based ethanol, oil-crop based biodiesel and straight vegetable oil, as well as biogas derived through anaerobic digestion. Typical feedstocks used in these processes include sugarcane and sugar beet, starch-bearing grains like corn and wheat, oil crops like rape (canola), soybean and oil palm, and in some cases animal fats and used cooking oils. Advanced biofuels (commonly referred to as second generation) are conversion technologies that are still in the R&D, pilot or demonstration phase. This category includes hydrotreated vegetable oil, which is based on animal fat and plant oil, as well as biofuels based on lignocellulosic biomass, such as cellulosic-ethanol, biomass-to-liquids-diesel and bio-synthetic gas. The category also includes novel technologies that are mainly in the R&D and pilot stage, such as algae-based biofuels and the conversion of sugar into diesel-type biofuels using biological or chemical catalysts. Capacity rather than production figures are given for advanced biofuels because it is difficult to estimate the actual output of plants during initial production years, as utilisation rates are generally well below nameplate capacity.

25 In the RFS2, "advanced biofuels" refers to all biofuels other than corn ethanol that provide at least 50% GHG emissions reduction compared to the reference fossil fuels. The advanced biofuels quota includes a specific quota for cellulosic-ethanol.

way to co-ordinate sustainability initiatives at the global level, including the Roundtable on Sustainable Biofuels – a voluntary international initiative – and through the International Organization for Standardization (ISO). International alignment among sustainability certification schemes is essential to avoid market disturbance.

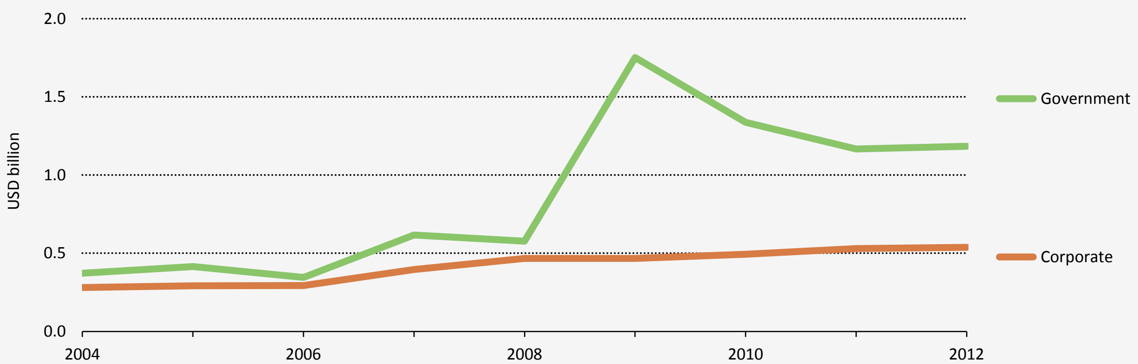
Following a peak in production capacity investment in 2007 (USD 28 billion), investment has declined sharply in the last five years, to USD 2.8 billion in 2012 (-90%) (Figure 3.23). Between 2004 and 2007, investments in the biofuel sector increased rapidly, fuelled by the growing number of blending mandates around the world and attractive economics. In 2007-2008, agricultural commodity prices rose sharply and led to a global discussion on the impact of biofuels on food prices. This discussion, in combination with reduced profit margins given high commodity costs, led to the sharp drop in capacity investments since that time. If investment spending remains low, it will be particularly challenging to provide the advanced biofuel volumes required to meet 2020 2DS targets.

Technology developments

While certain biofuels perform well economically, such as sugarcane ethanol, conventional biofuels are generally not competitive with fossil fuels at current market prices (Figure 3.24). The economics of conversion processes need to be further improved, for example through enhanced process efficiency and feedstock flexibility, to enable biofuels to compete better in the longer term. Ensuring that the true cost of fossil fuels is reflected in consumer prices is also necessary to spur further progress in biofuels.

R&D investments in biofuels stood at around USD 1.7 billion in 2012, with more than two-thirds of this stemming from government budgets (Figure 3.25). Governments spent over USD 1.1 billion in 2012, while private spending was around USD 500 million. While the total investments were similar to those in 2011 (USD 1.7 billion), government investments were USD 600 million less than 2009 spending levels (down 44%) (BNEF, 2013), as R&D funds from economic stimulus packages began to run out. Total investments in R&D in 2012 were nonetheless above the average of the last nine years (USD 1.2 billion). Sustained investments will be needed to support R&D on advanced biofuel technologies and on other parts of the supply chain, such as energy crop development.

Figure 3.25 Public and private RD&D investment in biofuels



Source: BNEF.

Key point *RD&D investments in biofuels have remained stable in recent years. Governments are contributing about two-thirds of the total budget.*

Recommendations for governments

- *To ensure large-scale market deployment of advanced biofuels, governments should reduce the risks for early investors through additional support mechanisms such as loan guarantees, guaranteed premiums for advanced biofuels, or direct financial support for first-of-a-kind investments. Such policy support will be needed at least until 2020, but a longer-term policy framework for advanced biofuels is crucial to ensure investor confidence and enable sustained expansion of production.*
- *Further RD&D is required to improve the cost and efficiency of conventional and advanced biofuels, and develop new sustainable feedstock sources. Governments should increase and sustain funding to this end.*
- *Governments should introduce a strong sustainability framework for biofuels, based on internationally agreed indicators, to ensure high GHG savings and avoid negative impacts on food security and biodiversity, drawing on experience with biofuels certification in the European Union and elsewhere.*

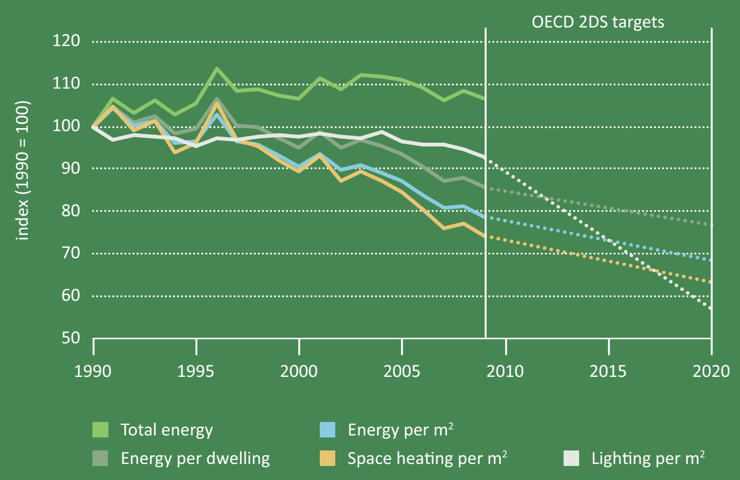
Buildings

Not on track

Existing technologies offer significant potential to achieve deep CO_2 emissions reduction in the buildings sector. To reach that potential, governments need to enforce stringent, performance-based building energy codes; promote energy renovation of existing buildings; and set minimum energy performance standards based on best-available technologies for building elements, appliances and equipment.

Technology penetration

3.26 Residential energy use in select IEA countries



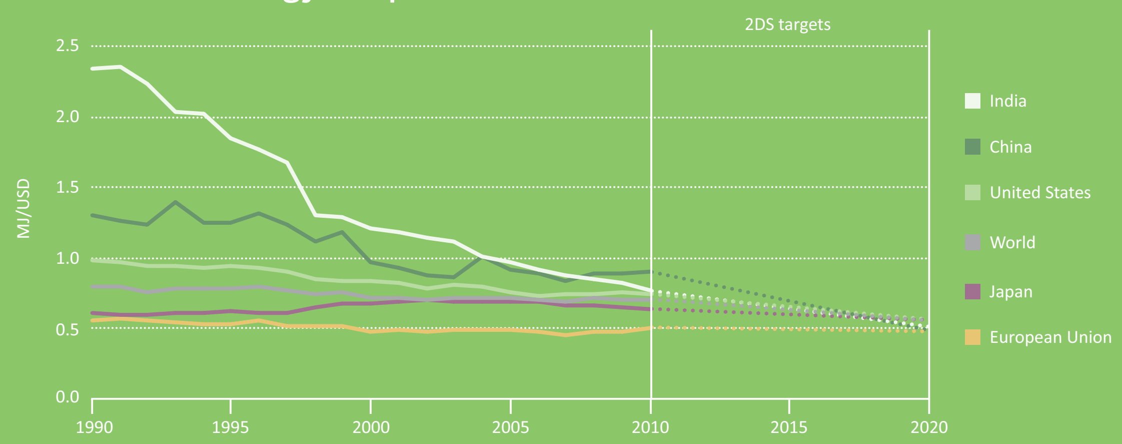
Building energy use

Residential consumption has been relatively static since 1990, despite energy efficiency improvements

Population growth, falling occupancy rates and greater ownership of personal appliances are key drivers

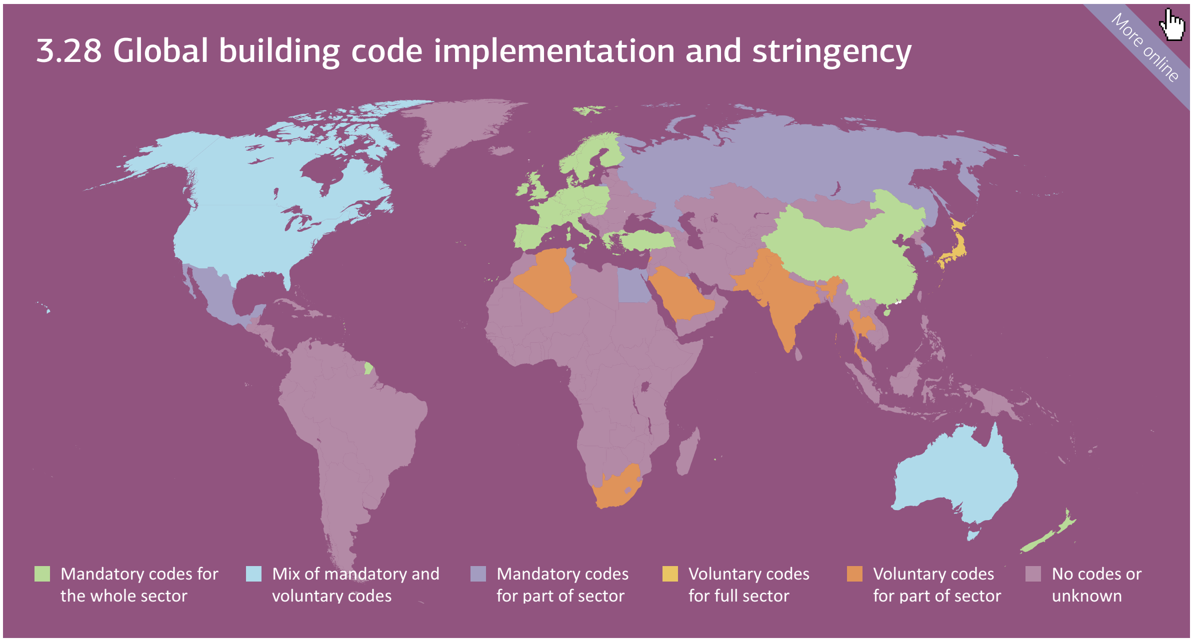
Energy consumption per unit value added in services has improved significantly, but growth means projected 2020 consumption is 9% greater than 2010 figures

3.27 Services energy use per value added



Market creation

3.28 Global building code implementation and stringency



3 COUNTRIES GLOBALLY WITH PERFORMANCE-BASED BUILDING ENERGY CODES, THE MOST ADVANCED CODES

Technology developments

3.29 Building shell efficiency improvement potential in 2020

For sources and notes see page 143

Recent developments

- In 2012 governments implemented several important policy measures to promote energy-efficient buildings, including the EU Energy Efficiency Directive (EED), adopted on 25 October 2012.[26] The EED obliges EU member states to develop a long-term strategy for mobilising investment to support renovation of existing building stock. It also introduces a mandatory renovation rate for buildings owned and occupied by central government (3% of the total floor area of heated and cooled buildings annually) and requires member states to ensure that individual consumption meters are installed for new buildings and apartments by 31 December 2016. While the restriction of the mandatory renovation rate to government buildings will reduce the impact of the EED, especially in federal countries, the directive is an important step forward. Most of the efficiency improvement potential, in OECD countries in particular, lies in retrofitting existing buildings. Metering of building energy consumption will enhance understanding of the sector's energy use and efficiency potential and create a market value for efficient buildings. It will also help raise consumers' awareness of the energy consumption of their buildings.
- The United Kingdom's Green Deal, launched on 1 October 2012, is aimed at increasing retrofit of the existing building stock. The Green Deal is the first market framework to address some of the major barriers to investment in a comprehensive way, including the incremental up-front costs of enhanced efficiency, and split incentives between owners and occupiers.
- The European Commission adopted a delegated regulation to supplement the European Energy Performance in Buildings directive (EPBD)[27] on 16 January 2012.[28] The regulation establishes a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements. It is innovative in that it introduces the concept of a societal cost-optimum level (*i.e.* one that takes into account impacts beyond pure cost, such as those from greenhouse gases) for a selection of energy measures.
- Japan's Innovative Strategy for Energy and Environment, published in September 2012, will make building energy codes (BECs), including minimum energy performance requirements, mandatory for all building types by 2020. This is an important step for Japan, which has previously had only voluntary agreements and guidelines.
- Governments also implemented several measures to enhance energy efficiency in building appliances and equipment in 2012. For example, the Indian Bureau of Energy Efficiency increased the stringency of energy performance standards for air conditioners by 8%, following introduction of a mandatory labelling programme in 2010.
- Forty-six countries agreed to phase out incandescent lamps by 2016 under the "en-lighten"[29] initiative, which aims to accelerate a global market transformation to environmentally sustainable lighting technologies. Australia introduced a first-of a-kind phase-in policy for best available lighting products.

26 Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC.

27 Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.

28 Commission delegation regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements.

29 The en-lighten initiative was established in 2009 as a partnership between UNEP, GEF, OSRAN AG, Philips Lighting and the National Test Centre in China. See www.enlighten-initiative.org.

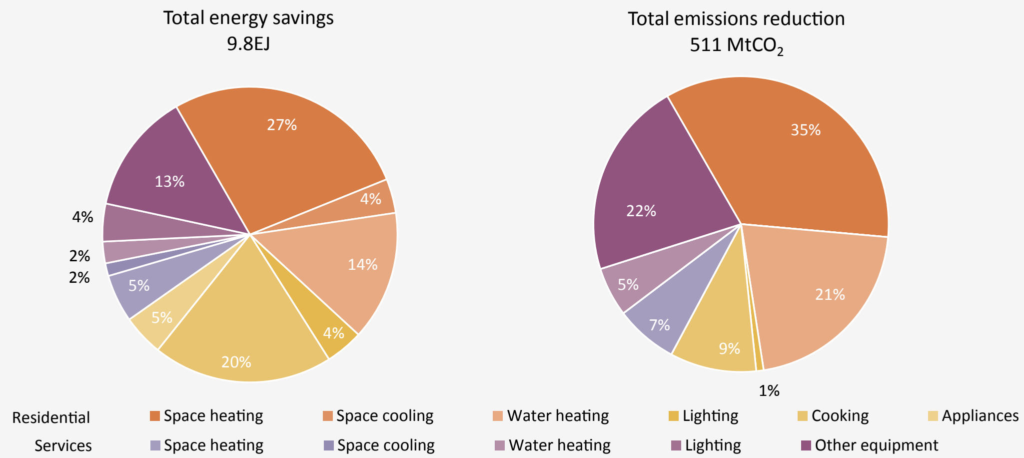
- Data on deployment of energy-efficient technologies in the buildings sector is currently limited. To facilitate sharing of information on building energy codes, labelling schemes, incentive programmes and energy consumption of low-energy buildings and efficient technologies, the IEA launched a Building Energy Efficiency Policies database (BEEP) in 2012.[30]

Overall progress assessment

The role of buildings in the 2DS

The energy consumption profile of buildings is complex; the 2DS relies on energy and CO_2 emissions savings in several areas to reach 2020 targets (Figure 3.30). In the scenario, energy consumption in the buildings sector is 9.8 EJ[31] below 6DS levels in 2020, an increase of only 6.6% from today's levels, and direct CO_2 emissions are 3 $GtCO_2$ (down 20% on 6DS levels) – despite projected increases of 24% in the number of households and 21% in services floor area.

Figure 3.30 2DS buildings sector energy savings and emissions reduction in 2020



Key point *Residential space heating offers the greatest energy and emission savings potential in buildings.*

Technology penetration and market creation

Building sector energy consumption grew 18% between 2000 and 2010, to reach 117 EJ – around one-third of global final energy use, producing about one-sixth of end-use direct CO_2 emissions. Several key factors influence the evolution of building energy consumption and emissions, including population growth, which increases demand for residential buildings and services. Global population increased by 14% from 2000 to 2011, to almost 7 billion, and is expected to rise by 10% from 2011 to 2020, to

30 www.sustainablebuildingscentre.org/pages/beep.

31 Energy consumption numbers in this section represent final energy consumption.

reach 7.6 billion.[32] Urbanisation is another important factor, as it brings greater access to commercial energy sources. The proportion of the world's population living in urban areas has risen from 47% in 2000 to slightly more than half today. By 2020, that share is expected to be 56%.

In the residential sub-sector, occupancy profiles and behaviour play a major role. In IEA member countries, average occupancy rates fell from 2.9 people per household in 1990 to 2.6 in 2009. As the average number of people per household decreases in many regions, the number of households is projected to increase faster than population growth. At the same time, the average floor area of households is expanding. Greater ownership of personal appliances is also increasing residential energy consumption, especially in emerging and developing economies. These trends are reflected in the fact that overall residential energy consumption has remained relatively static since 1990, despite energy-efficiency gains in space heating and cooling, lighting and other areas (Figure 3.26). The amount of energy used to heat a unit of floor area decreased over 25% from 1990 to 2009, for example.

Increased economic activity in the services sector and related growth in floor area is outpacing energy intensity improvements. Value added in the services sector grew rapidly between 2000 and 2010, at a rate of 2.8% yearly. Projected growth is 3.3% per year to 2020. As a result, services floor area is forecast to increase by 20% over 2010 levels in 2020. This means that, despite improvement in energy consumption per unit value added in services from 790 KJ/USD in 2000 to 710 KJ/USD in 2010 (Figure 3.27), energy consumption in the services sub-sector is set to increase by 9% to over 33 EJ in 2020, from 30 EJ in 2009.

Table 3.6 Key indicators in the residential and services sub-sectors

	Population (million)		Number of households (million)		GDP per capita (USD)		Services floor area (million m^2)	
	2010	2020	2010	2020	2010	2020	2010	2020
European Union	502	508	210	224	30 349	36 541	8 096	9 039
United States	310	337	113	126	47 331	56 071	7 534	8 278
China	1 345	1 388	385	460	7 820	16 063	10 243	13 471
India	1 171	1 387	249	324	3 471	6 011	776	1 215
Other OECD	459	489	166	192	25 210	30 778	5 322	6 227
Other non-OECD	3 174	3 673	764	1 007	5 753	7 647	4 983	6 458

Energy demand in the buildings sector is expected to increase by 6.6% to around 124 EJ in 2020, but deep emissions reductions can be achieved at low cost based on existing technologies. The challenge is to ensure that appropriate policies are in place to realise this potential through energy savings in new and existing residential and commercial buildings; efficient heating, ventilation and air conditioning (HVAC) technologies; improved appliance and equipment efficiency; and energy-efficient lighting.

Building energy codes

Improvements in the thermal envelope of buildings and other building envelope enhancements play an important role in achieving 2DS goals by 2020. They account for 17% of reduction in energy consumption compared with the 6DS in 2020.

32 UN National Accounts Main Aggregates database, 2011 figures.

Building energy codes (BECs) are the backbone policy instrument to improve efficiency. All OECD countries and several non-OECD countries including China, India and Russia, have BECs (Figure 3. 28). To be most effective, BECs should be mandatory and enforced; extend to new buildings and to existing buildings when they undergo renovation or extension; be overall performance-based; and set minimum energy performance standards at the efficiency level of best-available technologies for building elements, appliances and equipment.

Currently, only three countries have performance-based BECs, the most advanced codes – Denmark, France and Tunisia (Figure 3.28; Box 3.4). Performance-based BECs set absolute minimum energy performance requirements for building design and overall energy consumption of regulated loads (*i.e.* heating, cooling, ventilation, hot water and, in some countries, lighting). They require designers and developers to use an integrated building design to meet pre-defined energy performance or CO_2 emissions requirements for each building segment and various climate zones. This contrasts with prescriptive building energy codes, which set minimum energy performance requirements for each building element (*i.e.* windows, roofs, walls), are more restrictive on designers and developers as each requirement needs to be met individually, and may increase risk of "locking-in" energy efficiency standards, as replacement of building elements and equipment only happens during renovation. In OECD countries, renovation is usually undertaken approximately every 30 years for the residential sector and every 20 years for the non-residential sector. The most advanced performance-based BECs are dynamic and include different tiers for energy performance, which enable the market to adjust to upcoming energy targets. Denmark is the only country to have implemented such a BEC; it includes different minimum energy performance standards from 2012 and 2015; the targeted performance for 2020 is zero-energy buildings, as required by the Energy Performance of Buildings Directive (EPBD) recast for all EU countries.

Box 3.4 France's performance-based BEC

The French BEC was updated in 2012 to implement an overall performance-based approach for new buildings, as required by the EPBD and its 2010 update.[33] The BEC sets maximum allowed primary energy consumption for heating, cooling, ventilation, lighting and hot water, defined for each climate zone and building segment. The update is revolutionary: it reduces regulated energy consumption by 75% for electric-heated buildings and by 50% for other buildings, when compared with the previous update (2005).

The 2012 update also includes requirements on energy sufficiency measures, through the introduction of a bioclimatic indicator that assesses use of bioclimatic design principles such as solar gains and shadings. The objective is to minimise energy needs for heating, cooling and lighting independently from the efficiency of the installed systems, through effective consideration of the building design, shape, orientation and openings at the design stage. Designers are required to demonstrate that the bioclimatic indicator of each new project is lower than the maximum allowed bioclimatic value for the climate zone and building segment considered.

Finally, the revised BEC includes requirements on the use of renewable energy sources when technically feasible and economically viable.

See www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000022959397&categorieLien=id.

33 Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. EU member states were required to implement the EPBD update by the second half of 2012; France and Denmark are the first EU countries to implement the requirements of the update.

Only China[34] **and EU member states have mandatory BECs that cover the entire building stock** (Figure 3.28). In Australia, Canada and the United States, BECs are voluntary at the federal level, but mandatory in some states or provinces. Chile, India, Korea, Russia and Tunisia also have mandatory codes, but these cover some elements of the building stock only. Even in countries where BECs are mandatory, data on compliance checking and enforcement are not routinely available, which makes it difficult to gauge the efficacy of the codes. Implementing performance-based BECs is likely to make it easier to check compliance, because the overall performance of buildings can be metered during the occupancy of the building. Compliance of individual regulated building elements and equipment can be verified during construction.

BECs in most countries target new buildings but not existing buildings. Given that more than half the current global building stock is expected to still be standing in 2050 in OECD countries – and that routine refurbishments rarely include energy-efficiency improvements – it is essential that BECs cover existing buildings when they undergo major renovation or extension, as well as new buildings.

Energy-efficient heating and cooling

In the 2DS, more efficient HVAC technologies, including low-CO_2 or CO_2-free technologies such as heat pumps or solar energy for space and water heating and cooling, account for 3.7 EJ of energy savings together with co-generation and large-scale heating technologies. Many of these technologies are already available and economical over their life cycles, but there is significant potential to enhance their deployment.

Heat pumps are a critical technology for achieving low-carbon thermal comfort in building interiors. The 2DS envisages efficient heat pumps delivering 10% of useful energy demand[35] for space heating in OECD regions by 2020, and almost 30% by 2050.[36] The current status of the global market for heat pumps is difficult to assess due to lack of data. In the European Union, the number of installed ground-source heat pumps passed 1 million at the end of 2010, making installed capacity around 12.5 GW. An estimated 104 000 units were sold in the region in 2010; a drop of 2.9% from 2009 levels, following a 6.6% drop from 2008 to 2009 (EurObserv'ER, 2011). This contraction is probably due to the impact of the global economic crisis in Europe, but growth in the ground-source heat pump market may also have been affected by public scepticism in some European countries. As a result of technological innovations, air-source heat pumps have, in recent years, been accepted under criteria outlined in the EU Renewable Energy Directive (RED).

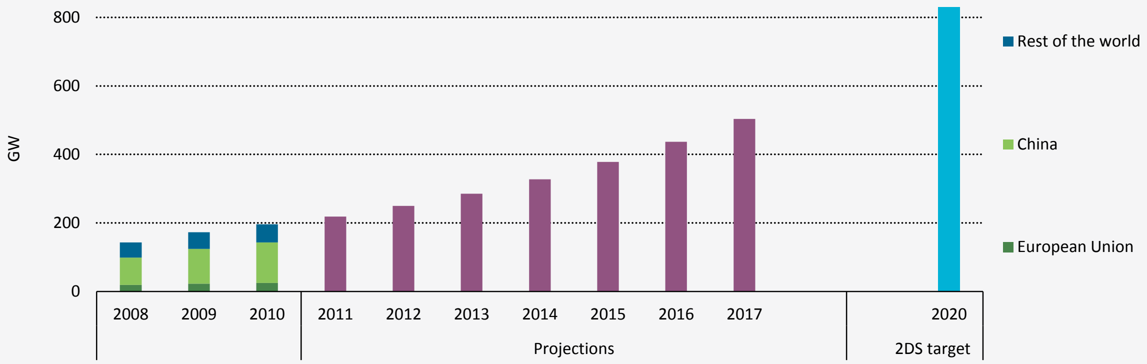
Installed solar thermal heating capacity reached around 196 GW by the end of 2010, up 14% on 2009 levels (Figure 3.31). This equates to around 280 million m^2 of collector area. China and Europe account for almost 80% of installations; they accounted for 95% of 2010 installations. Early estimates for 2011 put capacity at around 245 GW, with a corresponding collector area of around 350m^2 (Weiss, 2012). In 2010, the collector yield (energy output of installations) of all water-based solar thermal systems in operation was over 162 000 GW, equivalent to around 711 PJ and 53 Mt of CO_2 emissions savings annually. While solar thermal system deployment is set to increase in the medium term, the pace of deployment must pick up to achieve 2DS objectives by 2020.

34 In practice, however, in China BECs are implemented and enforced only in large cities.

35 The efficiency of the actual service provided, *e.g.* thermal comfort, instead of the energy delivered.

36 Heat pumps can be used to provide space heating, cooling and hot water, with the possibility of providing all three services from one integrated unit.

Figure 3.31 Solar thermal heating deployment



Sources: Weiss, 2012; IEA, 2012d.

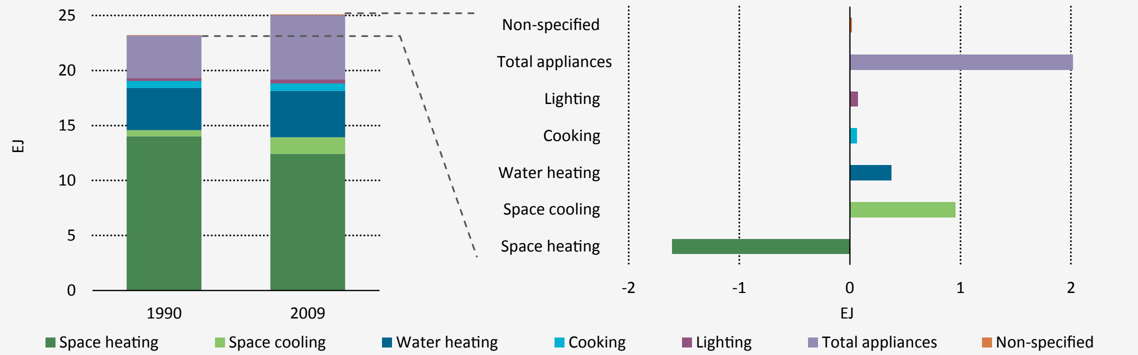
Key point *Installed solar thermal capacity increased by 14% in 2010.*

In the 2DS, significant savings are achieved by upgrading air conditioners, chillers and other cooling systems to BAT levels. Energy used for cooling in the 2DS is 9% below 6DS levels in 2020. Space cooling demand is highly correlated to income. Penetration rates of air conditioning in urban households in China, for example, grew from 2.3% in 1993 to 61% in 2003 (McNeil and Letschert, 2007). Cooling demand in regions where urbanisation is continuing and incomes are rising – including Southeast Asia, Latin America, India and China – is projected to increase to almost 2 EJ in 2020, from around 1.3 EJ in 2010. Energy-use data for cooling is not systematically collected at an international level; it is generally assigned to overall electricity use in buildings. Nevertheless, in OECD regions, where performance standards have generally been implemented and tightened, average efficiency of new air conditioners is estimated to be significantly inferior to the efficiency level of BAT. A comparison of new split and unitary domestic air conditioners in Australia, Canada, the European Union, Korea and the United States – as well as China – demonstrates that, despite around 3% annual efficiency improvements since 2000, the average efficiency of split products remains at just over 50% of best product efficiency (IEA, 2012l). The average efficiency of unitary products has remained fairly static, and also sits at around 50% of best product performance. Split air conditioners in Korea are around 20% more efficient on average than in other countries, probably due to minimum energy performance standards introduced in 2004. There is therefore clear scope for improving average air conditioner efficiency, including by implementing and tightening of minimum energy performance standards. Following a tightening in 2010, China now has the most stringent minimum energy performance standards for unitary products (IEA, 2012m).

Energy-efficient appliances and lighting

Appliances are estimated to represent 12% of energy consumption in residential buildings in 2020. Increased ownership of small and large appliances has driven growth in electricity demand in non-OECD countries as living standards improve. In OECD countries, energy efficiency of large appliances has improved due to government policy, but this has been more than offset by an explosion in ownership of telecoms and IT appliances, which has pushed up the share of residential energy needs met by electricity by 48% between 1990 and 2009 (Figure 3.32). Consumer electronics and computer equipment now represent 15% of global residential electricity consumption.

Figure 3.32 Energy consumption by end use in residential buildings and share in increase in energy consumption



Note: countries analysed: Australia, Austria, Canada, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Japan, the Netherlands, New Zealand, Slovak Republic, Spain, Sweden, Switzerland, the United Kingdom and the United States.

Key point *The increase in household appliance ownership has outpaced improvements in appliance efficiency.*

More efficient appliances, lighting and miscellaneous electrical equipment account for 10% of required energy savings compared with the 6DS in 2020, reflecting the significance of electrical end-use growth. Minimum energy performance standards and labels (Table 3.7) have led to encouraging progress; energy efficiency of refrigerators and freezers, for example, has improved in almost all regions because of effective policy action. The rate of improvement and achieved efficiencies vary considerably among countries; differences in energy consumption in Australia, Canada, Korea and the United Kingdom indicate the potential scope for a typical refrigerator-freezer to use 20% less energy (4E, 2012). However because countries use different test procedures to determine efficiency levels, it is difficult to come up with precise figures. A lack of available data also complicates progress tracking in this area. Efficiency improvements continue in other appliance categories, including washing machines and dryers, but are being offset by the growth in ownership of appliances. In addition, not all appliances and equipment are covered by standards in all countries, so there is still considerable potential for further efficiency gains.

Despite improvement, considerable potential remains to reduce energy demand from lighting worldwide. Solid-state lighting, including light-emitting diodes (LEDs), offer the greatest potential. Policy action to phase out inefficient lamps is improving the average efficiency of lighting across markets (Figure 3.33), but significant potential remains. Benchmarking of developments in Australia, Austria, Canada, Denmark, the European Union, France, Korea, Taiwan, the United Kingdom and the United States demonstrates that the average efficiency of lighting sold in certain countries is up to two times that of other regions, even where regulatory action has already initiated improvement (4E IA, 2012). The stringency and coverage of minimum energy performance standards explain the difference in performance between countries. Inefficient halogen lamps appear to be maintaining a constant share in sales, which minimises efficiency improvement from a switch from incandescent lamps. To increase the market share of LEDs, which remains relatively low, OECD countries need to introduce phase-in policies.

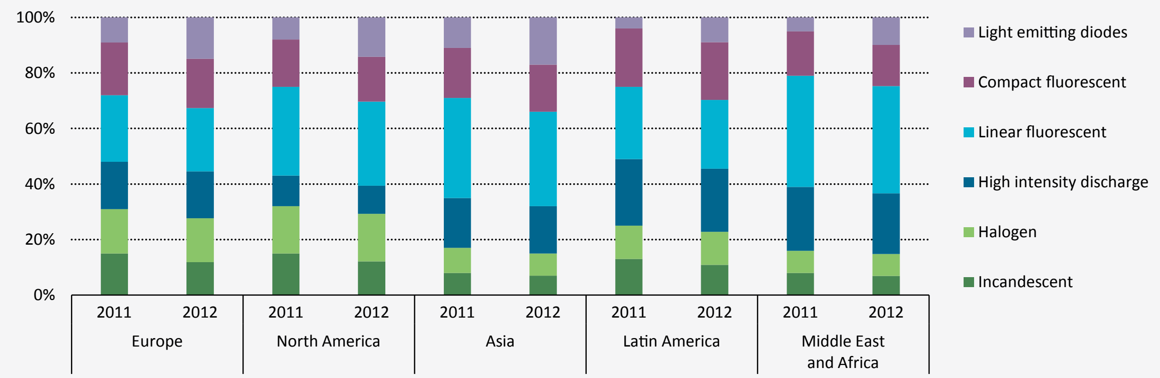
Table 3.7 Minimum energy performance standards for equipment and appliances

Appliances	AUS	BRA	CAN	CHN	EU	IND	JPN	KOR	MEX	NZL	ZAF	CHE	ARE	USA
Clothes washers		Mandatory	Mandatory	Mandatory	Mandatory	Voluntary		Mandatory	Mandatory	Mandatory				Mandatory
Residential refrigerators	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory		Mandatory		Mandatory
Commercial refrigerators	Mandatory	Mandatory	Mandatory		Mandatory	Mandatory	Mandatory		Mandatory	Mandatory		Mandatory		Mandatory
Computers	Mandatory					Voluntary	Mandatory							
Distribution transformers	Mandatory	Mandatory		Mandatory	Mandatory	Mandatory	Mandatory		Mandatory					Mandatory
Fans			Mandatory			Voluntary		Mandatory		Mandatory				
Motors	Mandatory		Mandatory	Mandatory	Mandatory			Mandatory	Mandatory	Mandatory		Voluntary		Mandatory
Room air conditioners	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Mandatory	Voluntary	Mandatory	Mandatory	Mandatory
Standby power					Mandatory				Mandatory		Mandatory			Mandatory
Television	Mandatory	Mandatory		Mandatory	Mandatory		Mandatory							Mandatory
Phase out of conventional incandescent light bulbs	Mandatory	Mandatory		Voluntary	Mandatory		Voluntary		Mandatory	Voluntary		Mandatory		Mandatory

● Mandatory ● Voluntary

Source: CLASP database, IEA analysis.

Figure 3.33 Market penetration of different lighting technologies



Source: McKinsey, 2012.

Key point *Highly efficient lighting technologies such as LED and CFL still only hold minor market shares.*

Recommendations for governments

- *A first, fundamental step in improving energy efficiency in the buildings sector is for all countries to develop and enforce stringent, performance-based BECs that cover both new and existing buildings when they undergo renovation or extension. BECs should be dynamic, with energy performance targets adjusted over time. Given that currently only Denmark has such a BEC, all countries have scope to drive efficiency improvements through enhanced BEC ambition and coverage. Once in place, compliance checking and enforcement are essential to ensure energy efficiency potential is fully achieved.*
- *In OECD regions, where existing, less-efficient building stock represents the greatest potential for improvement, governments should implement enhanced renovation rates for public buildings and pursue policies to drive retrofits in the private sector. Energy reduction targets should be set with a long-term view and ensure renovation is deep enough to avoid "locking in" energy efficiency potential. Governments should create market-based solutions to enable renovation markets.*
- *Governments should improve methodologies for setting minimum energy performance requirements for appliances and equipment. Increasing the level of ambition for performance standards and setting them at the efficiency level of best available technologies is essential to accelerate deployment of efficient technologies; requirements should be regularly reviewed to avoid locking in sub-optimal efficiency requirements. Policies and measures targeting public awareness, such as labelling, should be implemented to ensure maximum take-up of most efficient products. A systems approach when setting performance standards – rather than component approach – can help ensure that all potential is realised.*
- *Several targeted policies to support greater use of low-carbon heating and cooling technologies are beginning to attract attention, particularly renewable heat policies (e.g. direct capital cost subsidies, tax incentives and soft loans for the purchase of renewable heating systems, renewable obligations and feed-in tariffs). Sharpening the focus on developing dedicated renewable heat policies and sharing experiences on the more effective policy designs would accelerate deployment of renewable heat technologies.*
- *Current data limitations in the building sector mean that any assessment of progress is necessarily incomplete. More comprehensive global data collection, including through systematic metering of building energy consumption, would enable better tracking of progress in building sector energy efficiency, and more targeted analysis of priority areas for policy making. Harmonisation of test procedures for appliances would also assist, by enabling more accurate benchmarking.*

Chapter 4

Systems Integration

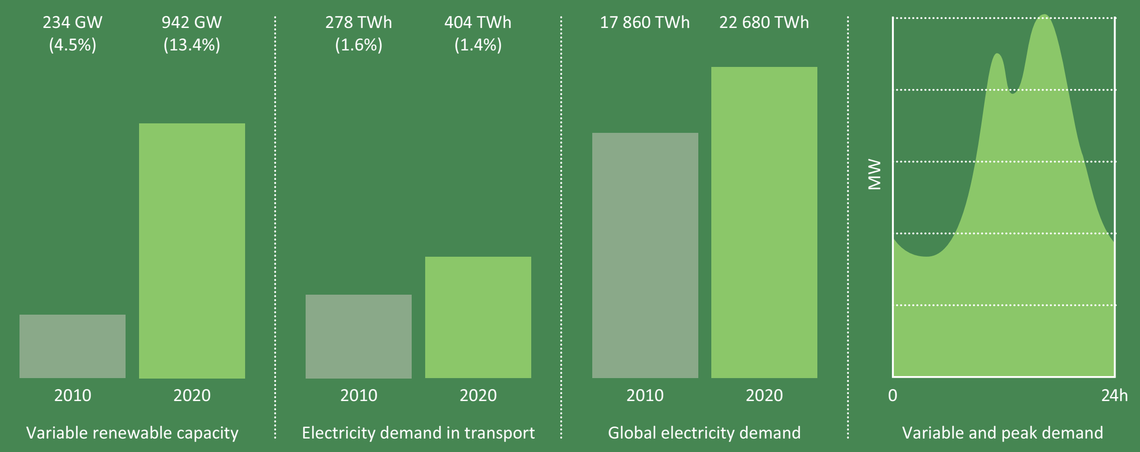
Smart Grids

Improvement needed

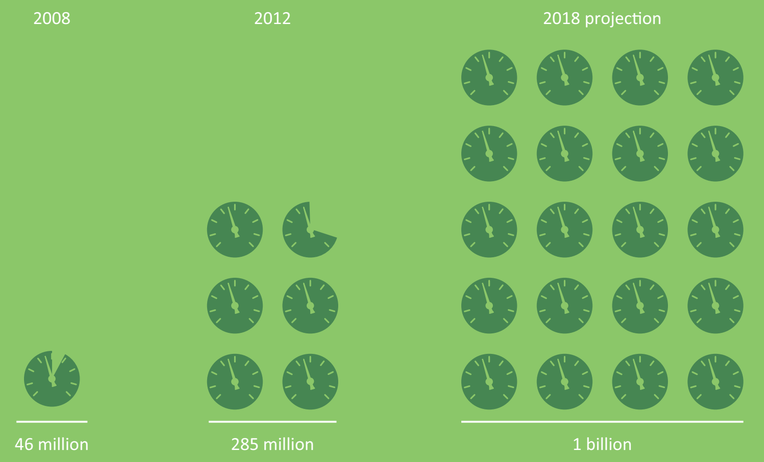
Demonstration and deployment of smart grid technologies is intensifying, driven by forces such as accelerating integration of large-scale variable renewable energy sources. Data collection and deployment metrics need to be improved, however. Reaching 2DS targets will require accelerated investment and new regulatory and business models that enable sharing of smart grid costs and benefits.

Technology penetration

4.1 Drivers for smart grid deployment in the 2DS



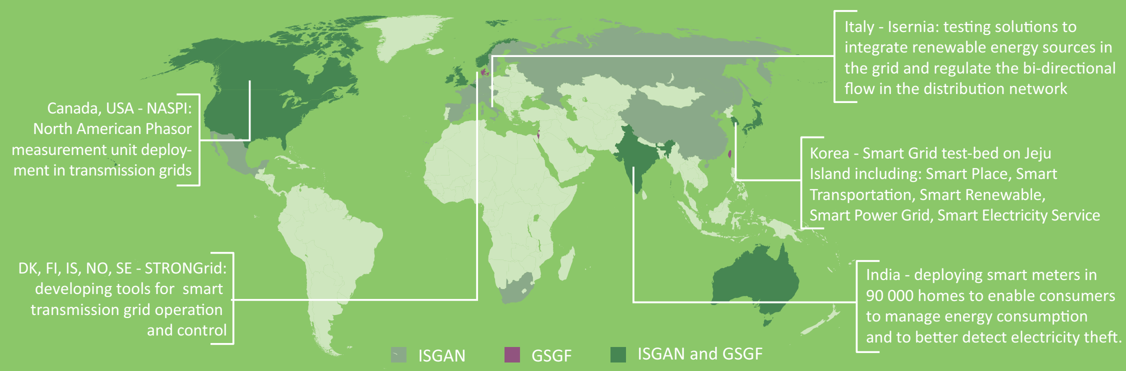
4.2 Global cumulative smart meter installations



National deployment drivers

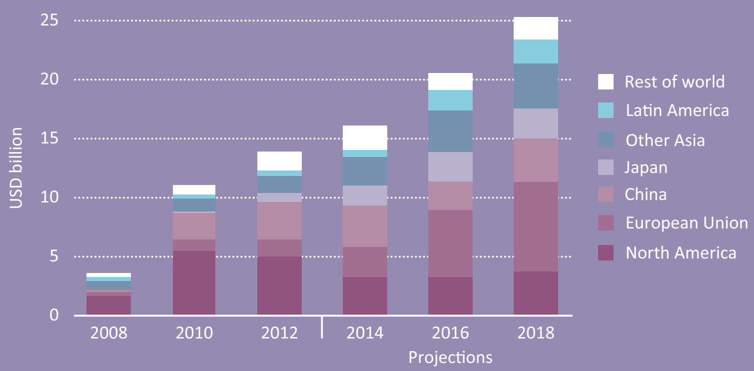
1. Renewable power
2. Network efficiency
3. Reliability
4. Customer choice and participation
5. New products, services and markets
6. Energy efficiency

4.3 International smart grid collaboration



Market creation

4.4 Global smart grid investment



Investment trends

Tracked smart grid investment reached almost 14 billion in 2012, a fourfold increase from 2008, but remains below 2DS targets

Cost reductions enabled by smart grids are not always reflected in sectors where investments are made

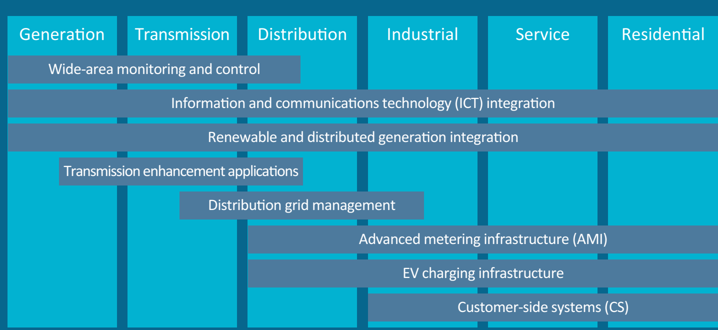
Technology developments

Key points

Integration of the many individual smart grid technologies is the key challenge in development and deployment of smart grids

Tracking progress in smart grid deployment is complex and efforts are ongoing to determine appropriate metrics

4.5 Smart grid technologies



For sources and notes see page 143

Recent developments

- Pilot, demonstration and at-scale deployment of smart grid technologies continued to accelerate in 2012, and is starting to generate experience that can be replicated and built-on for future projects.
- The Global Smart Grid Federation (GSGF), for example – a collaboration of national and regional smart grid associations – reported in 2012 on best practice arising from early deployment experience in Australia, Canada, Europe, Korea, Japan and the United States.[1] The report highlights the key role for governments in enabling early deployment through: development of suitable deployment strategies; financing; implementation of regulation to enable cost-effective investment; and consumer education on smart grid deployment.
- Tracking progress in smart grid technology deployment remains a challenge, however. Several organisations, including the International Smart Grid Action Network (ISGAN), continued efforts in 2012 to define simplified, quantitative indicators and metrics to assess progress and assist in indentifying gaps.
- Investment in advanced metering infrastructure, distribution automation and advanced smart grid applications reached USD[2] 13.9 billion in 2012, a modest increase over 2011. While only indicative of grid modernisation spending, the figures suggest that spending is below levels needed to reach 2DS targets. Further progress in implementing regulatory frameworks that enable sharing of smart grid costs and benefits is also needed to accelerate deployment.
- Several jurisdictions and utilities including Australia, the Netherlands and North America, have now adopted "opt-out" policies with respect to smart meter installation, reflecting privacy and health considerations.

Overall progress assessment

The role of smart grids in the 2DS

Smart grid deployment permeates the entire electricity system in the 2DS. Smart grid technologies contribute between 0.2 and 0.5 $GtCO_2$ emissions reductions in 2020, through both direct and enabled reductions. Direct reductions include from energy savings from peak load management, accelerated deployment of end-use and system energy-efficiency programmes, and reduced system losses; enabled reductions include reductions from integration of large-scale, variable renewable power generation and facilitation of electric vehicle deployment.

Technology penetration

Key driving forces for smart grid technology deployment are intensifying (Figure 4.1). Between 2000 and 2010, global electricity demand increased by 41% to more than 17 860 TWh. That figure is anticipated to rise to 22 680 TWh in 2020 in the 2DS, which should provide increased motivation for energy savings and using smart grids as a cost-effective way to minimise traditional network reinforcement. Variable renewable capacity (*i.e.* wind and solar capacity) increased by around 215 GW between 2000 and 2010 (+28% per annum). By 2017, that figure is set to increase to about 730 GW, compared with 234 GW in 2010 (+12% annually).[3] Mass-market deployment of EVs, including plug-in hybrid-electric vehicles and full-battery electric vehicles, commenced in 2011. Global stock reached around 180 000 by the end of 2012; the 2DS envisages deployment of

1 www.globalsmartgridfederation.org/documents/May31GSGF_report_digital_single.pdf.
2 Unless otherwise stated, all costs and prices are in real 2010 USD, *i.e.* excluding inflation. Other currencies have been converted into USD using purchasing power parity (PPP) exchange rates.
3 See the renewable power section.

20 million EVs by 2020.[4] Associated electricity demand will be about 40 TWh in 2020. Although this is modest on a global level, local effects on distribution systems or at the city level are expected to be significant. These developments increase impetus for smart grid deployment globally. Other key motivating factors include improving system reliability; enabling new electricity products, markets and services; and enabling customer choice and participation (Figure 4.2). Reasons for deploying smart grids vary depending on circumstances specific to each country and region.

Efforts are continuing worldwide to determine clear and identifiable indicators to assess progress in smart grid deployment. Smart grid technologies are numerous and span the electricity system. The US government has identified 21 metrics relevant to smart grid deployment, many of which are qualitative, such as cyber security and regulatory recovery of smart grid investments (US DoE, 2012). The European Commission's Joint Research Centre has identified over 50 key performance indicators for a smart grid, including power quality indicators and management of energy losses in transmission and distribution (JRC, 2012). Tracking progress in smart grid deployment therefore implies assessing the progress of multiple technologies; at the same time, it has not yet been determined which technologies can be considered authoritative indicators of the "smartening" of electricity grids. In addition, data on the deployment of smart grid technologies is limited. Some smart grids are also highly specific to local conditions, and therefore not necessarily scalable or replicable.

Individual smart grid technologies and projects provide an indicative view of progress. Global, cumulative smart meter deployment increased by 500% between 2008 and 2012, from 46 million to 285 million meters installed (Figure 4.2). Cumulative installations are projected to increase to approximately almost one billion before the end of 2018; this provides some indication of market activity, as smart meters are one of the foundational technologies for overall smart grid deployment. Taking a regional example, phasor measurement unit (PMU) deployment in the North American power grid has now reached 600 networked PMUs installed, up from around 200 in 2009 (NASPI, 2009); approximately 1 100 PMUs are anticipated to be in place and networked by the end of 2014. PMUs improve system reliability and visibility through wide area measurement and control. Globally, there are hundreds of smart grid projects, including the following examples (Figure 4.3).

- Thirty-five US utilities and the Canadian province of Ontario are participating in a "Green Button Initiative", providing 16 million households and businesses with voluntary electronic access to their electricity usage data in a standardised format. Customer numbers are expected to grow to 36 million by the end of 2013. The initiative is expected to support continued development of electronic products and services tailored to the energy sector.
- The Power Grid Corporation of India is deploying smart meters in 90 000 homes in Puducherry, a union territory, to enable consumers to manage energy consumption and the utility to better detect electricity theft. The project aims to reduce aggregate technical and commercial losses from over 20% to less than 10%.
- Nordic transmission system operators are undertaking a joint R&D project with several Nordic universities to develop smart transmission system monitoring and control applications. The aim is to set up a common hardware and software platform for developing and testing wide area monitoring and control applications.
- Following its "Telegstore" advanced metering infrastructure deployment project, Italy's Enel Distribuzione is trialling renewable energy integration options and regulation of bi-directional electricity flow in the distribution network as part of its "Isernia" project. The project includes energy storage systems integrated with PV panels and an EV recharging infrastructure to manage energy flow, as well as a forecasting system for distributed generation.

4 See the EVs/HEVs section.

Market creation

Smart grid investment is growing, but falls short of levels required by the 2DS (Figure 4.4). Globally, public and private investment in advanced metering infrastructure, distribution automation and advanced smart grid applications was USD 3.4 billion in 2008. The 2012 investment figure of almost USD 14 billion represents a fourfold increase from 2008. China and North America accounted for almost 60% of investment spending in that year. Investment is expected to rise in the medium term, to over USD 25 billion, as other countries and regions such as the European Union, Japan and other parts of Asia increase expenditure. In other regions, however, including China and the United States, future growth in expenditure is less certain, as government stimulus funding is running out, governments, regulators and the private sector are awaiting results from demonstration projects before committing additional amounts, or deployment targets are achieved (in particular smart meter targets). Tracked investment remains significantly below levels required to meet 2DS goals, although available data is limited. Cumulative investment requirements are considerable, but the benefits of deployment are likely to outweigh investment cost, as smart grids enable financial savings in generation, transmission and distribution, retail operations, and the overall system (Table 4.1).

Table 4.1 Cumulative smart grid investment costs and benefits in the 2DS to 2020

USD billion	Cost		Benefit	
	min	max	min	max
OECD Europe	124	143	430	730
OECD Americas	126	148	461	820
OECD Asia Oceania	54	61	305	452
China	177	239	483	786
India	113	147	264	391

Cost reductions enabled by smart grids do not necessarily accrue in the same sectors in which investments are made, so governments must address market barriers. Smart meter deployment costs are paid by distribution system actors and customers, for example, but their deployment can create benefits throughout the entire electricity system. Regulation and business cases are needed to help resolve this conflict, which is preventing broad-scale use of smart grid technology. In particular, long-term strategic plans are needed to facilitate smart grid investments, supported by adaptive regulation and policy that can accommodate new technology advances. Korea is addressing market barriers and encouraging smart grid market development. Its Smart Grid Stimulus Law, enacted in 2011, provides legislative support for mid- and long-term smart grid planning, including pilot, demonstration and commercial investments. The law also addresses potential barriers such as information use and data protection. Some other countries and regions, including Italy and the United States, have developed roadmaps or other policy initiatives to support development and deployment, but many regions are yet to make progress.

Technology developments

Integration of the many individual smart grid technologies is the largest challenge in development and deployment of smart grids (Figure 4.5). Many smart grid technologies are mature but require further demonstration in integrated system applications to determine how they can work in a coordinated fashion. There is a continued need for additional pilot and demonstration projects.

Interoperability, put into practice through technical standards and grid codes, is a key element of technology development. The European standardisation organisations and the Smart Grid Coordination Group in Europe are developing standards to facilitate the implementation of smart grid technologies and services. Similarly, in the United States, the Smart Grid Interoperability Panel is engaging with all interested parties to identify applicable standards, gaps in available standards and priorities for new standards. These efforts are important to ensure that smart grid technologies can work together when placed in a real system context, and that global markets for smart grid technologies can be developed competitively, while reducing risks for early adopters.

Recommendations for governments

- *Improved data collection and knowledge sharing are essential to harness lessons learnt from the many smart grid projects under way globally, and ensure replicability and scalability for future projects. Governments should accelerate national data collection and support international data coordination efforts.*
- *Electricity system regulation currently supports conventional approaches to system development. To accelerate smart grid deployment, governments must develop and demonstrate new regulations and business models that enable practical sharing of smart grid costs and benefits. Countries such as Korea and Italy may serve as examples to countries wanting to move forward in this area.*
- *As deployment of sensor and measurement technologies such as smart meters and PMUs generates increasing amounts of data, innovative efforts will be required to manage, protect and process system data. Much of the value of smart grid deployment lies in translating these vast amounts of data into useful insights for utility operations. To ensure that privacy concerns do not become a barrier to smart grid deployment, governments should proactively address data and cyber security issues through regulation and by applying best practice in generation, transmission, distribution and end-user sectors.*

Co-Generation and District Heating and Cooling

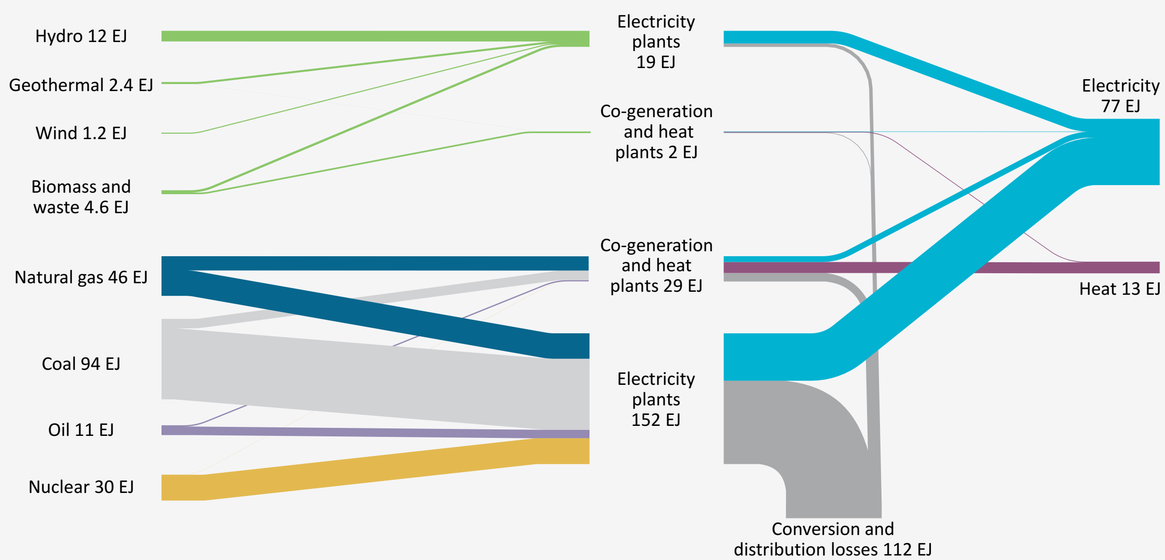
Improvement needed

Co-generation and district energy networks have significant potential to decarbonise heating and cooling, but this remains largely untapped. Better heating and cooling data and strategic planning are required to accelerate deployment.

Reducing CO_2 emissions from heating and cooling is key to a low-carbon economy, but is a neglected area of energy policy. Thermal demand represents an estimated 46% of global final energy demand.[5] Globally, 67% of heat is generated by fossil fuels; this share rises to 85% in OECD countries.

Few low-carbon policies explicitly target heating and cooling. The area is highly heterogeneous, spanning many energy sectors, and the best ways of decarbonising it are

Figure 4.6 Energy flows in the global power sector, 2010



Notes: following IEA energy balance conventions, for autoproducer co-generation plants, only heat generation and fuel input for heat sold is considered, whereas the fuel input for heat used within the autoproducer's establishment is not included, but accounted for in the final energy demand in the appropriate consuming sector. Solar and ocean energy combined equal 0.12 EJ and do not appear in the graph. Totals may not equal the sum of their components due to rounding.
Figures and data that appear in this report can be downloaded from www.iea.org/etp/tracking.
Source: unless otherwise noted, all tables and figures in this report derive from IEA data and analysis.

Key point *More than half of the energy going into electricity, co-generation and heat plants is lost before it reaches the end user.*

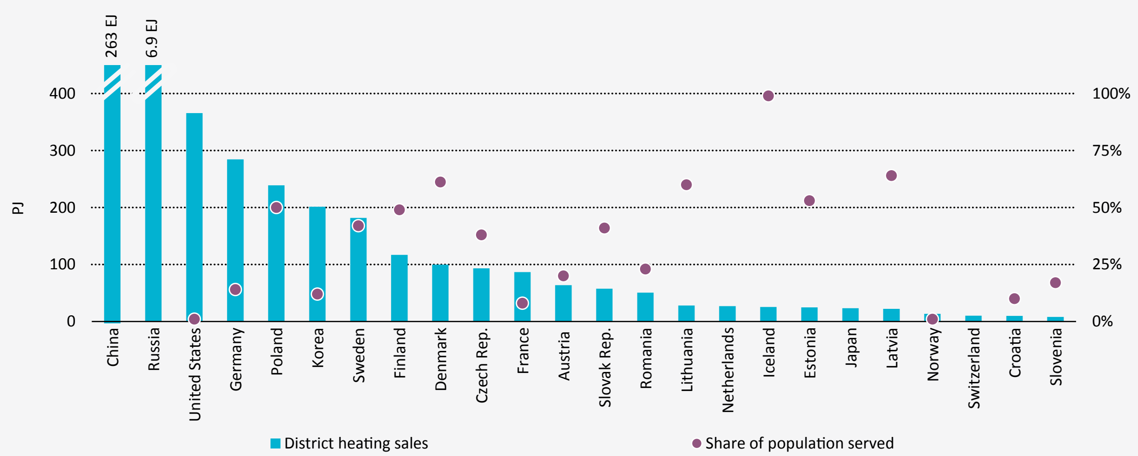
5 Heat generated by auto-producers for their own use is not generally reported or registered and is therefore not included in this estimate.

not well understood. Heat loss in current energy systems is also high – estimated at around 60% of energy input to thermal power generation plants (Figure 4.6). This means there is much potential to optimise the use of heat and recover waste heat for other purposes such as space and water heating or industrial applications.

Co-generation and district energy networks have the potential to play a fundamental decarbonising role. Efficient district heating networks connect locally available sources of heat, such as waste heat from industrial facilities or heat from cogeneration plants, with consumers. District cooling networks convert local heat sources and cool energy sources, such as cold water from river or lakes or ground water reservoirs, into cooling. District energy networks facilitate integration of variable renewable and waste energy sources with efficient cogeneration, thereby drastically reducing carbon intensity. Co-generation technologies use heat output from electricity production to increase overall energy efficiency, thereby reducing losses. State-of-the-art plants can reach efficiencies of up to 90%; the global average for traditional fossil-fuel based plants is 35%-37% (IEA, 2011d).

The decarbonisation potential of district networks and co-generation remains largely unrealised. While district energy infrastructure is already being deployed to good effect in countries such as Denmark, Iceland and Latvia, serving more than 60% of the population in certain cases (Figure 4.7), efficient networks are highly dependent on strategic planning and promotion and are underutilised globally. Only around 10% of global electricity generation is from co-generation, with just a few countries having successfully expanded penetration rates to around 30%-50% (Figure 4.8). This is despite the maturity of co-generation technologies and their clear energy benefits.

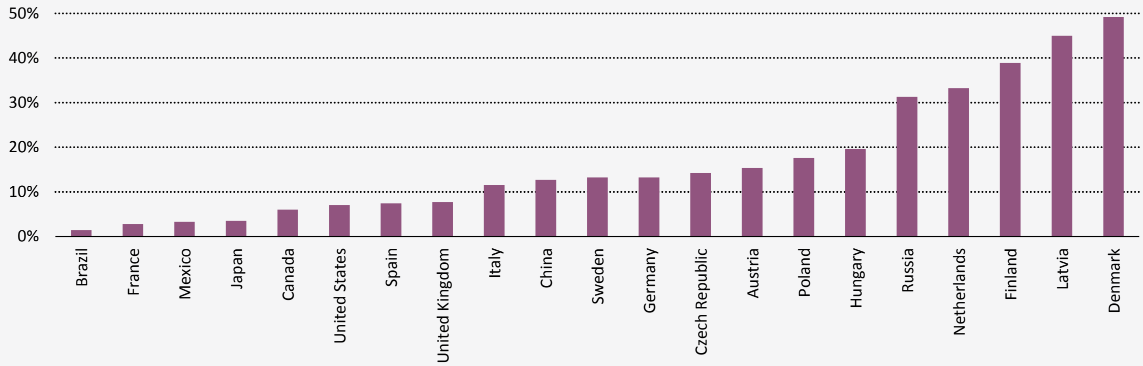
Figure 4.7 District heat sales and share of population served in 2009



Source: Euroheat&Power, 2011.

Key point *District heating only fulfils its potential in a small number of countries.*

Figure 4.8 Co-generation share of national power production



Source: data merged from years 2001, 2005, 2006, 2010.

Key point *Only around 10% of global electricity generation is from co-generation, despite it being an efficient and mature technology.*

The quality and coverage of global- and national-level heating and cooling data is a key barrier to further exploitation of district networks and co-generation technologies. A clear understanding of the nature and magnitude of heating and cooling demand and supply, and potential for heat-recovery and reutilisation, is critical to further market penetration. Such data is required to underpin strategic heating and cooling planning. Additional barriers to deployment of co-generation technologies include grid access and interconnection regulations, particularly for large scale cogeneration plants, and high upfront investment costs.

Some governments are starting to implement policy measures to promote greater strategic planning, but much more effort is needed. Article 14 of the 2012 EU Energy Efficiency Directive, for example, promotes high-efficiency district heating and cogeneration. It includes a requirement for national heat mapping, to facilitate strategic planning of new capacity (EU, 2012). The US government is aiming to achieve 40 GW of new, cost-effective industrial co-generation by the end of 2020 (US, 2012). Similarly, China has strongly indicated the intention to reach 50 GW of gas-fired distributed co-generation capacity by 2020 (NRDC, *et al.* 2011).

To accelerate deployment, governments should:

- Improve national heating and cooling data collection, to enable robust analysis and effective planning.
- Undertake strategic planning of heating and cooling, to develop a clear picture of supply, demand and waste-heat recovery potential.
- Take a systems integration approach to cogeneration deployment, focused not only on electricity generation but also on heat load and its distribution through efficient networks, to ensure all available potential is captured.

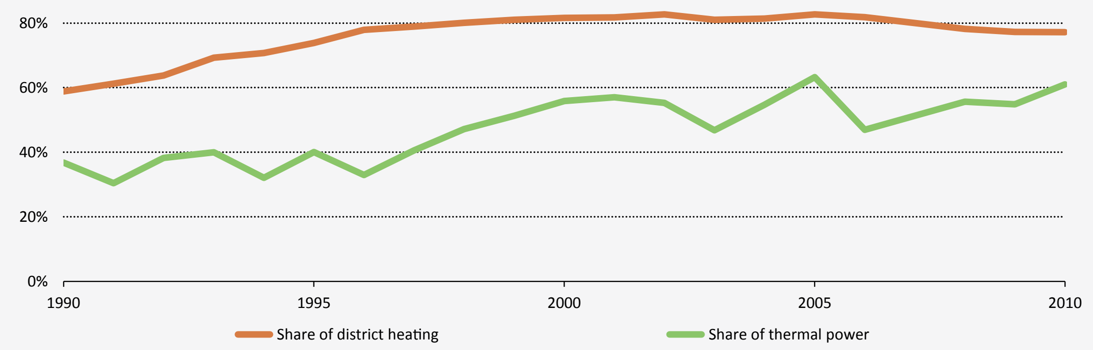
Box 4.1 District heat and co-generation in Denmark

Strong policy has driven district heating and co-generation deployment in Denmark, where 61% of thermal electricity and 77% of district heating are produced by co-generation (DEA, 2011).

The first Heat Supply Law of 1979 introduced heat planning as a new instrument and set national deployment targets, including for the introduction of natural gas, increased use of waste heat from co-generation, industry and waste incineration and the use of biomass for heating (IEA, 2008). In the 1990s, existing heat-only plants based on coal or oil converted to co-generation plants fuelled with natural gas, when available. Waste incineration plants converted to co-generation, and district heat producing units converted to biomass in areas without natural gas. This resulted in a significant increase of electricity and district heating co-generation shares in Denmark (Figure 4.9).

Denmark's Energy Strategies 2025 and 2050 build on this track record, aiming to promote new clean technologies and increase the share of renewables and co-generation through well-functioning energy markets and international co-operation.

Figure 4.9 Co-generation's contribution to energy production



Note: no data for 2007.
Source: DEA, 2011.

Key point *Denmark demonstrates how co-generation can make a contribution to heat and electricity production.*

Energy Sector Carbon Intensity Index

Energy sector carbon intensity has remained static for the last 40 years. It must reduce dramatically to reach 2DS goals.

The IEA Energy Sector Carbon Intensity Index (ESCII) is a way of assessing the aggregate impact of technology shifts on carbon emissions in the energy sector. It measures how many tonnes of CO_2 are emitted for each unit of energy supplied. Under the ESCII, 100 represents CO_2 intensity in 2010, providing a base to measure progress.[6] The ESCII shows only one side of the energy sector decarbonisation challenge: the world must slow the growth of energy demand as well as making energy supply cleaner.

Past trends and the 2DS challenge

The evolution of the ESCII is striking: carbon intensity has remained largely flat for the last 40 years (Figure 4.10). Between 1975 and 1985, the world's energy supply shifted strongly away from oil, with a massive expansion of nuclear electricity capacity and a switch to natural gas. The ESCII dropped by only 5% in this decade of rapid change, however. From 1990 to 2010, the shift away from oil continued, notably in the late 2000s. Oil was replaced by natural gas (with lower emissions) and coal (with higher emissions), with the net result that the overall carbon intensity of the energy mix has remained very stable, changing by less than 1% between 1990 and 2010 (Table 4.2).

The ESCII shows that the global energy mix is not getting cleaner at the rate necessary to achieve climate goals. It is necessary to address energy supply on a comprehensive basis. Improvements on one front (such as increased renewable generation or lowered oil demand) have been undermined by other developments (notably the increased use of coal). Ever-increasing global greenhouse gas emissions are not due to energy supplies getting dirtier on average: they are linked to rising global energy demand.

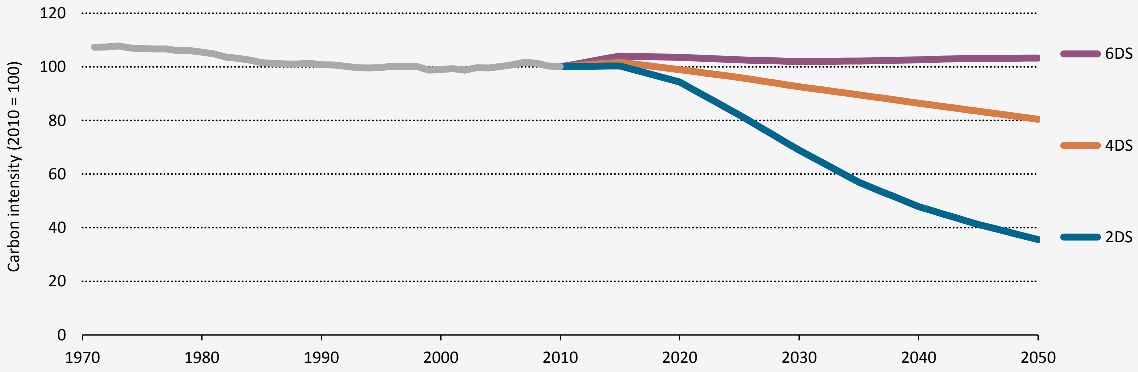
A dramatic reduction in carbon intensity is needed, together with aggressive energy efficiency improvements, to reach 2DS goals. At a global level the ESCII needs to break from its 40-year stable trend and decline by 5.7% by 2020, 43% by 2035, and over 60% by 2050 (Figure 4.10 and Table 4.2). If the current trend in the ESCII over the past 20 years continues, global temperatures would rise by more than 4°C.

2020 2DS targets

To 2020, the ESCII needs to decline to 94.3 to be consistent with 2DS goals (Figure 4.11). This is an average improvement of about 0.5% per year, which represents the equivalent of replacing about 1% of global annual coal production with renewables every year. Broken down into OECD and non-OECD country groups, the overall message is that the energy supplies of both OECD and non-OECD regions need to be cleaner by 2020 than they are now. For OECD countries, this means an acceleration of the existing trend toward cleaner supply to reach an ESCII of 93.1 in 2020. For non-OECD countries, it means reversing the trend between 2000 and 2008, when their critical economic and social development was driven by an increasing reliance on coal. By following a cleaner development path, they could reach an ESCII of 94.9 in 2020.

6 CO_2 (sectoral basis)/TPES. Given the stability of global emissions intensity over the last 20 years, the particular choice of a reference year between 1990 and 2010 hardly matters.

Figure 4.10 The Energy Sector Carbon Intensity Index (ESCII)



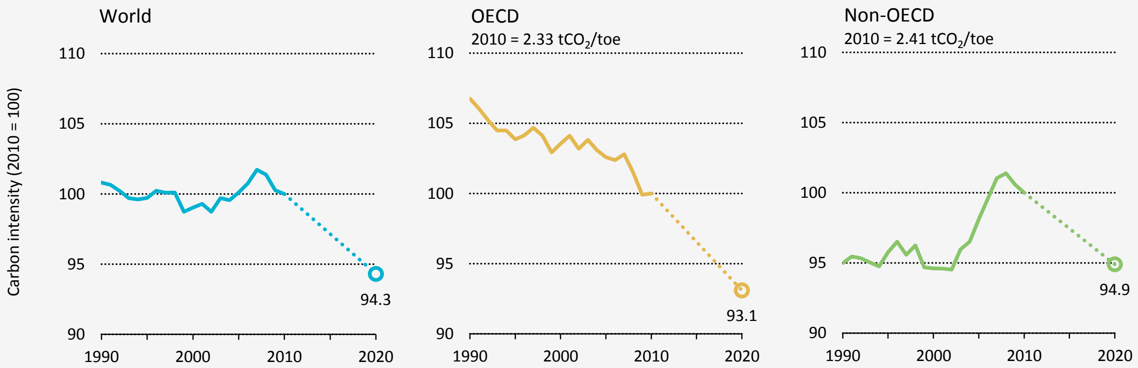
Source: IEA 2012a, 2012b.

Key point *The carbon intensity of energy supply has been stable for the last 40 years, but needs to decrease rapidly in future.*

Table 4.2 ESCII for the 2DS

	Energy sector carbon intensity (tCO_2/toe)	ESCII	% improvement required on 2010
1971	2.54	107.3	
1990	2.39	100.8	
2010	2.37	100	
2020	2.24	94.3	5.7%
2035	1.35	56.9	43.1%
2050	0.84	35.6	64.3%

Figure 4.11 ESCII and 2DS targets



Source: IEA 2012a, 2012b.

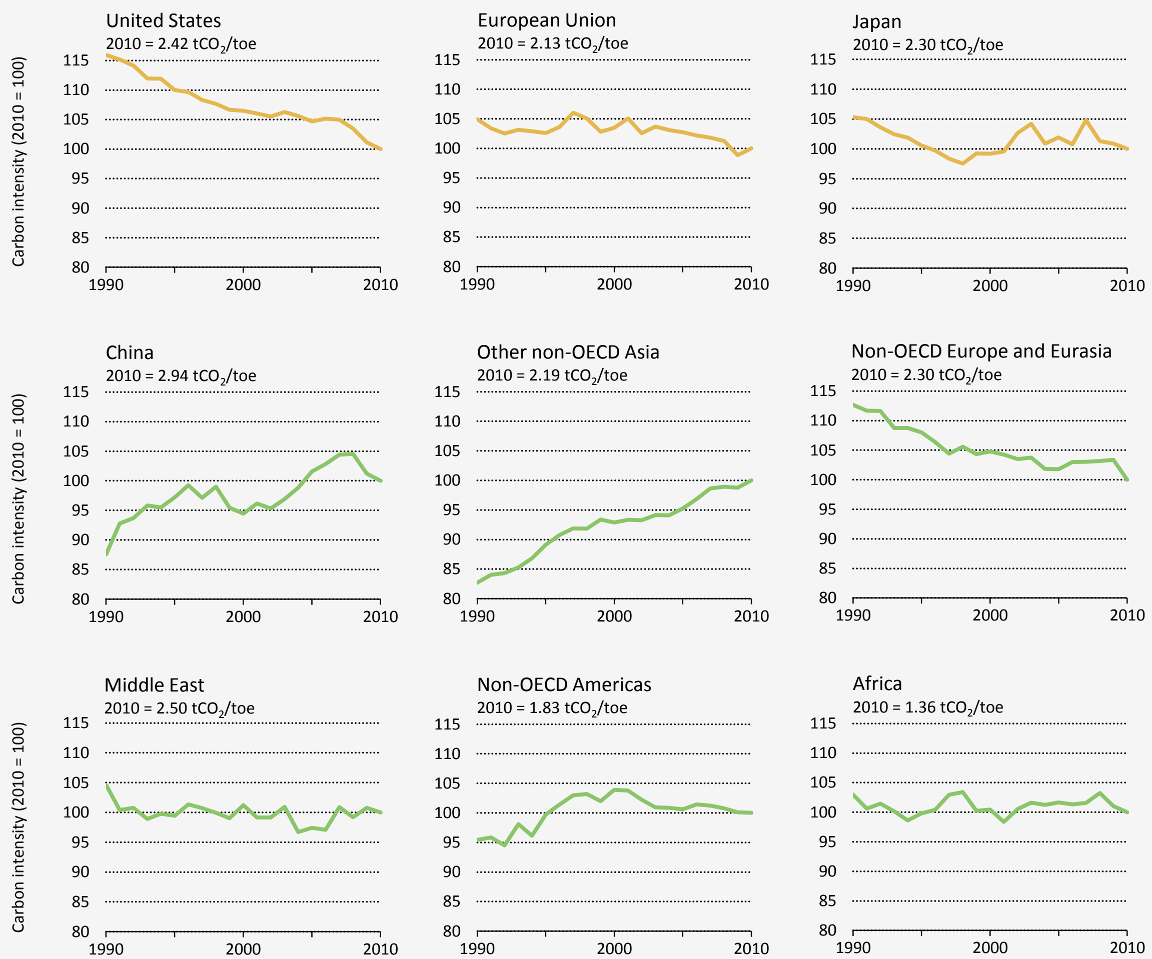
Key point *Both OECD and non-OECD energy supplies will need to be cleaner than today by 2020.*

The ESCII at the regional level

At the regional level, carbon intensity has varied widely since 1990, as is shown by a comparison of trends in the ESCII in nine countries and world regions (Figure 4.12). As for the global case, the ESCII starts all regions at 100, equalising their respective 2010 emissions intensities, in order to highlight overall trends. The absolute values of carbon intensity in 2010 vary: for OECD it was 2.33 tCO_2/toe, while non-OECD was 2.41 tCO_2/toe. Europe was at 2.13 tCO_2/toe, while China was at 2.94 tCO_2/toe. However, a comparison of absolute figures does not take into account regional differences in development stages and what these imply in terms of energy use, nor the availability of resources that may facilitate decarbonisation or, to the contrary, lock-in CO_2-intensive practices.

The varying trends in emissions intensity reflect policy action, availability of resources and other national circumstances, including economic growth rates. The rapidly falling ESCII in the European Union reflects a long-term shift from coal and oil toward

Figure 4.12 ESCII by region



Source: IEA 2012a, 2012b.

Key point *Trends in carbon intensity vary significantly between world regions.*

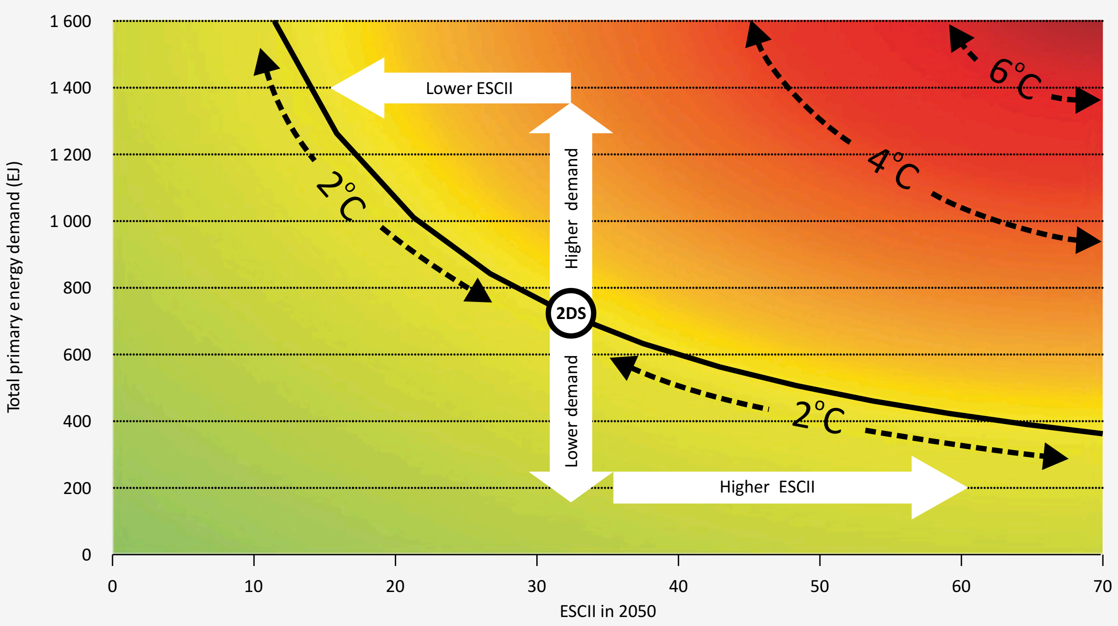
natural gas and renewable energy, while the rising ESCII in Asia reflects an increasing share of coal and oil as the energy supply expands to meet development needs. In spite of this increase, the absolute carbon intensity of Asia's energy supply (2.19 tCO_2/toe) is still below the average of OECD countries. In non-OECD Europe and Eurasia, the strong decrease in ESCII reflects an increasing share of natural gas in the energy supply. China's ESCII has fallen since 2008, after a rapid increase in the mid-2000s when coal's share of the energy supply increased. Since 2008 coal's share has stabilised, and the CO_2 produced per unit of coal- or oil-derived energy has decreased slightly.

Managing demand: how ESCII and energy efficiency are intertwined

The ESCII shows only one side of the energy sector decarbonisation challenge: the world must slow the growth of energy demand as well as making energy supply cleaner. The 2DS includes ambitious government policies to improve energy efficiency, in tandem with rising carbon prices that constrain energy demand.

2DS emissions targets can be reached via a range of ESCII-demand combinations (Figure 4.13). If energy efficiency policies are not pursued, energy demand will be higher than envisaged under the 2DS, so to reach the same emissions target an even cleaner energy supply (lower ESCII) would be needed. Conversely, if energy efficiency gains go beyond those foreseen, a higher ESCII could be tolerated. Increasing energy efficiency not only allows global growth within emissions constraints, but also provides a slightly more flexible timeframe if global efforts are slow in moving to a cleaner energy system.

Figure 4.13 Trade-off between improving ESCII and reducing energy demand



Source: 2012b.

Key point *Varying combinations of energy efficiency improvements and lower carbon intensity can deliver the CO_2 emissions level consistent with a 2°C scenario.*

Chapter 5

Energy Technology RD&D and Innovation

Energy Technology RD&D and Innovation

The need for new energy technology development is undisputed. Thus the accelerating innovation in emerging economies and a global increase in research investments in absolute terms in recent years are welcome developments. But energy receives only 4% of public research funds in IEA countries, and the gap between estimated needs and actual investments remains very large. This needs to change.

Key messages

- Governments' investment in energy RD&D has increased by 30% in absolute terms since the 1990s, but it still represents a small share of total spending on RD&D. Defence research receives 30% of OECD governments' support for RD&D, while energy's share, after reaching its peak in 1981 with 11%, has varied between 3% and 4% since 2000 (Figure 5.2).
- Over the last decade, spending on clean energy RD&D has shifted towards renewable sources, notably solar PV (Figure 5.3). Nuclear energy has seen the greatest decline in public RD&D spending, but nuclear fission still accounted for the largest share of funding in IEA countries at approximately 24% of total energy RD&D in 2010.
- RD&D investment in clean energy technology needs to increase by three to six times in order to achieve the 2DS. For advanced vehicles and CCS the gap may be even higher (Table 5.2). Public sources are expected to contribute at least half of the needs.
- To make sure new technologies are widely propagated, governments must supplement public funding schemes for RD&D (*e.g.* grants, loans and tax credits) with non-RD&D support for business innovation (*e.g.* support for venture capital, public-private partnerships and business networks, nascent entrepreneurial activities) and targeted policies that foster demand and markets for clean energy (*e.g.* pricing mechanisms, public procurement, minimum energy performance standards, energy efficiency labels and mandatory targets).
- RD&D and innovation efforts should focus on a portfolio of technologies selected through a structured mapping exercise (Figure 5.4) that identifies existing domestic resources, skills and knowledge, and the policy frameworks and market mechanisms required to support the development and deployment of the desired technologies. Such a process should also help in identifying priority partners for international co-operation, and improve efficiency of domestic efforts.
- Emerging economies are increasing their share of global innovation and RD&D. This will bring more resources to the energy field and ensure that all countries' contexts and priorities are considered in global energy markets.

Why governments must invest in clean energy RD&D and innovation

Government support for RD&D is vital to stimulate the development of an adequate portfolio of new and improved energy technologies on a scale and within the timeframe needed. Demonstration and deployment of tomorrow's innovations are underpinned by robust funding today of basic science and applied research and development in key areas. The private sector will not do this on its own, as companies face costs associated with environmental challenges, difficulties in reaping returns from their investments, and entry barriers (OECD, 2011a).

Industrial priorities focus on shorter-term, incremental improvements designed to maximise returns on energy RD&D investments. A survey of 240 000 businesses in the United States involved in energy technology innovation, from small start-ups to multinational corporations, found that a large fraction of them expected to recoup investments in only two to three years (Anadon *et al.*, 2011).

Investing in RD&D pays off. Government investment in RD&D has led to large improvements in the performance of specific energy technologies, energy sectors and national economies. For instance, of the 14 top innovations in PV over the past three decades in the United States, 13 were developed with government support, including nine that were fully funded by the public sector (Jenkins *et al.*, 2010).

Detailed evaluations of the specific outcomes of energy RD&D are difficult, but positive financial returns are evident. The European Union estimates an internal rate of return of 15% from 2010 to 2030 for RD&D investments in its Strategic Energy Technology Plan (Wiesenthal *et al.*, 2010). The US Department of Energy found that between 1978 and 2000, investment totalling USD[1] 17.5 billion – primarily in RD&D for energy efficiency and fossil energy – provided a yield of USD 41 billion (Gallagher, Holdren and Sagar, 2006).

Accelerated patent activity is another indicator of the success of public RD&D funding. In OECD countries, an increase in public expenditures on RD&D for fuel efficiency improvements in transport resulted in a rise in both EV and HEV patenting. Other low-carbon technologies also show statistically significant increases (OECD, 2011b).

However, the relationship between the level of national energy RD&D investments and changes in the trajectory of the country's energy system is complex. Significant variations in national trends between historic levels of public RD&D expenditures and improvements in the energy intensity or carbon footprint of a given economy indicate that other factors – such as changes in the structure of the economy, in energy supply sources or in domestic energy prices – substantially influence the trajectory of a country's energy sector (Sagar and van der Zwaan, 2006).

Innovation in the energy sector is particularly challenging though, because of the dominant patterns in energy and transport markets, long development cycles (including for infrastructure replacement and development), the large-scale infrastructure, high capital cost and liquidity constraints, and slow turnover time of the energy system. In some energy technologies, such as CCS, constructing a first-of-a-kind commercial-scale plant (a role usually played by the private sector in other fields) is very expensive, increasing the need for government support (Anadon et al., 2011).

There are also limits to the rate at which clean energy technologies such as EVs, nuclear and CCS can be deployed, which adds inertia to the system. Nevertheless, China provides an example of successful efforts to accelerate the deployment of onshore wind and supercritical coal-fired power generation technologies. Within 20 years, China transformed itself from a technology importer into a major manufacturer and exporter of several low-carbon technologies (Tan and Seligsohn, 2010).

Fostering innovation requires addressing the entire innovation chain. The combination of direct support for RD&D (*e.g.* grants, loans, tax credits) with non-RD&D support for business innovation (*e.g.* support for venture capital, public-private partnerships and business networks, starting up entrepreneurial activities) and targeted policies that

1 Unless otherwise stated, all costs and prices are in real 2010 USD, *i.e.* excluding inflation. Other currencies have been converted into USD using purchasing power parity (PPP) exchange rates.

foster demand and markets for clean energy (*e.g.* pricing mechanisms, public procurement, minimum energy performance standards, energy efficiency labels, mandatory targets) is an important consideration for countries when designing their mix of policy instruments to support innovation. Any of these policies implemented alone would be less effective and more expensive. The key challenge is to strike a balance between the various instruments.

Box 5.1 Definition of the stages of energy technology innovation

The process of technological innovation is often described, for analytical and prescriptive purposes, as a linear process composed of several stages or steps that include research, development, demonstration, deployment and diffusion. Mapping innovation in the real world is clearly more complex, as the process of innovation is not a linear progression. Feedback occurs between the different stages of the process. For example, demonstration projects can result in significant changes to the product. Feedback from the market and from technology users during the commercialisation and diffusion phases can lead to additional RD&D, driving continuous innovation. Free-market competition at the later stages of the RD&D chain, when technologies are closer to commercialisation, also plays an important role for continuous innovation.

Innovation is the implementation of a new or significantly improved product (good or service) or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations (OECD and Eurostat, 2005) that reduces costs or improves performance.

Research and development (R&D) comprises creative work undertaken on a systematic basis to devise new products, processes and applications, and improve existing ones. The term covers basic research, applied research and experimental development (OECD, 2002).

Demonstration is a fundamental part of the development of new technologies and can be defined as a project involving an innovation operated at or near full scale in a realistic environment to aid policy or promote the use of innovation (OECD, 2002), and to show the viability of its application to manufacturers and potential buyers.

RD&D referred to in this report comprises research, development and demonstration.

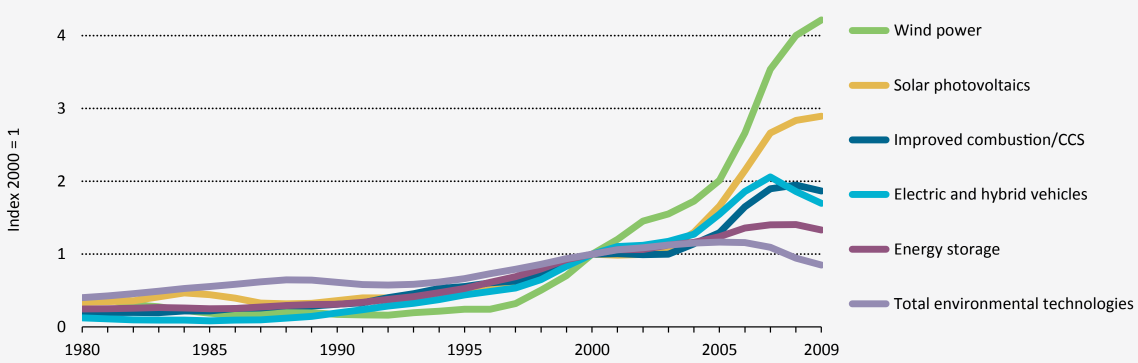
Innovation and RD&D investment trends

The rate of innovation appears to be accelerating in many clean energy technologies. The number of clean energy patents filed between 2000 and 2008 grew by 10% annually (Figure 5.1). There was a fourfold increase in renewable energy patents filed between 1999 and 2008, driven by technologies that were closest to being competitive – wind power, solar PV (but not thermal), and biofuels.

The number of CCS-related patent applications increased at a compound annual growth rate of 23% over the period 2000-11, and by 45% between 2006 and 2011. This was followed by a significant increase in the number of patents granted from around 2009. This is evidence that R&D activity has grown in response to greater policy focus on CCS since the middle of last decade.

Technologies to improve the efficiency of energy use in buildings experienced vastly different rates of development. Lighting, particularly LEDs and CFLs, has seen enormous sustained growth in patents filed since the early 1990s, which has accelerated further in the last decade. In contrast, technologies for improving building insulation have changed little. The same holds true for heating and cooling technologies, with little or no growth in innovation observed after 2000 (EPO/OECD Worldwide Patent Statistical database – PATSTAT).

Figure 5.1 Annual growth rate of low-carbon technology patenting

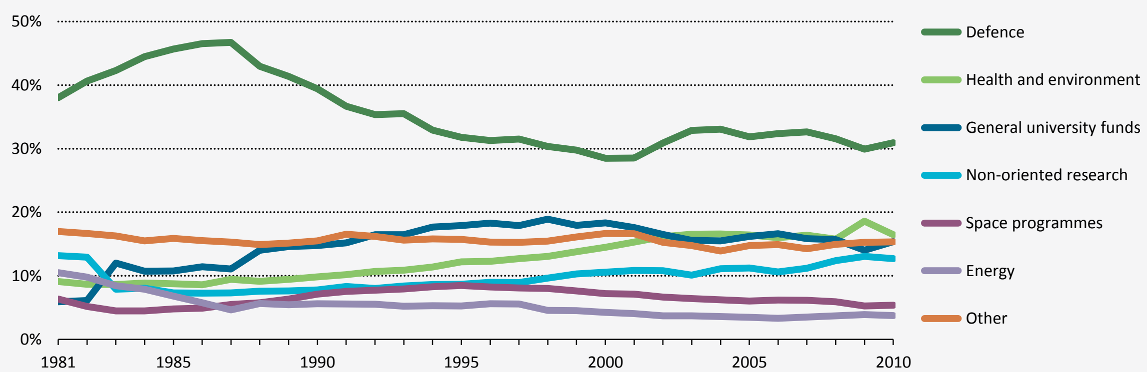


Figures and data that appear in this report can be downloaded from www.iea.org/etp/tracking.
Note: count of claimed priorities worldwide, three-year moving average, indexed on 1978 = 1.0.
Source: Haščič *et al.*, 2010.

Key point *Clean energy innovation has accelerated over the last 30 years.*

Energy gets a small slice of the research pie. OECD countries' spending on energy RD&D has been generally decreasing as a share of total research budgets over the past 30 years, as governments have preferred other areas of research, such as health, space programmes and general university research (Figure 5.2). Defence research receives the most government support, and while it has also seen its share of funding decline, it remains dominant with 30%. Energy's share has varied between 3% and 4% since 2000, after peaking in 1981, when it was over 11%.

Figure 5.2 OECD countries' spending on RD&D as a share of total R&D budgets

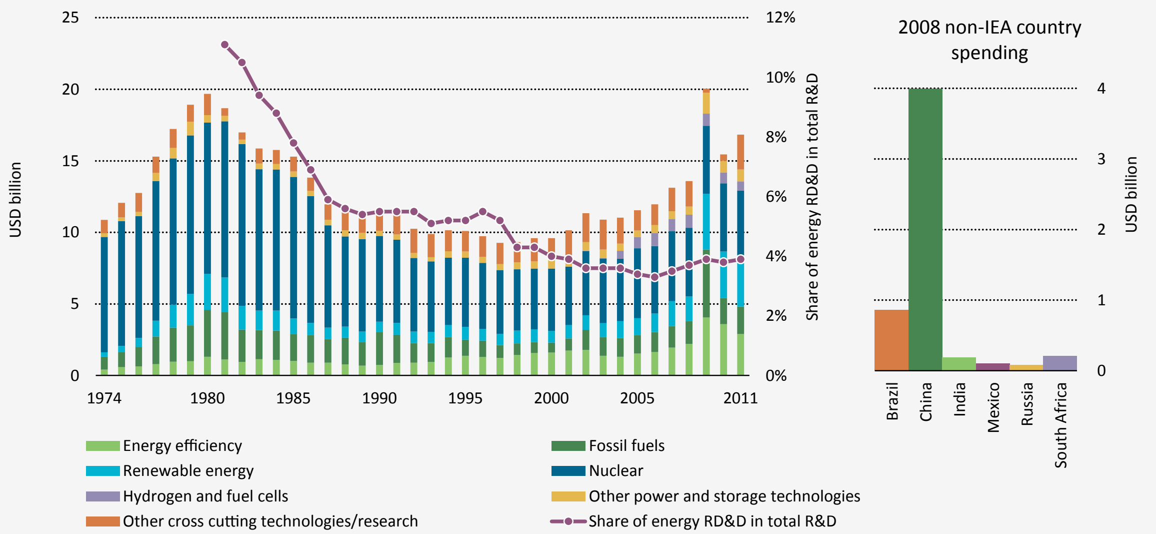


Source: OECD.Stat database.

Key point *Energy's share in RD&D budget has been declining in the OECD since the 1980s.*

In absolute terms, RD&D budgets for low-carbon technologies have been steadily increasing in IEA member countries over the past decade, from a low of USD 9.3 billion in 1997 to over USD 15 billion per year in the past three years. In 2011, the total was USD 16.8 billion. Funding has risen nearly every year since the late 1990s and received a substantial increase as part of "green stimulus" spending programmes in 2009. Such high levels of investment channelled money into innovation centres like the US Department of Energy's Advanced Research Projects Agency, which supports high-risk, potentially high-payoff projects that are not sufficiently advanced to attract venture capital investment. However, with growing concern over budget deficits, funding levels have decreased from peak levels in 2009 (Figure 5.3).

Figure 5.3 Government energy RD&D expenditure in IEA member countries



Source: IEA; Kempner *et al.*, 2010.

Key point *IEA member countries have increased absolute spending on energy related RD&D, but the overall share remains low. Nuclear energy has the largest share of energy RD&D.*

Nuclear fission still accounts for the largest share of investment in energy technology RD&D among IEA countries, roughly 24% in 2010 (nuclear fusion accounts for 5%). In general though, RD&D spending has moved away from nuclear, which accounted for over 70% in the mid-1970s, towards renewable energy, cleaner fossil fuel, and emerging technologies such as smart grids and EVs.

Renewables, hydrogen and fuel cells have seen the biggest increases since 2000. In particular, spending on renewable energy RD&D has risen sharply over the last decade and now accounts for over 24% of total public spending on clean energy RD&D. In general, the United States and Europe spend more on RD&D for renewables than the Pacific region or emerging economies. Data are less comprehensive for emerging economies than for IEA countries, but it is clear that RD&D is focused on nuclear energy, fossil fuels, and transmission, distribution and storage technologies, while deployment activities concentrate on renewables and energy efficiency (Kempner *et al.*, 2010).

Most of the 2009 stimulus funds for energy RD&D were attributed to cleaner fossil fuels research, but since then the trend has reversed and research spending on all fossil fuels and renewables is now about equal.

Cumulative spending on projects that demonstrate CCS reached almost USD 10.2 billion in the period between 2005 and 2012. This is a significant increase over previous periods, but is still far below the estimated investment needed to deliver CCS levels envisaged in the 2DS. Australia and Norway spend just over 30% of their clean energy RD&D budgets on CCS; Canada spends 37%.

Governments are also ramping up investments in EVs and HEVs, announcing ambitious targets for their sales (20 million by 2020). Enhanced RD&D will be fundamental to reaching these targets. Spending on research into energy efficiency has been fairly steady since 2000, distributed across industry, residential and commercial buildings.

Large differences are evident across countries in spending on clean energy RD&D as a function of GDP per capita, and in relation to their total CO_2 emissions. Scandinavian countries spend up to ten times more per capita than the United Kingdom or Spain. Finland, Japan and Australia spend the highest proportion of GDP on low-carbon RD&D, while Switzerland, France and Finland spend most in relation to total emissions. As private sector data are very limited, the picture may be distorted to some extent.

Countries have been favouring certain low-carbon technologies over others (Table 5.1). Public spending has fallen most for nuclear power, and has increased for renewable sources, notably solar PV, over the last five years. RD&D funding has also significantly increased for CCS, but trends in CCS and advanced vehicles are more difficult to gauge, as measurements of research spending by the public sector began only recently. Although many countries have reduced or maintained levels of spending on nuclear RD&D, it still receives the lion's share of funding.

Bridging the RD&D investment gap

Government investment in RD&D should at least triple. Global public spending on energy RD&D needs to increase substantially, as is shown by an assessment of the gap between current levels and the levels needed to achieve the 2DS by 2050 (Table 5.2). For some technologies, such as advanced vehicles and CCS, the gap between current levels of RD&D spending and estimated needs may be an order of magnitude.

The analysis indicates that governments need to cover at least 50% of RD&D needs. However, since data on private RD&D investment is scarce, analysis to underpin any assumption is difficult. Experience with the development of advanced energy technologies, particularly where environmental and other public benefits are primary motivations for their development (as in the case of CCS), suggests that the required public share is typically greater than 80%.

Table 5.1 Changes in public sector spending levels on low carbon RD&D

Country	Energy Efficiency			Renewables							
	Industry	Buildings	Transport	Solar excl. PV	Solar PV	Wind	Biofuels	Geothermal	Hydro	CCS	Nuclear fission
Australia	Increase <100%	Decrease <50%	Increase >300%	Increase >300%	Increase >300%	Increase <100%	Increase 100% to 300%	Increase <100%		Increase >300%	Decrease <50%
Austria	Increase 100% to 300%	Increase 100% to 300%	Increase 100% to 300%	Increase <100%	Increase 100% to 300%	Increase 100% to 300%	Increase <100%	Increase 100% to 300%	Increase 100% to 300%		
Canada	Increase <100%	Stable	Stable	Increase <100%	Increase <100%	Increase 100% to 300%	Increase 100% to 300%	Increase 100% to 300%	Increase >300%	Increase >300%	Increase 100% to 300%
Denmark	Increase 100% to 300%	Increase 100% to 300%		Increase 100% to 300%	Increase 100% to 300%	Increase 100% to 300%	Increase 100% to 300%				Decrease >50%
Finland	Increase 100% to 300%	Increase >300%	Increase 100% to 300%			Increase 100% to 300%	Increase <100%				Increase <100%
France	Increase <100%	Increase 100% to 300%	Increase <100%	Increase 100% to 300%	Increase <100%	Increase <100%	Increase >300%	Decrease <50%	Increase >300%	Increase 100% to 300%	Decrease <50%
Germany	Increase 100% to 300%	Increase <100%		Stable	Increase <100%	Increase 100% to 300%	Increase 100% to 300%	Increase <100%		Increase 100% to 300%	Increase 100% to 300%
Hungary						Decrease <50%	Increase <100%				Decrease <50%
Ireland	Increase <100%	Increase 100% to 300%		Increase <100%	Increase >300%	Increase 100% to 300%	Increase 100% to 300%	Increase 100% to 300%			
Italy	Increase <100%	Increase 100% to 300%	Increase >300%	Decrease >50%	Increase <100%	Increase 100% to 300%	Increase >300%			Increase 100% to 300%	Decrease <50%
Japan	Decrease <50%	Increase 100% to 300%	Increase 100% to 300%		Decrease >50%	Increase <100%	Decrease <50%			Increase >300%	Decrease <50%
Korea	Increase 100% to 300%	Increase >300%	Increase 100% to 300%			Increase 100% to 300%	Increase <100%	Increase 100% to 300%	Decrease >50%	Increase 100% to 300%	Decrease <50%
Netherlands	Increase <100%	Increase <100%	Stable		Increase <100%	Increase <100%	Increase <100%			Increase 100% to 300%	Decrease <50%
New Zealand	Increase 100% to 300%	Decrease >50%			Increase <100%		Increase >300%	Increase 100% to 300%		Increase <100%	
Norway	Increase >300%	Increase <100%			Increase >300%	Increase >300%	Increase >300%		Increase <100%	Increase 100% to 300%	Stable
Portugal	Decrease >50%			Decrease <50%	Increase >300%	Increase <100%	Decrease <50%				
Spain	Increase <100%	Increase 100% to 300%	Decrease <50%	Increase <100%	Increase <100%	Decrease <50%	Increase 100% to 300%		Decrease <50%	Increase <100%	Decrease <50%
Sweden	Decrease <50%	Increase <100%	Increase <100%		Increase 100% to 300%	Increase <100%	Increase 100% to 300%	Decrease >50%	Stable		Stable
Switzerland	Increase <100%	Increase <100%	Stable	Stable	Increase <100%	Increase <100%	Increase <100%	Increase 100% to 300%	Increase <100%		Stable
Turkey	Decrease >50%			Increase 100% to 300%	Increase <100%		Increase 100% to 300%	Increase <100%			
United Kingdom						Increase 100% to 300%	Increase >300%			Increase >300%	Increase >300%
United States	Increase 100% to 300%	Increase 100% to 300%	Increase 100% to 300%			Increase 100% to 300%	Increase >300%	Increase >300%		Increase >300%	Increase 100% to 300%

Decrease: >50% · <50% | Stable | Increase: <100% · 100% to 300% · >300%

Notes: the table compares two 5 year periods of data (2002-06 and 2007-11) for each country and assesses the magnitude of the change in spending from one period of time to the next. 2011 data are not available for Austria, Finland, France and Ireland. The intervals 2000-04 and 2005-10 were used for Turkey. Biofuels includes solid, liquid and gaseous biofuels. CCS data are available starting in 2004 thus recent trends were used to assess the change. Empty cells indicate data not available or not applicable.

Nuclear fission is the only technology where spending seems in line with the estimated needs, but this may not be an accurate picture: much of the nuclear RD&D needed is for generation IV reactor types, which are not fully captured in this analysis, as ETP scenarios assume they will not be available until late in the modelling period. The same is true for fusion technologies, which do not appear at all in the period before 2050 in ETP scenarios. Further, in some technology areas like wind energy, the private sector is believed to be the largest funder of RD&D, making it very difficult to evaluate whether sufficient funds are being allocated.

Table 5.2 RD&D gaps for selected technology groups

[USD Million]	Annual global total (private and public) RD&D needs to achieve the 2DS		Current global annual public RD&D spending	Estimated annual RD&D spending gap	
	min	max		min	max
Advanced vehicles (includes electric vehicles and fuel cell vehicles; EE in transport)	17 500	35 000	2 583	15 000	32 700
Bio-energy (biomass combustion & biofuels)	1 800	3 500	1 498	340	2 200
CCS (power generation, industry, fuel transformation)	12 500	25 000	902	11 600	24 100
Higher-efficiency coal (IGCC & USCSC)	1 100	2 100	351	700	1 800
Solar (PV, CSP and heating)	2 100	4 200	1 071	1 000	3 100
Wind energy (onshore and offshore)	2 100	4 200	455	1 700	3 800
Nuclear fission	1 800	3 700	3 740	-1 900	- 50

Notes: RD&D investment needs are derived using 10% to 20% of average RDD&D costs for the 2DS. RDD&D costs are approximated by the cumulative investment expenditures in the 2DS until a technology becomes cost-competitive. Public sources are expected to contribute at least 50% of this.
IEA 2010 data with the following exceptions: country submissions for Russia and Brazil; Kempner *et al.* (2010) for South Africa, China and Mexico. Estimates were not available for RD&D needs for energy efficiency in buildings and industry, or for smart grids. IGCC: Integrated gasification combined cycle. USCSC: ultra-supercritical steam cycle. Other analyses are consistent with these findings. The UNFCCC (2007) has proposed a doubling in global expenditure on energy R&D to about USD 20 billion a year. Kerr and Chiavari (2009) highlight other studies that have called for increases of two to ten times current levels of energy RD&D expenditures.

Bridging the RD&D investment gap is a major challenge, particularly in the light of the current financial crisis. Some high-risk technologies that governments are supporting will not meet expectations and others will be called upon to help meet the overall goal of reducing emissions. The actual performance of each technology cannot be known in advance; some over-investment may be needed to ensure sufficient overall success. Other factors, such as public acceptance and environmental repercussions, would also affect the rate of technology deployment and the level of investment needed.

A review based on announced technology programmes or strategies reveals significant discrepancies between stated energy RD&D priorities and actual funding. Only France, Brazil, Japan and Norway spend over 75% of their energy RD&D budgets on technology areas specified in their national strategies (Table 5.3).

Table 5.3 Stated energy RD&D priorities versus actual funding

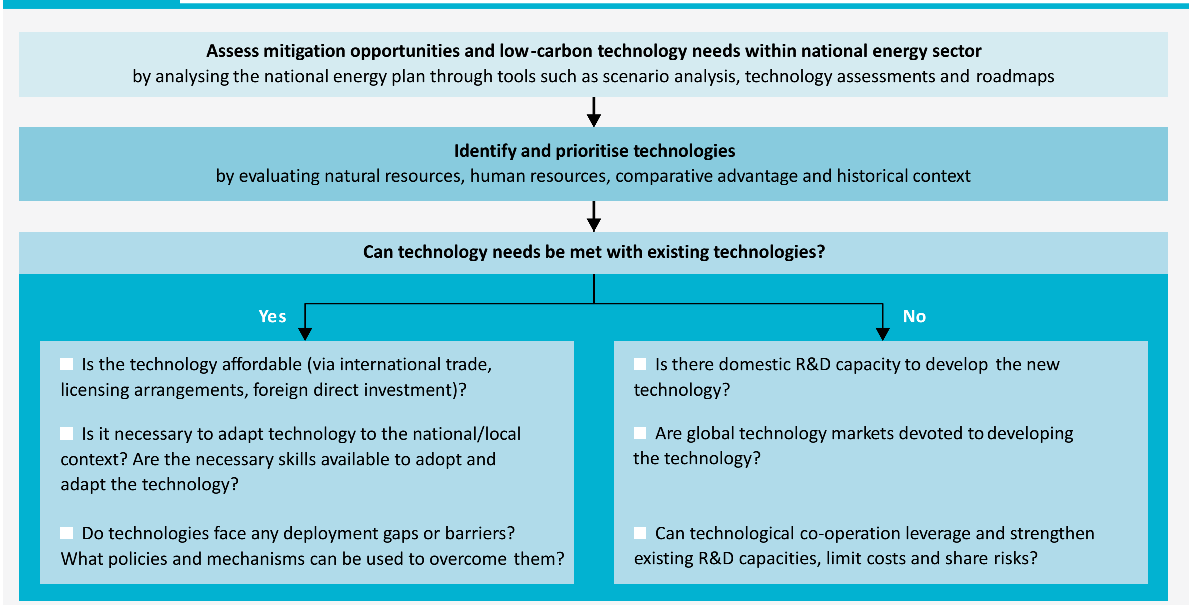
Country	Name of programme or strategy	Programme or strategy priorities	Share of RD&D spending on priorities	Do stated priorities and actual spending match?
Australia	Clean Energy Initiative	CCS, low emissions coal, renewable energy (specifically solar).	CCS 19%, low emissions coal 8.3%, renewables 22% of which 14.5% is solar (PV 11%).	Stated priorities account for 50% of total energy RD&D budgets.
Brazil	Science, Technology and Innovation Platform for National Development 2007–10	Biofuels, T&D, hydrogen, renewables, oil, gas, coal and nuclear.	Biofuels 14%, T&D 23.5%, hydrogen 2%, hydro 11% and nuclear 23%.	Stated priorities account for 81% of total energy RD&D budgets.
Canada	Energy RD&D programme divided into 9 portfolios	Oil and gas, clean coal, CCS, distributed power, generation IV nuclear, bio-based energy systems, industrial systems, clean transportation, built environment.	Non-conventional oil and gas 6%, coal 7%, CCS 15.5%, fuel cells 3.66%, EE in industry 3.22%, EE in the transport 2.5% and nuclear 29%.	Stated priorities account for 67% of total energy RD&D budgets.
France	National Strategy for Energy Research 2007	Nuclear, renewables, fuel cells, energy storage, CCS, EE in buildings, biofuels, low carbon vehicles.	Nuclear 50%, renewable energy 11%, fuel cells 3%, CCS 4.5%, EE in buildings 3%, and biofuels 4.5%.	Stated priorities account for 80% of total energy RD&D budgets.
Germany	Innovation and New Energy Technologies 2005	CCS, PV, solar thermal, wind, fuel cells and hydrogen, technologies and processes for energy-optimised buildings, technologies and processes for use of biomass for energy.	CCS 1%, PV 9%, solar thermal 1.3%, wind 5%, fuel cells and hydrogen 5.1%, technologies and processes for energy-optimised buildings 3%, technologies and processes for use of biomass for energy 1.32%, nuclear 34%	Stated priorities account for 60% of total energy RD&D budgets
Japan	Science and Technology Basic Plan 2006	Energy efficiency, nuclear, transport, fuel cells, hydrogen, solar PV and biomass energy, oil, gas and coal	Energy efficiency 10%, nuclear 64%, transport, fuel cells 3%, hydrogen 1.4%, solar PV 1.4% and biomass energy .27%, oil gas and coal 9.3%.	Stated priorities account for 80% of total energy RD&D budgets.
Korea	Green Energy Strategy Roadmap 2009	PV, wind power, fuel cells, LED, smart grids, IGCC, energy storage, clean fuels, CCS, nuclear power, green cars, heat pumps, energy efficient buildings, CHP, superconductivity.	Wind power 6.5%, fuel cells 8.6%, IGCC.1%, energy storage 3.8%, CCS 4.5%, nuclear power 16%, energy efficient buildings 5%.	Stated priorities account for over 50% of total energy RD&D budgets.
Norway	OG 21 2001 and Eneri 21 2008	Oil and gas, energy systems, renewable electricity, energy efficiency in industry, renewable thermal energy and CCS.	Oil and gas 37%, energy systems 4.7%, renewable electricity 15.5%, energy efficiency in industry 2.3, renewable thermal energy 1.2% and CCS 15.6%.	Stated priorities account for 76% of total energy RD&D budgets.
Spain	National Strategy for Science and Technology 2006–15	Energy efficiency, clean combustion, renewable energy, sustainable mobility, modal shift in transport, sustainable buildings.	Energy efficiency 8.3%, renewable energy 43%, coal 1%, energy efficiency in the transport sector 1%, energy efficiency in buildings 5%.	Stated priorities account for 60% of total energy RD&D budgets.

Sweden	National Energy Research Programme 2006	energy systems studies, buildings as energy systems, transport, energy-intensive industry, electricity generation and distribution, bioenergy, CHP.	energy systems studies, energy efficiency in buildings 4.7%, transport 22%, energy intensive industry, 8.4%, electricity generation and distribution 7.7% and bioenergy 10.6%.	Stated priorities account for 70% of total energy RD&D budgets.
United Kingdom			wind 10%, ocean energy 4%, CCS 6%.	Technologies where the UK has a leading edge capability account for 20% of total energy RD&D budgets.

Notes: this sample is not an exhaustive list, but rather a showcase of the variety of practices across countries and institutions. Analysis is based on data for the following years: Australia, Canada, Japan, Norway, Spain: 2007-11; Germany, Sweden and the United Kingdom: 2006-10; Brazil: 2009-10; France: 2007-09; Korea: 2009-11; the Netherlands: 2008-09.
Source: Chiavari and Tam, 2011.

Countries have been favouring certain technologies without using structured analysis and documented processes to determine clear priorities, resulting in a lack of coherence in RD&D strategies. Governments should identify existing skills and knowledge, and those that are required to support the development and deployment of priority technologies. This will enable an assessment of any gaps that may exist and the subsequent development of targeted programmes to address them (Figure 5.4).

Figure 5.4 Process for developing an energy RD&D strategy



Key point *RD&D priorities should be closely linked to the national energy strategy.*

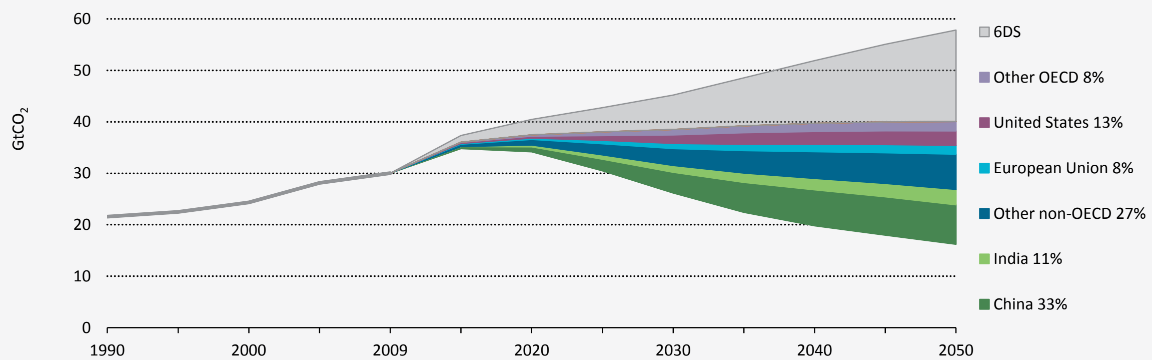
R&D and innovation in emerging economies

RD&D in non-OECD countries is predominantly funded by governments, and is focused on basic and applied research rather than on development. Adaptation and improvements on existing technologies are the main source of innovation. The scientific agenda in many of these countries tends to concentrate on areas of interest for OECD countries (Correa, 2011).

However, there are growing differences among non-OECD countries in terms of their RD&D and innovative capacities. Exceptional growth and capital accumulation have increased the exposure of emerging economies to international technology through trade and flows of foreign direct investment. Combined with strong investment in domestic skills development, this has contributed to their growing capacity for innovation. Several emerging economies have established ambitious RD&D policies and identified technology priorities.

As emerging economies increase their energy use and their CO_2 emissions, there is an urgent need to understand better their energy innovation policies, the magnitude of their RD&D budgets, and the effectiveness of their initiatives. In the 2DS, emerging economies make the biggest contribution to CO_2 abatement (Figure 5.5).

Figure 5.5 World energy-related CO_2 emissions abatement by region



Note: the shaded areas represent emissions reductions needed to go from the 6DS to the 4DS. Percentages are cumulative contributions by region in going from the 4DS to the 2DS.

Key point *All regions need to contribute with emissions reduction in order to achieve the 2DS.*

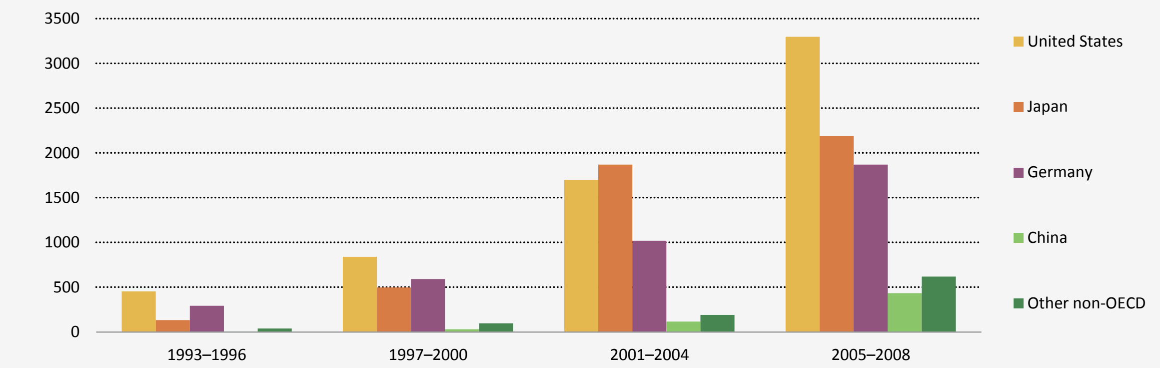
Data collection on RD&D investment and strategies in emerging economies needs to be more comprehensive to help decision-making and international collaboration. Several international initiatives, including the CEM, have attempted to collect data and report on energy technology RD&D in emerging economies, but most analyses focus on OECD countries. The IEA is one of the few agencies collecting data on energy technology RD&D budgets for its members. Absence of a centralised, reliable source for RD&D spending data for non-OECD countries makes it very difficult to compare countries' initiatives, and to estimate global public spending on clean energy RD&D.

The information that is available indicates that emerging economies are increasing their share of global RD&D and innovation. In Brazil, China and India, where governments are investing more in RD&D than other emerging economies, the private sector is also more heavily involved in RD&D. All three countries are starting to reap benefits from decades of investments in education, research infrastructure and manufacturing capacity. Brazil, China and India are already playing leading roles in developing, manufacturing, deploying and exporting (including to OECD countries) clean energy technologies such as solar panels, wind turbines and biofuel technologies (UNCSD, 2011).

Emerging economies could leapfrog towards a competitive, low-carbon economy not only by applying technology developed elsewhere but also through domestic innovation. In 2008, the governments of six emerging economies (Brazil, China, India, Mexico, Russia and South Africa) may have controlled larger amounts of energy RD&D funding than the governments of the IEA countries, including investments by state-owned enterprises (Kempner *et al.*, 2010).

Despite the increase in RD&D spending by emerging economies, however, OECD countries hold an overwhelming majority of patents in all categories of clean energy technology, led by Japan, the United States and Germany, followed by Korea (which has had exceptionally high growth rates in recent years), the United Kingdom and France (Figure 5.6). While patents are a useful indicator of product and process innovation, they do not capture the entire landscape of innovation and knowledge protection. Intellectual property protection mechanisms include other ways of protecting innovations, such as copyrights and trademarks.

Figure 5.6 Clean energy patents filed by inventor's country of residence



Source: European Patent Office (EPO)/OECD Worldwide Patent Statistical database (PATSTAT).

Key point *Clean energy patent filing has grown quickly. OECD countries still dominate.*

The country ranking is similar across all technology fields, but different countries have specialised in different clean energy technologies. For instance, Japan and Korea are particularly prominent in solar PV, Denmark in wind power and Norway in hydroelectric and marine technologies (Haščič *et al.*, 2010).

Patent data also show that emerging economies are becoming increasingly active, including China, India and South Africa. China, in particular, has been catching up in the last few years in several clean energy technologies (except carbon capture), although it is possible that many patent filings are made by the Chinese subsidiaries of multinational enterprises (Lee *et al.*, 2009).

International collaboration can enable governments to conduct more RD&D at a lower cost and with less duplication, but most current collaborative activities in emerging economies focus on facilitating deployment rather than RD&D. Collaborative RD&D is often difficult, because sharing knowledge is risky, capabilities for innovation are limited in some countries, and national regulations and policies related to RD&D tend to differ (UNFCCC, 2010). The IEA, which has a long history of facilitating international RD&D co-operation through its Implementing Agreements, has documented innovative models for co-operation, such as the US-China Clean Energy Research Center (US-China CERC) (Chiavari and Tam, 2011).

RD&D in emerging economies is strongly focused on renewables, with far fewer collaborative RD&D activities in industry, transport and energy efficiency in buildings. Governments should develop clear criteria for setting priorities not only in technology areas and but also in selecting partners for international RD&D collaboration.

Box 5.2 Opportunities for low-carbon technology innovation in India

India faces formidable energy challenges. It relies heavily on fossil fuels and its energy demand is set to grow more than fourfold over the coming decades (IEA, 2012a). Current trends will drive up imports of fossil fuels, local pollution and greenhouse gas emissions, and put energy security at risk. But India is also well placed to take advantage of new clean energy technologies that could head off these dangers, with a solid engineering base and a strong, innovative private sector that has consistently surprised the world with pioneering and affordable technology solutions.

According to the Planning Commission of India, the greatest potential lies in enhancing efficiency in power generation and improving its end-use efficiency, as well as accelerating the deployment of renewable technologies (PCI, 2011). Sources of low-carbon technology include technology transfer, especially through joint ventures, which have a potential to maximise technology access by local firms, as opposed to foreign direct investment. For example, joint ventures between Japanese and Indian companies have enabled the production in India of high-efficiency, low-emission coal technologies. BP Solar's joint venture with Tata Group has driven solar PV activity in India.

Access to low-carbon technologies has also been facilitated by the purchase of production equipment or through the strategic acquisition of companies based in OECD countries. For instance, a key part of the leading Indian wind turbine manufacturer Suzlon's strategy has been to acquire majority shares in European technology companies, expand its R&D facilities in several countries in Europe, and engage into collaborative R&D. Although technology acquisition may not always be the primary driver in many of these transactions, technology diffusion is often a consequence.

India has managed to switch from being an importer to becoming a net exporter of products and components used for wind, solar and hydro power. Imports into India increased by 172% between 2005 and 2008, amounting to USD 2.8 billion in 2008, while exports increased by 494%, reaching USD 3 billion in 2008 (IEA, 2010). Based on patent data, India presents above average competence in hydropower and solar thermal power, and it has acquired export specialisation in wind power systems, playing an important role as a technology innovator.

Although India has relevant industries and a vibrant entrepreneurial ecosystem, R&D activities are predominantly government-led, and Indian research is strongly directed towards goals set by the government. High interest rates and short-term loans increase the cost of renewable energy projects in India by up to a third compared with similar projects in the United States and Europe (Shrimali *et al.*, 2012). Funding constraints have been affecting all stages of the innovation process in India, particularly since the 2008 financial crisis, but the government can help to address these by building partnerships and networks with the private sector, and providing incentives to drive capital investment in low-carbon technologies, through supportive policies like grants, soft loans and tax incentives.

Recent initiatives to establish dedicated university and training courses for new energy technologies, including solar, and to provide training for energy managers and energy technicians, will go a long way not only to transform the energy system but also to prepare human resources for the challenges ahead. Enhancing support for R&D and technology cooperation within India and with selected international partners could offer many benefits.

Recommendations for governments

Governments that want to realise the 2DS goals must enact ambitious policies over the next decade that prioritise the development and deployment of clean energy and energy-efficient technologies in the power generation, industry, buildings and transport sectors.

Governments can accelerate technological change through a variety of support measures, including economic instruments such as carbon pricing and energy taxes, regulatory measures such as standards and mandates, and direct public support for RD&D.

While the optimal level of public funding and the appropriate combination of policy measures depends on the specific technology and country circumstances, and the importance of technology support policies tends to decrease as technologies mature, in all cases it is vital to establish a supportive policy environment in which innovation can thrive, and within which effectiveness and efficiency of individual policies can be assessed.

Governments can accelerate the development and early adoption of advanced low-carbon technologies by providing public funds, mainly through domestic research budgets, grants and soft loans, to support R&D – the highest-risk activity – and the translation of resulting technologies to prototype products. They may also need to support applied R&D to adapt existing technologies to local conditions (*e.g.* adapting coal power plants to specific coal characteristics or wind turbines to difficult environmental conditions) or sometimes to use known technologies in a new way (*e.g.* mobile device electrical energy storage towards electric vehicle batteries; thin-film production technologies of flat screens towards thin-film solar cells).

As a technology moves towards commercialisation, risk declines but funding requirements increase. As a result, the share of government involvement generally decreases, since private companies generally do a better job than governments in shaping technologies for the marketplace. Governments do need to partner with the private sector, however, to enhance the effectiveness of public investment by leveraging private sector funds. The roadmapping process is a good opportunity to set the stage for partnership with industry. For example, Japan's government relies heavily on its technology roadmap to gather information and share the long-term technology perspective with the private sector.

Successful innovation builds on a carefully chosen combination of stakeholders with different appetites for risk, over a long period. Venture capitalists and so-called angel investors, who typically invest their own money, often support start-up and pre-commercial initiatives, while private equity investors, banks and financial institutions come in when RD&D has advanced sufficiently to ensure a reasonable financial return. Governments can help companies reduce the cost of demonstrating new technologies (e.g. networking with banks to design appropriate financing instruments), and provide support for venture capital funding and research infrastructure.

Once technologies are proven and, in principle, commercially available, governments can help them to avoid the vicious circle of small volume and high costs – "the valley of death of commercialisation" – by addressing barriers such as infrastructure needs, slow capital turnover, poor market organisation, and information and financing constraints. Achieving widespread deployment of clean energy technologies requires strong, predictable, transparent and credible government policies that create demand and markets for more mature technologies, like solar PV and onshore wind, and gains in energy efficiency in the end-use sector, and support future operational cashflow. Such policies include pricing mechanisms, innovation-friendly public procurement, standards that promote consumer acceptance, energy efficiency labels for appliances, and feed-in tariffs for renewables. Financing pre-normative research, to provide a scientific base for setting norms and standards, and harmonising standards internationally can also have a leveraging effect for energy technology innovation.

If demand for innovation is augmented, a continuing flow of technology developments will improve the portfolio of available CO_2 mitigation options, bring down the costs of achieving global climate goals, and provide significant economic, environmental and security benefits. But scale, timing and duration of policies to foster demand need to be determined carefully and modified as necessary, and should allow for gradual removal of support as technologies reach maturity, such as in the case of gas and nuclear.

These policies will be even more effective if combined with other measures to overcome non-economic barriers, such as access to networks, permitting and social acceptance issues. Phasing out fossil fuel subsidies – which in 2011 were almost seven times higher worldwide than the support for renewable energy (IEA, 2012b) – is also critical to level the playing field across all fuels and technologies.

To scale up RD&D and foster innovation, governments should:

- *Develop a coherent energy strategy, with clear priorities and objectives for the short, medium and long term. This should consider the entire innovation chain, in close consultation with major stakeholders in the public and private sectors, and be consistent with other related policy areas, such as science and technology, education, economic development and industry.*
- *Triple public sector investment in technology RD&D, particularly in promising energy technologies such as CSP, advanced biofuels, advanced vehicles, and capital-intensive technologies such as CCS and IGCC, which have significant potential but still face technology and cost challenges.*
- *Facilitate the emergence of disruptive, "game changing" technologies – innovations that could dramatically alter the energy landscape. The process of energy technology innovation is uncertain and no one can predict where or when the most important breakthroughs may arise. For instance, US public investment aimed at producing fuels from coal and oil shale in the 1970s (often referred to as a failed initiative) gave rise to a key demonstration of coal gasification technology – the Great Plains Synfuels Plant in North Dakota (Jenkins* et al.*, 2010). Technology policy needs to be able to enable, identify and support positive disruptive processes and technologies.*
- *Invest in cross-cutting technology areas – such as advanced materials, nanotechnologies, life sciences, green chemistry, and information and communication technologies – because breakthroughs in energy technology often depend on progress in other fields. For example, chemistry research helps increase the efficiency with which energy is generated, transmitted, stored and used. Advanced materials research is essential to develop and produce more efficient photovoltaic products, lighter vehicles and better batteries, and enable ultra-supercritical coal-fired power plants, hydrogen storage and fusion power. Governments should examine how research advances in other fields could cross-fertilise innovation and accelerate energy technology development.*
- *Expand international technology collaboration to increase and leverage public resources and improve efficiency of national energy RD&D investments.*
- *Improve public and private RD&D data quality, completeness and transparency.*
- *Provide support for business innovation other than RD&D-related schemes (*e.g.* support for venture capital, public-private partnerships and business networks, nascent entrepreneurial activities) and create explicit links between research programmes and market needs to encourage cost reductions, information sharing and technology transfer.*
- *Combine public funding schemes with policies that foster demand (*e.g.* pricing mechanisms, public procurement, minimum energy performance standards) in order to attract private investment, enable continued learning and cost reductions, help available technologies to penetrate the market faster, and improve the long-term cost-effectiveness and feasibility of climate policy. This will require mechanisms to enhance government co-ordination, stakeholder involvement and competencies in public administrations.*

Annexes

Acronyms, Abbreviations and Units

Acronyms

AUD	Australian dollar
BAT	best available technology
BEEP	Building Energy Efficiency Policies database
BEV	battery electric vehicle
BTX	benzene, toluene and xylene
BPT	best practice technology
CCS	carbon capture and storage
CCGT	combined cycle gas turbine
CCUS	carbon capture use and storage
CEM	Clean Energy Ministerial
CFL	compact fluorescent light bulb
CHP	combined heat and power
CSP	concentrated solar power
DOE	Department of Energy (United States)
DRI	direct reduced iron
EC	European Commission
EE	energy efficiency
EED	Energy Efficiency Directive (EU)
EOR	enhanced oil recovery
EPA	Environmental Protection Agency (United States)
EPBD	Energy Performance of Buildings Directive (EU)
ESCII	Energy Sector Carbon Intensity Index
ETP	Energy Technology Perspectives 2012
ETS	emissions trading scheme
EU	European Union
EUR	euro
EV	electric vehicle (including plug-in hybrid-electric vehicles and battery electric vehicles)
EVI	Electric Vehicles Initiative
FIT	feed-in tariff
GBP	Great Britain pound
GDP	gross domestic product

GCCSI	Global Carbon Capture and Storage Institute
GFEI	Global Fuel Economy Initiative
GHG	greenhouse gas
GSGF	Global Smart Grid Federation
HDV	heavy duty vehicle
HELE	higher-efficiency, lower emissions (coal)
HEV	hybrid-electric vehicles
HVAC	heating, cooling and ventilation
HVC	high-value chemicals
ICE	internal combustion engine
ICT	information and communications technology
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
ISGAN	International Smart Grid Action Network
JRC	Joint Research Centre (European Commission)
LDV	light-duty vehicle
LED	light-emitting diode
LCIP	large-scale integrated project
MEPS	minimum energy performance standards
MVE	monitoring, verification and enforcement
NDRC	National Development and Reform Commission (China)
OCGT	open cycle gas turbine
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
PHEV	plug-in hybrid-electric vehicle
PMU	phasor measurement unit
PV	photovoltaic
R&D	research and development
RD&D	research, development & demonstration
RHI	Renewable Heat Incentive
RPS	renewable portfolio standard
SC	supercritical
S&L	standards and labelling
SME	small and medium-sized enterprises

SMR	small modular reactors
SUV	sport utility vehicle
TJ	terajoule
TOE	tonne of oil equivalent
USC	ultra-supercritical
USD	United States dollar

Abbreviations

CO_2	carbon dioxide
2DS	2°C scenario
4DS	4°C scenario
6DS	6°C scenario

Units of measure

bbl	barrel (oil)
EJ	exajoule
Gt	gigatonne
Gtoe	gigatonnes of oil equivalent
GW	gigawatt
km	kilometre
kW	kilowatt
kWh	kilowatt-hour
L	litre
L/100 km	litre per 100 kilometres
lge	litres gasoline equivalent
LHV	lower heating value
LNG	liquefied natural gas
m^2	square metre
MBtu	1 000 British thermal units
MJ	megajoule
Mt	megatonne
Mtoe	million tonne of oil equivalent
MW	megawatt
MWh	megawatt-hour
TWh	terawatt-hour

Technology Overview Notes

Enhanced interactive data visualisations are available at www.iea.org/etp/tracking for the figures marked with the "more online" ribbon.

Unless otherwise noted, data in the two page technology info graphic at the start of each section derives from IEA statistics and analysis. The notes below provide additional sources and details related to data and methodologies.

Renewable Power (page 22)

Figures 1.1, 1.2: source: data for 2011-2017 from IEA, 2012c.

Figure 1.3: source: Bloomberg New Energy Finance, 2013, United Nations Environment Programme-Bloomberg New Energy Finance, 2012 (http://fs-unep-centre.org/publications/global-trends-renewable-energy-investment-2012), and IEA analysis.

Figure 1.4: costs refer to overnight investment costs. Overnight cost is the present value cost of total project construction, assuming a lump sum up-front payment and excluding the cost of financing.

Figure 1.5: data in USD 2011 prices and exchange rates.

Nuclear Power (page 32)

Figure 1.8: source: historic data from IAEA, PRIS Database.

Figure 1.9: source: historic data from IAEA, PRIS Database. 2DS numbers are required average yearly capacity additions: 16 GW/year in the decade to 2020, and 20 GW/year between 2020 and 2030. Projections from NEA, 2012b.

Figure 1.11: 2DS number represents required yearly average investment to 2025.

Figure 1.12: data in USD 2011 prices and PPP.

Natural Gas-Fired Power (page 38)

Figure 1.16: underlying assumptions: overnight investment costs: coal 2 300 USD/kW, gas 1 000 USD/kW +-30%; fixed O&M costs: 2% of overnight costs; construction time: coal 4 years, gas 3 years; load factor: coal 85%, gas 60%; efficiency: coal 45%, gas 60%; fuel cost: coal 88-118 USD/tonne; gas 4-11 USD/MBtu; Carbon price: 0-30 USD/t CO_2; specific emissions: coal, 760 g/kWh, gas 354 g/kWh; discount rate: 8%. Short term switch price is what would be required to shift generation in existing installations. Long term switch price is what would make new gas generation capacity competitive against coal, given assumptions on investments costs, fuel prices etc.

Figure 1.17: Source: Mom, 2013.

Coal-Fired Power (page 46)

Figure 1.22: source: 2011-2017 projections from IEA, 2012e.

Figure 1.23: source: Platts database.

Figure 1.24: total investments calculated are based on capacity additions from Platts database, and cost and construction time estimates from the IEA. Total investment is allocated to the year in which the plant is assumed to have begun construction. This method was chosen to allow for consistency of comparison between different technology areas.

Carbon Capture and Storage (page 56)

Figure 2.1: source: GCCSI, 2012; IEA analysis.

CTL: coal to liquids; DRI: direct reduced iron.

Large-scale projects are defined in accordance with the definitions of the Global CCS Institute (The Global Status of CCS: 2012, GCCSI): projects involving the capture, transport and storage of CO_2 at a scale of at least 800 000 tonnes of CO_2 annually for a coal-based power plant, or at least 400 000 tonnes of CO_2 annually for other emission-intensive industrial facilities (including natural gas-based power generation). Advanced stage of planning has been defined as projects that have reached at least the Define stage in accordance with the Global CCS Institute's Asset Lifecycle Model (The Global Status of CCS: 2012, GCCSI). Projects that were not selected for funding under the EU NER300 funding scheme in 2012 and which were not considered to have sufficient clarity at the end of 2012 over the support needed to become operational by 2019 have not been included. Projects included are those undertaking sufficient monitoring to provide confidence that injected CO_2 is permanently contained, which is assumed to be the case for all projects becoming operational after 2012.

Figure 2.2: Source: GCCSI, 2012; IEA analysis. Large-scale projects are defined as per Figure 2.1. Projects are included that supply captured CO_2 to enhanced oil recovery or monitored CO_2 storage.

Figure 2.3: source: Bloomberg New Energy Finance, 2012.

Private spending represents the publically disclosed cost of projects including CCS that are in construction or operation and have a capacity equal to or greater than 100 MW in power generation (and all industrial projects). Private spending figures reflect the total cost of a project (*i.e.* the entire cost of a facility equipped with CCS) with the exception of a small number of cases where cost estimates for the CCS process are publically available. Grants represent all public funds awarded to projects in construction or operation, excluding repayable loads, tax incentives, and bonds. All figures shown do not include spending prior to 2005 on CCS projects such as In Salah, Sleipner, and Weyburn. Figures are in nominal prices.

Figure 2.4: data in USD 2011 prices and PPP.

Figure 2.5: source: Science-Metrix Inc.

The CCS patent database was constructed using a combination of keywords and patent classification codes to retrieve CCS-related patents in the United States, European and Japanese patent offices. Patents were sought for their pertinence to a range of practices including inter alia CO_2 capture from flue gases, CO_2 capture from industrial processes, natural gas clean-up, CO_2 enhanced oil recovery, CO_2 storage site management, CO_2 stream clean-up and oxyfuel power generation. The results were examined by subject matter experts to remove as many irrelevant patents as possible. Duplicates and triplicates (*i.e.*, patents appearing in more than one patent office) were consolidated into single patents for the computation of these statistics.

Fuel Economy (page 74)

Figure 3.7: Data for Australia, Canada and the United States include all light duty vehicles. For all other countries data refers to passenger light duty vehicles only.

Figure 3.8: source: ICCT, 2012, Global transportation energy and climate roadmap, www.theicct.org/global-transportation-energy-and-climate-roadmap.

NEDC New European Driving Cycle.

Figure 3.9: the IEA fuel economy readiness index is a scoring system combining countries' implementation of four key policies to incentivise fuel economy: fuel tax, CO_2-based vehicle purchase taxation, labelling schemes, and fuel economy standards for light duty vehicles (LDVs) and heavy duty vehicles (HDVs). More details on the scoring methodology can be found in IEA, 2012i.

Figure 3.10: adapted from US DOE, 2012, Fuel Economy: Where the Energy Goes, www.fueleconomy.gov/feg/atv.shtml.

Figure 3.11: source: Global Fuel Economy Initiative, international comparison of light-duty vehicle fuel economy: An update using 2010 and 2011 new registration data, www.globalfueleconomy.org/Documents/Publications/wp8_international_comparison.pdf.

Electric and Hybrid Electric Vehicles (page 80)

Figure 3.12: source: Electric Vehicles Initiative and MarkLines Database.

Figure 3.13: source: MarkLines Database.

Figure 3.14: source: MarkLines Database.

Figure 3.15: source: Electric Vehicles Initiative.

Figure 3.16: source: IEA, US DOE.

Biofuels (page 88)

Figure 3.20: an 85% capacity utilisation is assumed to derive the capacity requirements for the 2DS. Utilisation rates of new projects can lie well below this level in the first year of production. Projections from IEA 2012k.

Figure 3.21: projections from IEA 2012k.

Figure 3.22: for Australia and China data only covers some provinces; United States data estimated from volumetric quota set under the RFS2; Canada: federal mandate 5% ethanol, 2% biodiesel, up to 8.5% ethanol in some provinces.

Figure 3.23: source: Bloomberg New Energy Finance, 2012.

Figure 3.24: (textbox): source: Bloomberg New Energy Finance, 2012.

Buildings (page 94)

Figure 3.26: Countries included: Australia, Austria, Canada, Czech Rep, Finland, France, Germany, Italy, Netherlands, New Zealand, Slovakia, Spain, Sweden, Switzerland, and United Kingdom.

Figure 3.27: Value added data from IEA 2012h.

Figure 3.28: Source: IEA BEEP database.

Smart Grids (page 106)

Figure 4.2: source: Bloomberg New Energy Finance, 2012. Text box: ISGAN, 2012.

Figure 4.4: source: Bloomberg New Energy Finance, 2012.

Data includes spending on advanced metering infrastructure, distribution automation and advanced smart grid applications. It does not include transmission system-based smart grid applications.

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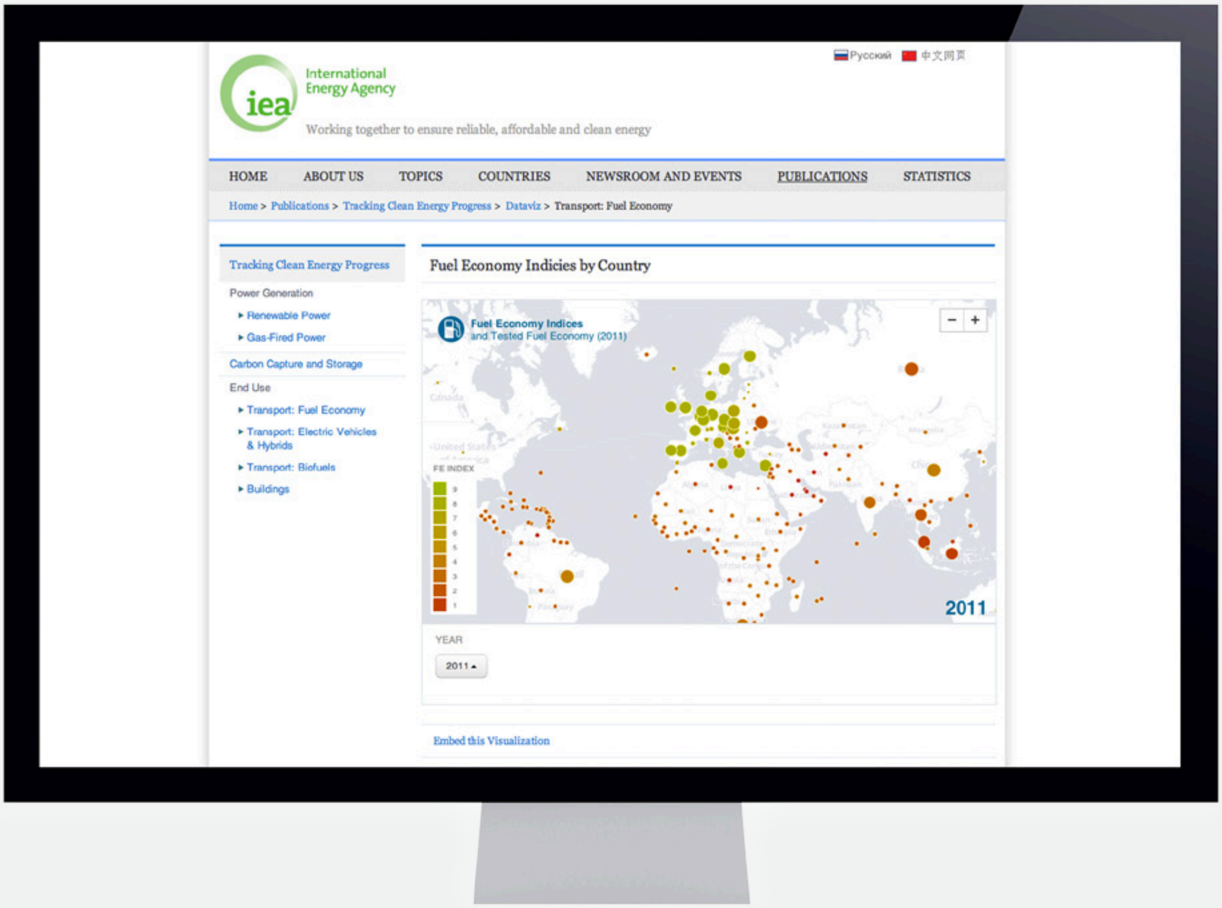

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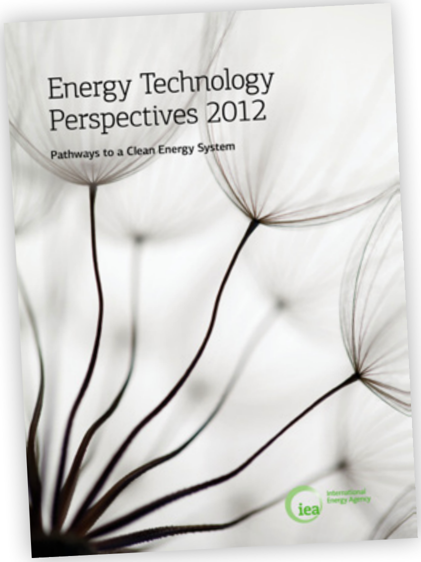

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