

Energy Technology Perspectives 2014

Harnessing Electricity's Potential

Executive
Summary



International
Energy Agency

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Energy Technology Perspectives 2014 (ETP 2014) charts a course by which policy and technology together become driving forces – rather than reactionary tools – in transforming the energy sector over the next 40 years. Recent technology developments, markets and energy-related events have asserted their capacity to influence global energy systems. They have also reinforced the central role of policy in the increasingly urgent need to meet growing energy demand while addressing related concerns for energy security, costs and energy-related environmental impacts. Radical action is needed to actively transform energy supply and end use.

In addition to analysing the global outlook to 2050 under different scenarios, across the entire energy system for more than 500 technology options, *ETP 2014* explores pathways to a sustainable energy future in which policy support and technology choices are driven by economics, energy security and environmental factors. Starting from the premise that electricity will be an increasingly important vector in energy systems of the future, *ETP 2014* takes a deep dive into actions needed to support deployment of sustainable options for power generation, distribution and end-use consumption.

ETP 2014 analyses three possible energy futures to 2050:

- 6°C Scenario (6DS), where the world is now heading with potentially devastating results
- 4°C Scenario (4DS) reflects stated intentions by countries to cut emissions and boost energy efficiency
- 2°C Scenario (2DS) offers a vision of a sustainable energy system of reduced greenhouse gas and carbon dioxide (CO₂) emissions.

Status and recent trends are highlighted in *Tracking Clean Energy Progress*, providing a snapshot of advances or lack of progress in major low-carbon energy technologies. Collectively, *ETP 2014* lays out the wide range of necessary and achievable steps that can be taken in the near and medium terms to set the stage for long-term energy policy objectives, clearly identifying the roles of energy sector players, policy makers and industry.

Global energy trends show advances in decoupling demand from economic growth, but also reveal bottlenecks and uncertainties

ETP 2014's 2DS confirms that global population and economic growth can be decoupled from energy demand, even for oil. Extending recent trends to 2050 in the 6DS, global energy demand grows by 70% and emissions grow by more than 60% against 2011 levels. Under the same projections for population and gross domestic product, radical action in the 2DS dramatically improves energy efficiency to limit increases in demand by just over 25% while emissions are cut by more than 50%. One of the most notable differences between the two scenarios is this: in the 6DS, oil remains the most important primary energy carrier with demand increasing by 45%, while the policy and technology choices made under the 2DS deliver a 30% reduction in oil demand.

Solar, hydropower and onshore wind are presently forging ahead, while development is mixed for other clean energy supply. Policy certainty remains vital to a positive investment outlook for clean energy technologies. Cost per unit of energy generated by onshore wind and solar photovoltaic (PV) continued to fall in 2013, albeit at a slower rate than in previous years. Their cost-competitiveness is improving, in some countries, partly due to innovative market design. Despite their flexibility, concentrating solar power plants are being deployed much more slowly, with a slower decline in costs. Global nuclear capacity is stagnating at this time as a modest capacity increase from new reactors coming on line has been offset by the retirement of ageing or non-profitable plants in member countries of the Organisation for Economic Co-operation and Development (OECD). Looking at a midpoint to 2050 2DS targets, installed global nuclear capacity in 2025 will likely be 5% to 24% below needed levels, demonstrating significant uncertainty.

Emerging economies have stepped up their ambitions and become leaders in deploying low-carbon energy technologies. Emerging markets more than compensated for slowing or more volatile renewable power growth in Europe and the United States, with Asia deploying more than half of global solar PV additions in 2013. China's bold measures to support clean transport as a means of improving urban air quality has led to some 150 million electric 2-wheelers on the road and greater deployment of electric buses. Globally, sales of hybrid electric vehicles and electric vehicles (EVs) set new records in 2013, but still fall short of the 2DS trajectory.

Continued increase in coal use counteracts emissions reduction from recent progress in the deployment of renewables, underlining the need to improve coal plant efficiency and scale up carbon capture and storage (CCS). Growth in coal-fired generation since 2010 has been greater than that of all non-fossil sources combined, continuing a 20-year trend; 60% of new coal capacity built in the past decade was subcritical, the least efficient class of commercially available coal-fired generation technologies. The future of CCS is uncertain; at present, the technology is advancing slowly, due to high costs and lack of political and financial commitment. Near-term progress in CCS research, development and demonstration is needed to ensure long-term and cost-competitive deployment towards meeting climate goals.

Fossil fuel use decreases by 2050 in the 2DS, but its share of primary energy supply remains above 40%, reflecting its particularly important role for use in industry, transport and electricity generation. The ability of the different industrial sub-sectors to incorporate renewable energy sources into their processes varies greatly depending on the nature of the final product and diverse operational limitations. CCS is needed to capture both

energy- and process-based emissions. In the transport sector, high energy density is an important characteristic of fuels. Apart from conventional fossil fuels, only biofuels and hydrogen show potential to support non-grid-connected, long-distance travel modes such as road freight, aviation and shipping (various battery and charging options can more easily support electric mobility in urban areas). Even in the 2DS, by 2050 the largely decarbonised electricity mix still depends on fossil fuels for 20% of electricity generation (down from 70% in 2011), most of which is combined with CCS.

Energy efficiency makes the largest contribution to global emissions reduction in the 2DS, but needs to be combined with other technologies to meet long term targets.

Between the 6DS and 2DS until 2050, energy efficiency accounts for 38% of cumulative emissions reductions, renewables account for 30%, and CCS accounts for 14% with fuel switching and nuclear making up the difference. The 2DS shows substantial efficiency gains in all end-use sectors. In transport, fuel economy of the whole vehicle fleet doubles over the projection period, keeping sectoral energy use flat while travel activity almost doubles. Industry, through adoption of best available technologies and greater penetration of less-energy intensive process routes related in some cases to the use of recycled materials, cuts energy use by 25%. Despite global floor area increasing by more than 70%, energy demand in buildings grows just 11%, without changing the comfort levels of buildings or requiring households and businesses to reduce their purchases of appliances and electronics equipment.

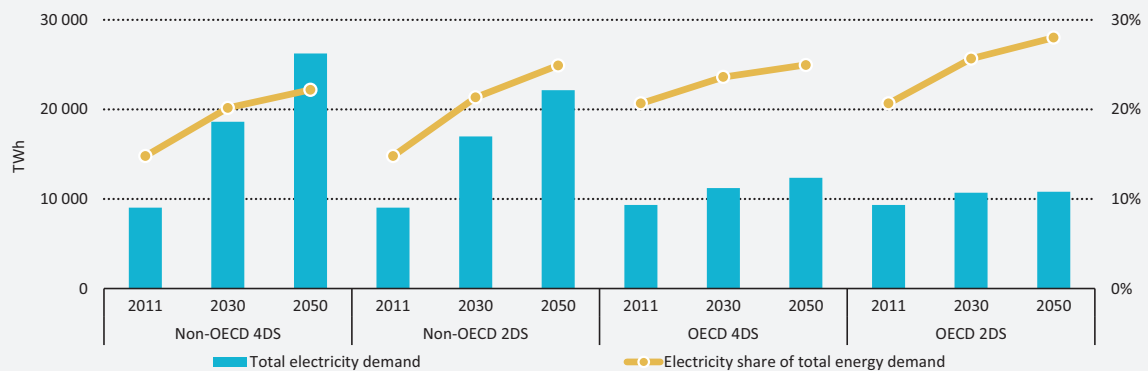
Increased electrification is a driving force across the global energy system

Globally, growth in electricity demand is outpacing all other final energy carriers; this creates potential for radically transforming both energy supply and end use.

Since the 1970s, electricity's overall share of total energy demand has risen from 9% to over 17%. Across all scenarios globally, it climbs to 25%, while electricity demand grows by 80% in the 2DS and 130% in the 6DS by 2050. But regional growth rates in actual demand are vastly different: OECD countries remain almost flat with an average 16% demand growth; in non-OECD regions, growth skyrockets as high as 300%. *ETP 2014* investigates the potential for pushing the limits of electrification in supply and end use, analysing variants with increased deployment of renewable generation and increased electrification of transport and buildings.

The transition to electrification is not neutral: in fact, decarbonisation requires a massive reversal of recent trends that have shown continued reliance on unabated fossil fuels for generation.

To meet 2DS targets, CO₂ emissions per unit of electricity must decrease by 90% by 2050. A continuation of current trends – which saw overall electricity emissions increase by 75% between 1990 and 2011, due to rising demand but little change in emissions intensity – would dangerously drive up electricity-related emissions. Ongoing use of imported fossil fuels in generation by some countries increases energy security risk and exposure to fuel supply volatility, creating competitiveness issues. By contrast, the 2DS demonstrates the opportunity to substantially reduce emissions intensity, reduce fuel imports and increase efficiency in end use to moderate growth of electricity demand.

Figure I.1 Electricity demand and share of electricity

Note: TWh = terawatt hours.

Key point

Electricity demand growth differs between OECD and non-OECD countries, but the dominant trend is towards an increasing share of electricity in the overall energy mix.

The potential of increased electrification requires drastic changes in supply and demand, facilitated by increased stakeholder co-ordination

Impressive deployment of renewable technologies is beginning to shape a substantially different future in supply.

This is true even though fossil energy carriers still accounted, in 2011, for two-thirds of primary fuel in the global electricity mix and covered most of recent demand growth. Double-digit growth rates for wind and solar PV electricity generation over the last several years helped push the global share of renewables to 20% in 2011; the 2DS shows that renewables could reach 65% by 2050. In the 2DS-High Renewables Scenario (2DS hi-Ren), solar becomes the dominant electricity source by 2040, providing 26% of global generation by 2050.

Over the medium term, the 2DS sees strong interplay between variable renewables and the flexibility of natural gas to supply both base-load and balancing generation.

Gas-fired generation supports two elements of a cleaner energy system: increasing integration of renewables and displacing coal-fired generation. Its evolving role in a given system will depend on the regional resource endowment and electricity generation mix. Shifting gas-fired generation towards flexible operation opens up competition among generation technologies: internal combustion engines, open-cycle gas turbines, combined-cycle gas turbines (CCGTs) and even fuel cells could become attractive. In regions with ambitious deployment plans for renewable electricity, part-load efficiency, ramp rate, turndown ratio and start-up times are more relevant for gas-fired plants than full-load efficiency. The outcome of competition between coal and gas depends more on the economics of CO₂ emissions and fuel prices than on technology improvements. If coal and CO₂ prices are low, unabated coal plants are sufficiently flexible and will remain profitable.

Natural gas should be seen only as a bridge to cleaner energy technologies unless CCS is deployed.

After 2025 in the 2DS, emissions from gas-fired plants are higher than the average carbon intensity of the global electricity mix; natural gas loses its status as a low-carbon fuel. Recognising that base-load gas-fired plants will require CCS to meet 2DS targets, *ETP 2014* undertook a comparison of the costs and benefits of applying CCS to both coal- and gas-fired generation. Overall, the cost per tonne of CO₂ (tCO₂) is higher for gas than coal, but when comparing the cost of low-emissions electricity, gas is more attractive than coal-fired generation. At a carbon price of around USD 100/tCO₂ (and at reasonable gas and coal price assumptions), CCGT with CCS has a lower levelised cost of electricity (LCOE) than CCGT alone, and is less costly than supercritical pulverised coal with CCS.

Decarbonising the electricity sector can deliver the spillover effect of reducing emissions from end-use sectors, without needing further end-use investments.

Yet to fully leverage the benefits of increased shares of decarbonised electricity, including reaching 2DS emissions targets, comprehensive approaches are needed to combine electrification with end-use initiatives. Improving the efficiency of consumption and applying demand-side management is vital to limiting the need for capacity expansion and reducing investment costs across the electricity chain.

Box I.1

ETP 2014 Country case study: Electrifying India

With electricity demand in India expected to more than double in the next decade, the power sector faces two main challenges: adequately powering the projected economic growth and bringing electricity to the 300 million citizens who currently lack access.

Coal is India's most abundant primary energy resource: presently, 68% of electricity comes from coal. At 33.1%, the average efficiency of its coal-fired power plants is low and emissions (over 1 100 grammes of CO₂ per kilowatt hour [gCO₂/kWh]) are well above global state-of-the-art levels (750 gCO₂/kWh). Policies to halt construction of subcritical units and encourage more efficient technology are insufficient to achieve the CO₂ emissions reduction needed. Additionally, continued reliance on

fossil fuels will require that India heavily supplement domestic supplies of coal and gas with imports.

India is to be commended for its ambitious plans to better exploit its abundant potential for generation from wind and solar, while also expanding geothermal, biomass and small hydropower. Expanding nuclear and large-scale hydropower capacity will assist in managing congested grids and integrating variable renewables capacity.

The projected demand growth should make India an attractive opportunity for energy sector investors. Addressing the complex administrative processes and investment risks is vital to bringing down the high cost of financing new projects.

Increased electrification of buildings through the deployment of heat pumps as part of a comprehensive approach to improving buildings energy efficiency can significantly displace natural gas demand.

Heat pumps for heating/cooling of space and water allow electricity to displace use of natural gas. The 2DS Electrified Buildings (2DS-EB) Scenario considers deployment of heat pumps beyond 2DS levels for both space and water heating applications, with a focus on the European Union and China. The EU gas share falls from 34% in 2011 to a 2050 level of 32% in the 2DS and even lower at 25% in the 2DS-EB. In 2011, China's share of natural gas in buildings was around 6%. In the 2DS, large expected economic growth and urbanisation drive up China's buildings energy consumption by 24% in 2050; increased demand for space and water heating drive the share of natural gas for those purposes to almost 20%. In the 2DS-EB, increased deployment of heat pump technology avoids most of this growth in natural gas demand while also moderating the overall change in electricity demand for buildings: the European Union sees a decrease of about 4% over the 2DS, while demand in China increases by only around 4%.

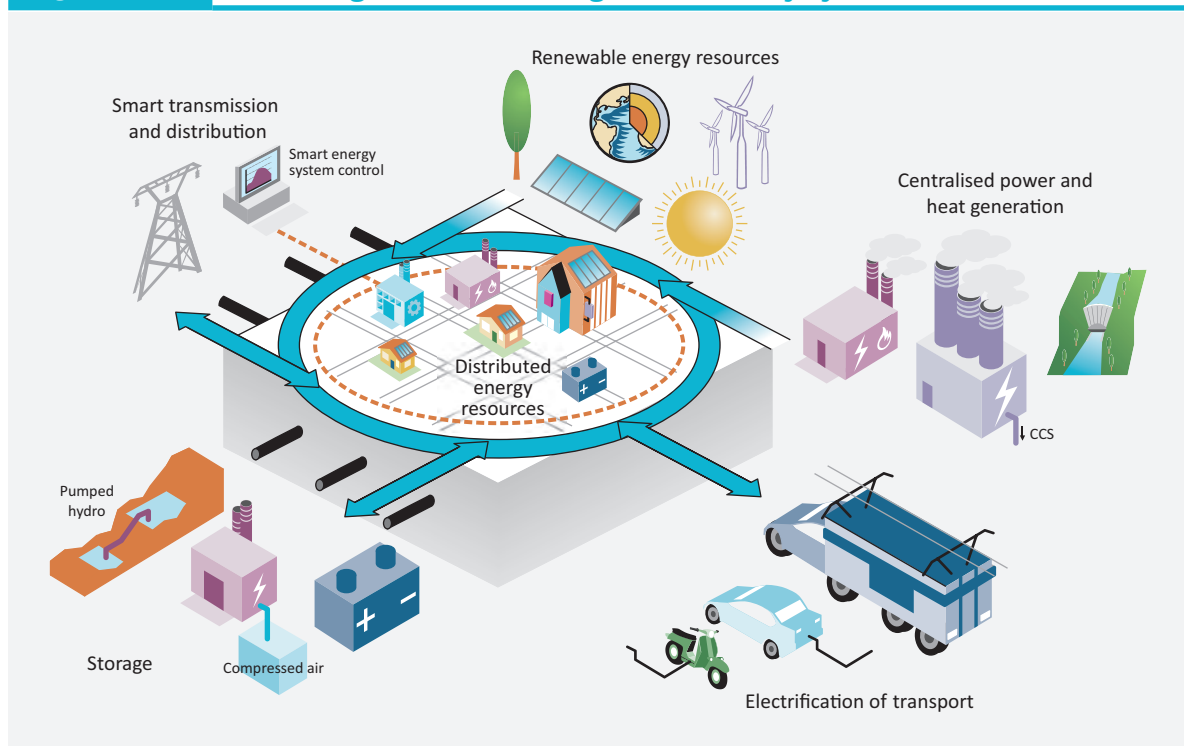
Electrification of transport, together with improved fuel economy, fuel switching and new vehicle technologies, substantially reduces transport sector oil use in the 2DS without considerably increasing overall electricity demand. The 2DS rapidly electrifies both personal and public passenger transport and extends electrification of rail freight. An “Electrified Transport” variant of the 2DS (2DS-ET) pushes the envelope by also putting in place the infrastructure needed to electrify heavy-duty vehicles, delivering a further 5% reduction in oil demand for a similar level of transport activity in 2050. Because transport is heavily oil-dependent, even incremental steps in electrification deliver substantial savings: although electricity makes up only 11% of total transport energy demand in 2050 in the 2DS, it accounts for approximately 50% of transport efficiency gains. Yet even with aggressive electrification, transport’s share of electricity demand remains below 15%.

A framework of “systems thinking” can enable optimised cross-sector integration

The choice of technologies and their placement along the steps of generation, transmission and distribution (T&D) and consumption of electricity will play a critical role in the cost-effective development of integrated electricity systems. The energy community has largely recognised the need to integrate a broad range of technologies and policies across the supply, T&D, and demand sectors over the long term to establish a clean and resilient system that supports efficient, flexible, reliable and affordable operation (Figure I.2).

Figure I.2

The integrated and intelligent electricity system of the future



Key point

To better integrate all elements of electricity systems will increase complexity, but improve operations, efficiency and resilience while optimising energy resources and investments.

“Systems thinking” is particularly important during the transition to optimise electricity system investments and ensure efficient management of future systems in which electricity from wind and solar dominate generation. This approach is also needed to prompt all stakeholders to optimise use of existing infrastructure and to direct research, development, demonstration and deployment towards integration.

Electricity storage can play multiple roles in integrated low-carbon electricity systems; ETP 2014 analysis finds that storage, in itself, is unlikely to be a transformative force.

The role of electricity storage in a given power system will depend on system-wide development. Pumped hydro storage (PHS) currently represents 99% of all deployed electricity storage, and remains well-suited for many storage applications. Although none have yet been deployed at a capacity scale comparable to PHS, a broad range of other technologies are emerging. The value of the flexibility that electricity storage technologies can provide will appreciate as the share of variable renewables in electricity systems increases. For these services, however, storage technologies will compete with other resources such as stronger internal grids, interconnection, demand-side integration and flexible generation. Under current market structures, cost is a major barrier to deployment of storage. Frequency regulation, load following and off-grid applications for electricity storage represent the most attractive deployment opportunities in the near to medium term, and could spur cost reductions; in most markets, however, storage will be deployed after more economic solutions have been maximised.

Smart coupling of the convergence of electricity generation from PV with rising demand from e-mobility would facilitate higher penetrations of both technologies; combining PV with electricity storage opens new possibilities.

Effective management of increasing electricity demand arising from EVs and appliances can support integrated system operation by leveraging existing infrastructure and technology and optimising deployment of new options. While unmanaged charging of EVs would risk further increase in demand peaks, well-organised midday and off-peak charging could help flatten the net load curve and ease PV integration. In electrified areas, load management, interconnections, flexible generation and storage capabilities can all be used to integrate large shares of PV and will compete on cost and performance. Solar PV panels combined with small-scale electricity storage are suitable for off-grid applications and can provide access to electricity in remote areas.

Policy, finance and markets must be adapted to support active transformation of the global energy system

ETP 2014 presents evidence that the USD 44 trillion¹ additional investment needed to decarbonise the energy system in line with the 2DS by 2050 is more than offset by over USD 115 trillion in fuel savings – resulting in net savings of USD 71 trillion.

Even with a 10% discount rate, the net savings are more than USD 5 trillion. To achieve the potential of integrated energy systems and unlock these savings, a coordinated policy approach must be used to actively transform both the energy system and the underlying markets. Acknowledging that the necessary financing has not yet been mobilised, *ETP 2014* examines how investors assess risk and return. Ultimately, the analysis shows a disconnect between the energy sector’s use of LCOE and investor reliance on net present values.

¹ Unless otherwise stated, all costs and prices are in real 2012 USD, i.e. excluding inflation.

Financing low-carbon power plants (renewables, nuclear, CCS) in a framework of competitive markets requires returns that compensate for the risks associated with potentially changing revenue streams from electricity generation, including unpredictable prices for carbon, gas and coal in the future.

Learning from the clean technologies now entering energy markets shows that regulation and market transformation can help or hinder the potential of individual technologies, including their competitiveness. To date, low-carbon investments have been driven by support schemes, including feed-in tariffs, output-based subsidies and quota systems. Governments need to assess whether these mechanisms remain relevant or need to be replaced with new options. Moving from a regulated environment with support mechanisms to a market-based approach considerably raises the risk to which investors are exposed. This increases the risk of uncertain carbon markets and wholesale electricity prices for technology investors, and may require different regulatory counterbalances. Innovative business models have, in some cases, proven an effective means by which emerging technologies can capture new niche markets. EVs, for example, account for more than 10% of car-sharing programmes recently launched around the world – compared with less than 1% market share of global vehicle sales. The car-sharing business model relieves users of the up-front costs and driving range concerns that undermine personal decisions to purchase EVs.

Without the stimulus of carbon pricing, alternative policy instruments will be necessary to trigger low-carbon investment in competitive markets. A high carbon price continues to show strong potential as a policy instrument by which governments can stimulate the low-carbon investment needed. In the absence of carbon markets, innovation in technology deployment, policy action and investments can enable progress. *ETP 2014* demonstrates, for example, that countries with a strong focus on low-carbon intensity and/or high shares of oil imports in transport can quickly reap significant benefits from massive deployment of e-mobility. The Low-Carbon Electric Transportation Maximisation Index (LETMIX) shows that, already today, more than 27% of the world's countries could obtain significant CO₂ savings from EVs, irrespective of mode. The LETMIX also identifies where and in what time frame electrifying transport can yield maximal benefits, although many transport technology solutions are mode-specific and require substantial build-up of infrastructure.

***ETP 2014* demonstrates that, as they mature, technologies can enable new and innovative options for policy, regulation and markets, complementing technology support mechanisms.** Smart-grid technologies will offer new options for technical operation of electricity systems and for evolving electricity markets, for example by enabling much more distributed generation and demand response. Broad based urban transport electrification can be part of integrated planning for land use, walking, biking, networked mobility and low-carbon electricity. Evaluating a range of possible technological options for more integrated energy systems will reveal an increased range of solutions that countries and regions can use to design, plan and operate energy systems in ways that best meet their respective needs. Technology can be used to actively support the adaptation of markets, regulation and policy that will truly transform global energy systems.

Explore the data behind *Energy Technology Perspectives 2014*



www.iea.org/etp2014

The IEA is expanding the availability of data used to create the *Energy Technology Perspectives* publication. Interactive data visualisations are available on the IEA website for free. After buying the book extensive additional data, interactive visuals and other tools will be made available on a restricted area of the website.

Also in the *ETP* series

Other *ETP* publications available in the IEA bookshop



Energy Technology Perspectives is the International Energy Agency's most ambitious project on new developments in energy technology. The analysis and scenarios published in *Energy Technology Perspectives* provide the benchmarks used in *Tracking Clean Energy Progress*, and also support other analysis in the ETP series. Starting from the premise that electricity will be an increasingly important vector in energy systems of the future, *Energy Technology Perspectives 2014* takes a deep dive into actions needed to support deployment of sustainable options for generation, distribution and consumption. www.iea.org/etp2014

Recently released

More Data, Less Energy (free for download in mid 2014). The growing energy demand of billions of networked devices such as smart phones, tablets and set-top boxes is a great cause of concern. In 2013, such devices consumed 616 terawatt hours (TWh) of electricity. The International Energy Agency uses this publication to set the stage for tackling the challenge of network standby. In exploring policy and technology solutions, the book charts a path forward and identifies which stakeholders should take the lead in particular areas. www.iea.org/etp/networkstandby

Resources to Reserves (released in May 2013). There is no shortage of oil, gas and coal in the ground, but quenching the world's thirst for them in a sustainable manner will call for major investment in modern technologies. The publication reviews recent and anticipated future technological developments in the production of oil, gas and coal and their impact on future supplies of hydrocarbons. www.iea.org/etp/resourcestoreserves

Technology Transition for Buildings: Strategies and Opportunities to 2050 (released in June 2013) addresses building energy trends and technologies in both the residential and services sectors and necessary technology pathways to achieve objectives identified in *Energy Technology Perspectives 2012*. www.iea.org/etp/buildings

The Technology Roadmaps are free publications that identify priority actions for governments, industry, financial partners and civil society that could advance technology developments described in the *ETP 2DS*. As of May 2014, 20 global roadmaps have been published, covering a wide range of energy demand and supply technologies including solar photovoltaic energy, electric vehicles, carbon capture and storage, hydropower, energy storage and energy efficient buildings: heating and cooling equipment. More will follow in 2014. www.iea.org/roadmaps

For more information, please visit www.iea.org/etp

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Energy Technology Perspectives 2014

Harnessing Electricity's Potential

Starting from the premise that electricity will be an increasingly important vector in energy systems of the future, *Energy Technology Perspectives 2014 (ETP 2014)* takes a deep dive into actions needed to support deployment of sustainable options for generation, distribution and consumption. In addition to modelling the global outlook to 2050 under different scenarios for more than 500 technology options, *ETP 2014* explores the possibility of “pushing the limits” in six key areas:

- Solar Power: Possibly the Dominant Source by 2050
- Natural Gas in Low-Carbon Electricity Systems
- Electrifying Transport: How Can E-mobility Replace Oil?
- Electricity Storage: Costs, Value and Competitiveness
- Attracting Finance for Low-Carbon Generation
- Power Generation in India

Since it was first published in 2006, *ETP* has evolved into a suite of publications that sets out pathways to a sustainable energy future in which optimal policy support and technology choices are driven by economics, energy security and environmental factors.

- Topic-specific books and papers explore particularly timely subjects or cross-cutting challenges.
- **Tracking Clean Energy Progress** provides a yearly snapshot of advances in diverse areas, while also showing the interplay among technologies.
- Supported by the *ETP* analysis, IEA **Technology Roadmaps** assess the potential for transformation across various technology areas, and outline actions and milestones for deployment.

Collectively, this series lays out the wide range of necessary and achievable steps that can be taken in the near and medium terms to set the stage for long-term energy policy objectives, clearly identifying the roles of energy sector players, policy makers and industry. Next editions will examine the role of technology innovation to meet climate goals (2015) and urban energy systems (2016).

Who will benefit from using *ETP 2014*? Past experience shows that *ETP* publications attract wide and varied audiences, including experts in the energy field (e.g. technology analysts and academics), policy makers and heads of governments, as well as business leaders and investors. This reflects the value of the series' detailed and transparent quantitative modelling analysis and well-rounded commentary, which ultimately support high-level policy messages.

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