Energy Technology Roadmaps

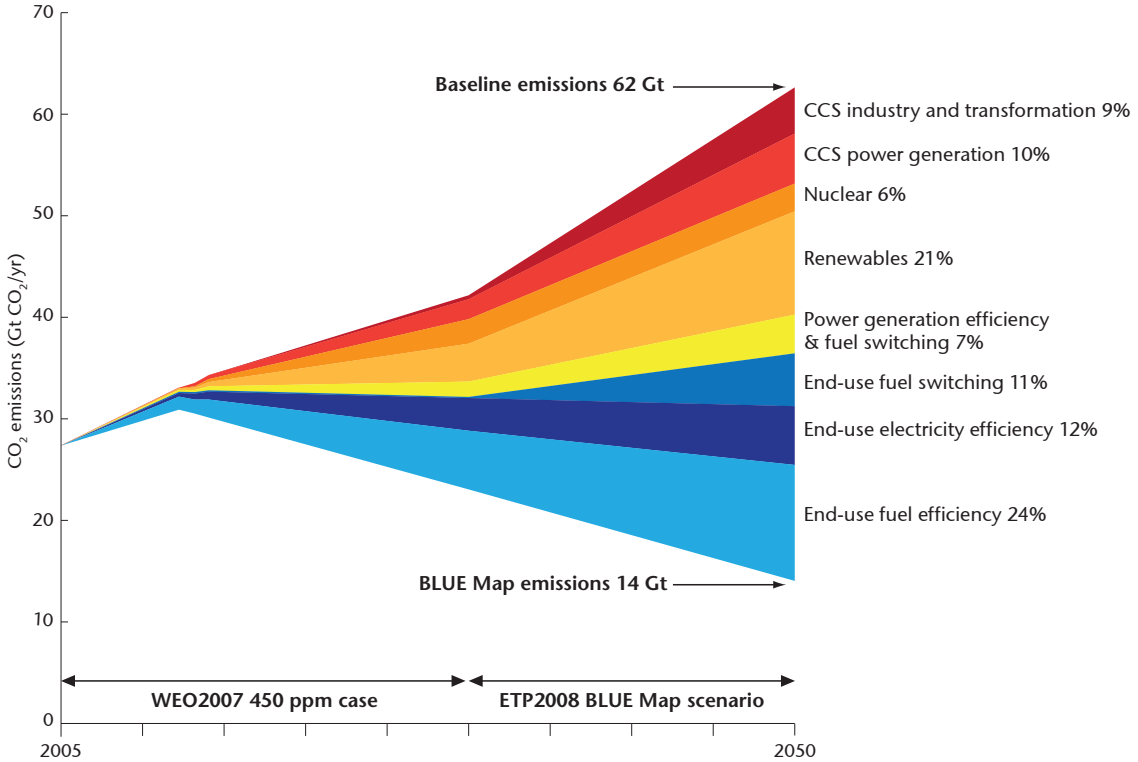
Charting a low-carbon energy revolution

International Energy Agency

Introduction

Current trends in energy supply and use are patently unsustainable – economically, environmentally and socially. Without decisive action, energy-related emissions of CO_2 will more than double by 2050 and increased oil demand will heighten concerns over the security of supplies. We can and must change the path that we are now on, but this will take an energy revolution and low-carbon energy technologies will have a crucial role to play.

Figure 1: Achieving international climate change goals necessitates an energy technology revolution



In its *Energy Technology Perspectives 2008* (*ETP 2008*) study, the International Energy Agency (IEA) demonstrated that an energy technology revolution would be required to achieve a 50% reduction in CO_2 emissions by 2050, compared with 2005 levels (the BLUE Map scenario). Such a revolution will involve rapid development and deployment of a portfolio of energy efficiency, renewable energy, carbon capture and storage, nuclear power and new transport technologies (Figure 1). Every major country and sector of the economy must be involved. The task is urgent; we must ensure that investment decisions taken now do not leave us with inefficient, high-emitting technologies in the long term. Funding programmes to surmount the global financial crisis can provide an opportunity to invest in a future powered by revolutionary green, low-carbon energy technologies.

How do we get there from here? The role of roadmaps

The key challenge in achieving this energy technology revolution is to turn political awareness and statements into concrete action. To spark this movement, at the request of the G8, the IEA is developing a series of roadmaps for some of the most important technologies. These roadmaps provide solid analytical footing that enables the international community to move forward on specific low-carbon technologies. Each roadmap further develops the growth path for a particular technology from today to 2050, and identifies milestones – for technology development, financing, policy and public engagement – that need to be achieved to realise the technology's full potential. Given the expected growth in energy use and related emissions outside of IEA member countries, the roadmaps also focus on technology development and diffusion in emerging economies. International collaboration will be critical to achieve these goals; the roadmaps are designed to facilitate wide collaboration among governments, business and civil society in both industrialised and developing countries.

Initial results from the first roadmaps

The IEA has completed the first set of international energy technology roadmaps for five important technologies or sectors:

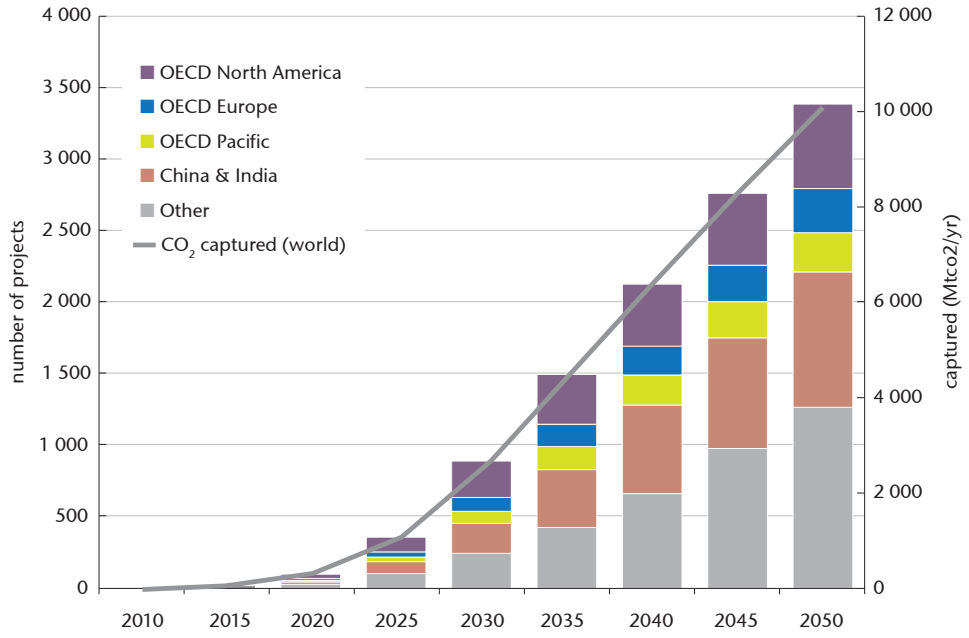
- **Carbon capture and storage (CCS)**
- **Cement**
- **Electric/plug-in hybrid electric vehicles (EVs/PHEVs)**
- **Solar photovoltaic (PV)**
- **Wind energy**

The key findings from these roadmaps provide a number of important insights.

Carbon capture and storage

The IEA CCS roadmap identifies, for the first time, a detailed scenario for the technology's growth from a handful of large-scale projects today to over three thousand projects by 2050. It confirms the critical role of CCS in de-carbonising our power, industrial and fuel transformation sectors, and indicates that while developed economies must lead in the development and demonstration of CCS, developing regions will eventually require the majority of CCS capacity (Figure 2).

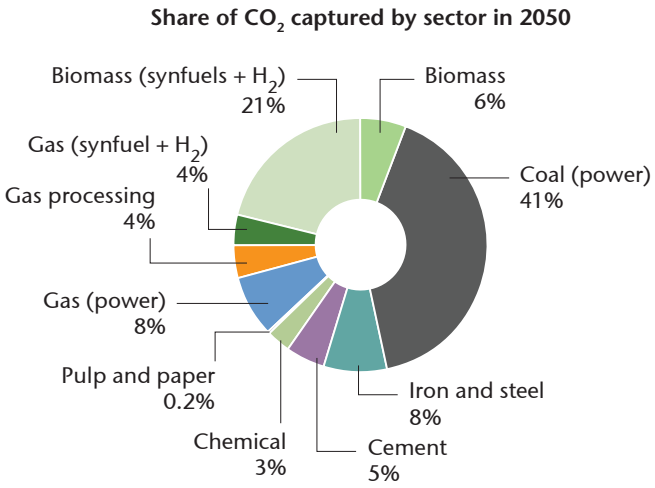
Figure 2: CCS roadmap growth pathway from 2010-2050



***KEY POINT**: CCS will need to be demonstrated in industrialised countries, then rapidly expanded to all fossil-based developing economies to achieve its CO_2 mitigation potential*

The roadmap concludes that the next decade is a key "make or break" period for CCS: governments, industry and public stakeholders must act rapidly to demonstrate and prove CCS at scale around the world in a variety of settings. CCS is not just a "clean coal" strategy; in fact, by 2050, coal-fired power plants make up only 41% of captured CO_2 (Figure 3). The bulk of capture will occur in emissions-intensive industrial sectors like cement and iron & steel, complemented by low-cost opportunities in enhanced oil recovery and gas processing.

Figure 3: CO_2 captured by sector in the roadmap scenario, 2010-2050



***KEY POINT**: CCS is not just a "clean coal" technology; it will also be needed in key emissions-intensive sectors to achieve global greenhouse gas reduction goals*

Near-term actions to advance CCS

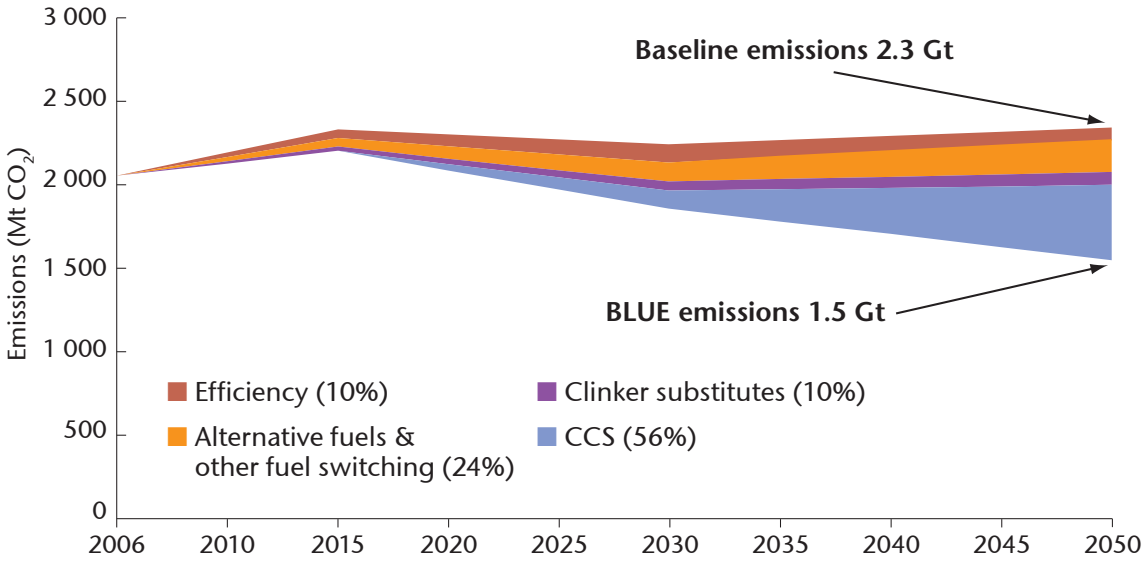
The roadmap concludes with a set of near-term actions that stakeholders will need to take to achieve the roadmap's vision. Chief among them include:

- ***For CO_2 capture**: demonstrate highly efficient technologies at scale in power plants and industrial sectors; reduce capital costs by 10% by 2020.*
- ***For CO_2 transport**: conduct regional analyses of source/sink distribution to identify clusters in OECD countries by 2012 and in non-OECD countries by 2015; provide incentives for CO_2 pipeline network development in all regions.*
- ***For CO_2 storage**: agree on a common global methodology for CO_2 storage capacity estimation by 2010; perform a comprehensive assessment of worldwide capacity for CO_2 storage by 2012.*
- ***For CCS financing**: increase OECD governments' funding for CCS demonstration to achieve an average annual investment of USD 3.5 – 4 bn from 2010 – 2020; provide an average annual investment for CCS of USD 1.5 bn – 2.5 bn from 2010 – 2020 in non-OECD regions.*
- ***For CCS legal/regulatory development**: review and adapt existing legal frameworks to regulate CCS demonstration projects by 2011 in OECD countries, 2013 in early-mover non-OECD countries, and 2015 in all non-OECD countries with CCS potential; all regions should have comprehensive legal regimes by 2020.*
- ***For public engagement on CCS**: expand government education and engagement efforts; provide transparent information about planned CCS projects in a timely manner and apply best practices to demonstration projects.*
- ***For international collaboration**: intensify and broaden capacity-building efforts in targeted developing economies with large fossil fuel use: Brazil, China, India and South Africa from 2010 – 2015.*

Cement

Recognising the urgency of identifying technologies that can reduce the CO_2 intensity of heavy industry, the IEA partnered with the World Business Council for Sustainable Development (WBCSD) Cement Sustainability Initiative (CSI) to pioneer its first industry roadmap, covering the cement sector. The roadmap outlines a vision that involves the cement industry reducing its emissions by 18% from current levels by 2050, despite a significant growth in cement demand. This is achieved through the use of four key technology 'reduction levers': thermal and electric efficiency, alternative fuel use, clinker substitution, and CCS (Figure 4).

Figure 4: Cement sector CO_2 reduction pathway



***KEY POINT**: there are four key technologies that must be used together to achieve cement sector sustainability*

Cement technology roadmap key findings

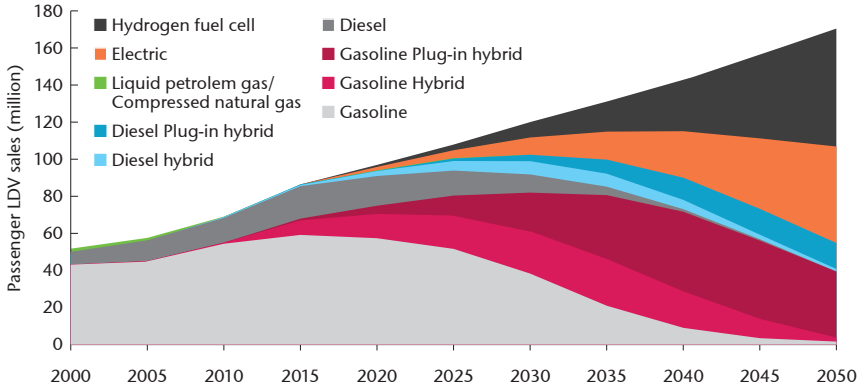
The roadmap's main messages include:

- ***Cement is an essential material**: demand reduction and/or substitution are not viable emissions reduction options.*
- ***Currently available mitigation technologies are insufficient**: to achieve significant emissions reductions, new technologies are needed, including CCS and new cement types.*
- ***Mitigation technologies will require a step change in RD&D**: the roadmap contains a vision for what is needed between today to 2050.*
- ***CCS is a particularly important technology for the cement sector**: it delivers roughly half of all reductions in 2050. This requires advancement of cement sector demonstration projects in the next decade, to learn in parallel with power sector and fuel transformation CCS projects.*
- ***Predictable and stable CO_2 incentives are needed**: in order to mitigate the high cost of reducing CO_2 emissions in the sector.*
- ***Greater international collaboration is required**: due to the rapid pace of change that is needed; public-private partnerships should be encouraged.*

Electric/plug-in hybrid electric vehicles

The EV/PHEV roadmap identifies a detailed pathway for the evolution of light-duty electric-drive vehicles, and envisions market penetration ramping up from annual sales of a few thousand by 2012, to several million by 2020, to over 100 million vehicles by 2050. Even with strong growth in overall global car sales, EVs/PHEVs would comprise more than 50% of light-duty vehicles sold in 2050 (figure 5).

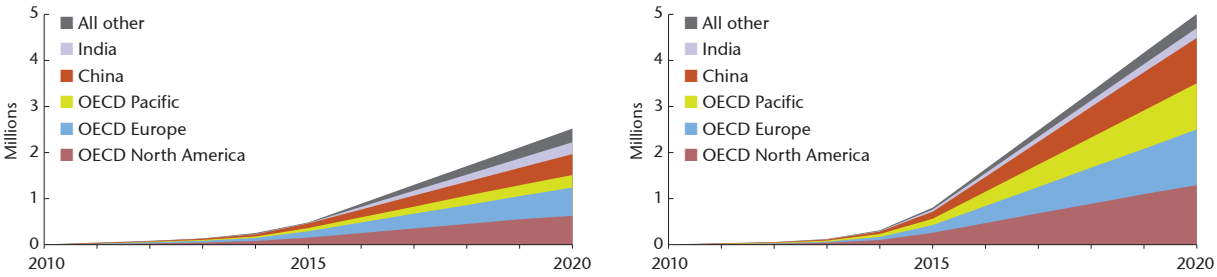
Figure 5: EV/PHEV roadmap vision for expansion in sales, 2010-2050



***KEY POINT**: EV/PHEVs will need to reach over 50% of light-duty vehicle sales in 2050*

While the roadmap's market penetration for these vehicle types is ambitious, through 2020 it is in fact similar to the combined EV/PHEV sales targets that have already been announced by various governments around the world. The roadmap also finds that while OECD countries will continue to be the leading markets for EV/PHEV sales through 2020, non-OECD countries will comprise an increasingly important share over time, for example reaching 40% of EV sales in 2020 (Figure 6).

Figure 6: EV/PHEV roadmap vision of sales by region



***KEY POINT**: EV/PHEV sales will need to dramatically increase in all major vehicle markets to achieve the roadmap's targets*

Near-term actions for EV/PHEV expansion

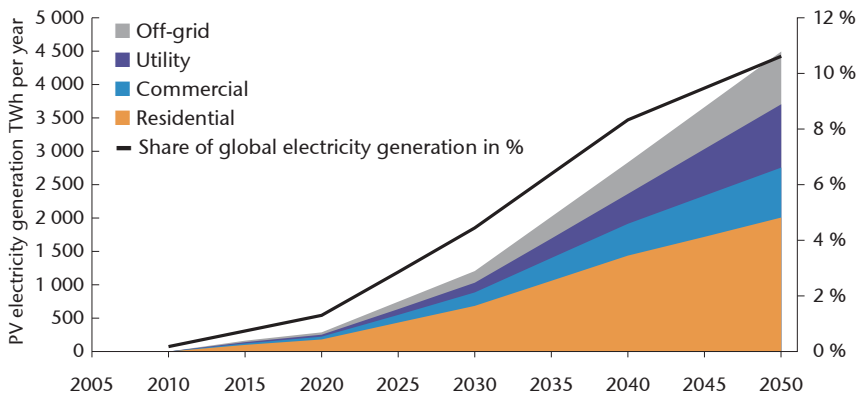
In the near term, governments, the auto industry, electric utilities and other stakeholders must work together to roll out vehicles and infrastructure in a co-ordinated fashion and ensure that the rapidly growing consumer market is ready to purchase electric vehicles. Key actions are:

- ***Set targets for electric vehicle sales**: to achieve the roadmap's vision, industry and governments must work together to identify attainable national targets that put the world on a path to achieve a combined EV/PHEV sales share of at least 50% of light-duty vehicle sales worldwide by 2050.*
- ***Develop co-ordinated strategies to support the market introduction of electric vehicles**: EV/PHEVs are unlikely to succeed without strong policy support, especially incentives that make vehicles cost-competitive with today's conventional vehicles.*
- ***Improve understanding of consumer needs and behaviours**: governments and industry must identify and target "early adopters" with successful business models for vehicles with different driving range and different price levels.*
- ***Develop performance metrics for characterising vehicles and to track progress**: these include vehicle performance metrics like driving range and technical battery requirements.*
- ***Expand RD&D initiatives to reduce battery costs and address resource issues**: in order to achieve a break-even cost with internal combustion engines, costs must be reduced from the current USD 500–800 per kilowatt-hour (kWh) to USD 300–400 per kWh by 2020.*
- ***Develop and implement recharging infrastructure**: reliable electricity supply must be available for vehicle recharging and assistance with home recharging systems may be needed. Public recharging stations must be conveniently located. It is critical to understand the impact of EV/PHEV use on electricity demand, generation and capacity, and to provide a strategic plan for electric utilities. Technologies for "smart grids" that optimise times of recharging and eventually allow electricity sales from vehicles-to-grid must be fully developed in the near term.*

Solar photovoltaic power

Solar PV has significant business opportunities and potential in most regions. The roadmap elaborates a vision whereby PV achieves parity with typical electricity grid prices by 2020 and then deployment further expands so that by 2050 it provides around 11% of global electricity production, reducing emissions by some 2.3 gigatonnes (Gt) CO_2 per year. It also shows how greater use of PV will enhance energy supply security in many countries through a wide set of applications, ranging from small off-grid and residential systems to GW utility-scale power plants (Figure 7).

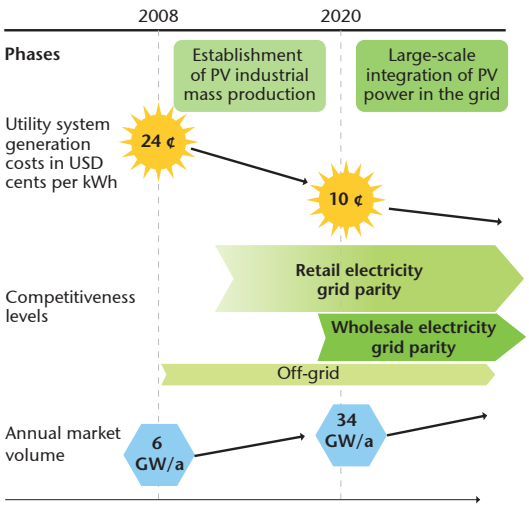
Figure 7: Solar PV electricity production by end-use sector, 2010-2050



***KEY POINT**: The roadmap sees solar PV providing 11% of global electricity generation by 2050*

Achieving this potential—with PV electricity generation costs reduced by half—will require a strong and balanced policy effort between 2010 and 2020, to provide sustained market growth, optimal technology progress, cost reduction, industrial manufacturing and mass deployment. If governments and industry can successfully meet the roadmap's targets, solar PV will become cost-competitive with the electricity grid average in many countries (Figure 8).

Figure 8: Solar PV cost and market competitiveness targets



***KEY POINT**: With the right mix of policies, solar PV can achieve grid parity as early as 2020*

As grid parity is achieved, the policy framework will then need to evolve to fostering self-sustained markets. It can do this by progressively phasing out economic incentives, yet ensuring access to grids and providing continued and sustained support for R&D. After 2020, as PV becomes a mainstream power supply technology, policies must shift to address issues like grid integration, storage and grid management. The PV industry, grid operators and utilities will need to co-operate to develop new technologies and strategies to integrate very large amounts of PV into flexible, efficient and smart grids.

Priority actions to achieve PV competitiveness by 2020

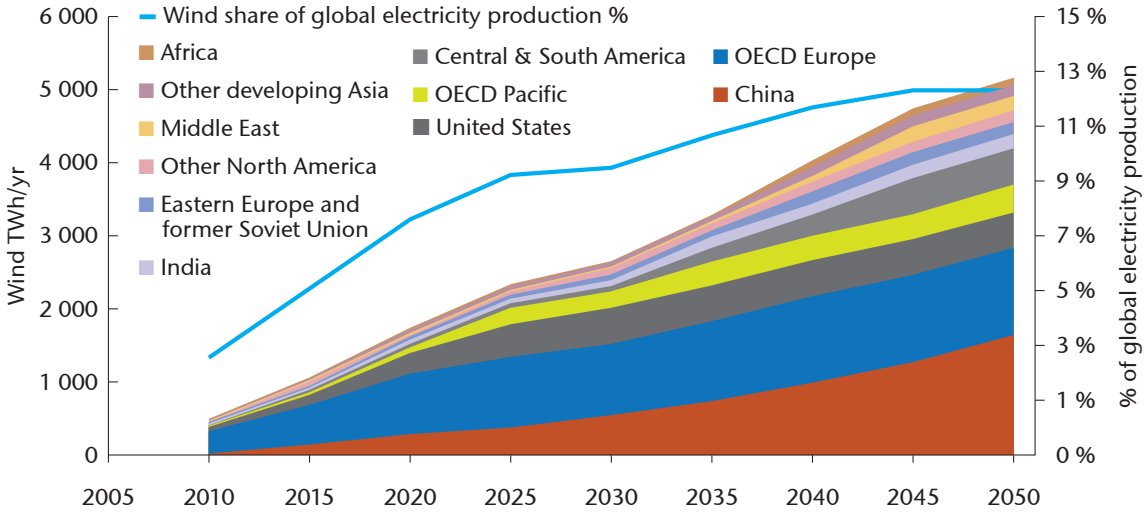
The next decade is a key period for PV, and requires smart policy making. To guide policy makers and industry, the PV roadmap includes a set of near-term actions:

- ***Provide a long-term target and supporting policies***: *this sort of policy framework is needed to build confidence for investments in manufacturing capacity and PV systems.*
- ***Apply effective incentive schemes***: *the optimal approach is likely to use support that can then be progressively phased out as PV achieves full competitiveness.*
- ***Create appropriate financing mechanisms***: *this will facilitate the investments in PV by a multitude of economic actors, particularly for residential, commercial and off-grid applications.*
- ***Increase R&D efforts to reduce costs and ensure PV readiness for rapid deployment***: *while also supporting the development of emerging longer-term breakthrough technologies.*
- ***Enhance education and training programmes***: *this will enable sustained PV workforce development and raise consumer awareness of the benefits and use of PV power.*
- ***Implement efficient administrative procedures***: *to streamline PV system approvals.*

Wind energy

The wind roadmap describes a vision in which the combination of onshore and offshore wind power delivers at least 9% of global electricity generation in 2030, and 12% by 2050 (Figure 9). Achieving more than 2 000 gigawatts (GW) of wind energy capacity in 2050 will require an average of 47 GW installed every year for the next 40 years, up from 27 GW in 2008, an additional 75% over present investment. Wind energy is also expected to grow rapidly from its current installed base in leading North American and European markets to other regions; from 2030 non-OECD economies – led by China, Latin America and India – will produce 17% of global wind energy, rising to 57% in 2050.

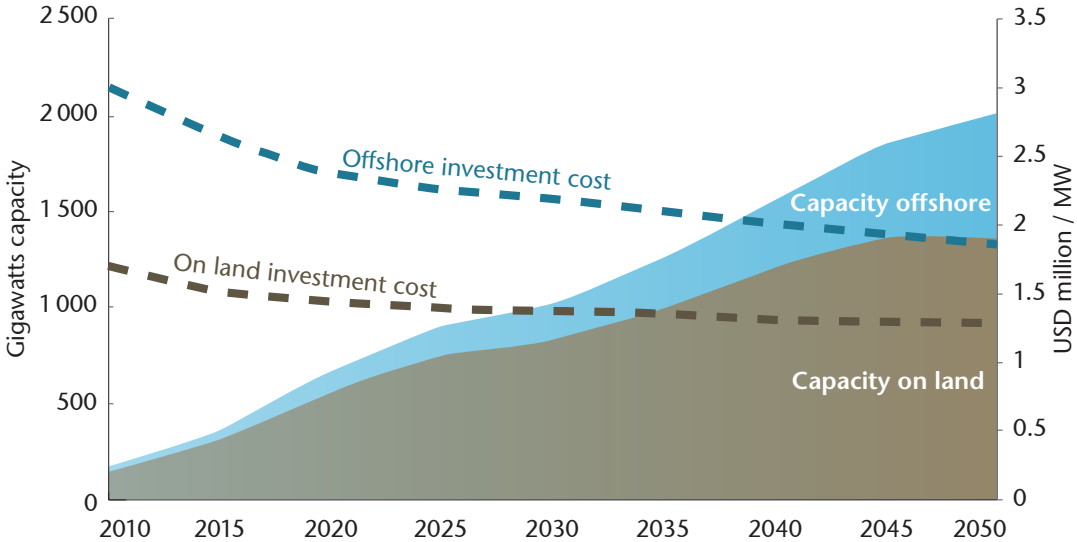
Figure 9: Regional wind electricity production to 2050



***KEY POINT**: Wind has the potential to provide 12% of global electricity production in 2050*

Wind power is already competitive in markets where the resource is strong, and where the cost of greenhouse gas emissions is taken into account. Costs are expected to decrease further as a result of technology development, deployment and economies of scale – by 23% onshore and 38% offshore by 2050 (Figure 10). Transitional support is needed to encourage deployment until full competition is achieved. Additional to the cost factor, reliable integration in power systems, energy market structures, and social acceptance of infrastructure are important.

Figure 10: Wind power capacity and investment cost reduction to 2050



***KEY POINT**: To achieve its potential, wind will need to continue to hit cost reduction targets; stronger RD&D support will enable this*

Near-term actions for wind power

To achieve the expansion of wind power that is envisioned in the IEA wind roadmap, there are a number of key issues that must be addressed. Priority actions include:

- ***Set long-term targets, supported by predictable policy**: to drive investment, while further cost reductions are pursued.*
- ***Develop long-term, strategic grid expansion plans**: taking into account the wind resource as well as competing land / sea usage. Mechanisms are needed to incentivise expansion and to recover and allocate costs. Governmental co-ordination agencies may be required to make multi-jurisdictional planning and permitting more efficient.*
- ***Increase the flexibility of power systems**: where large wind energy shares are targeted. Measures include more rapid trading of electricity in larger power markets, investing in "smart grid" technology, enhancing power market interconnection, and expanding the use of flexible generation capacity, demand response and energy storage.*
- ***Raise public awareness of the benefits of wind power**: (additional to CO_2 abatement) and of the accompanying need for grid expansion. Improve techniques for assessing, minimising and mitigating social and environmental impacts and risks.*
- ***Share best policy and technology practice with developing countries**: facilitate investment by targeting development finance at deployment bottlenecks and further use of carbon finance mechanisms like the Clean Development Mechanism.*
- ***Strengthen RD&D efforts to drive targeted cost reductions**: particularly in the offshore sector, where conditions are less well understood and new designs are needed.*

Roadmap implementation: creating a platform for international technology collaboration

These first roadmaps have been developed to help guide the world toward a low-carbon energy future. However, they are just a start. The IEA aims to develop roadmaps for all the most important clean energy technologies in the coming years. The next set of roadmaps—to be released in 2010—includes biofuels, concentrating solar power, efficiency heating and cooling in buildings, nuclear energy and electricity networks.

To this end, the IEA is already working with member and non-member governments and experts, international organisations and the business community on a variety of initiatives to promote the spread of clean energy technology. However, much more needs to be done. With this in mind, the IEA presented proposals to its Ministerial meeting in October 2009 for an international low-carbon energy technology platform that would aim to enhance international collaboration among all the key stakeholders in accelerating technology development and deployment. Among other activities, the platform would draw upon the technology roadmap work and other analytical exercises to identify concrete actions that governments and the private sector may take for advancing particular technologies and to enable public tracking and reporting on progress towards the roadmap milestones.

For further information on the IEA technology roadmaps, contact:

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