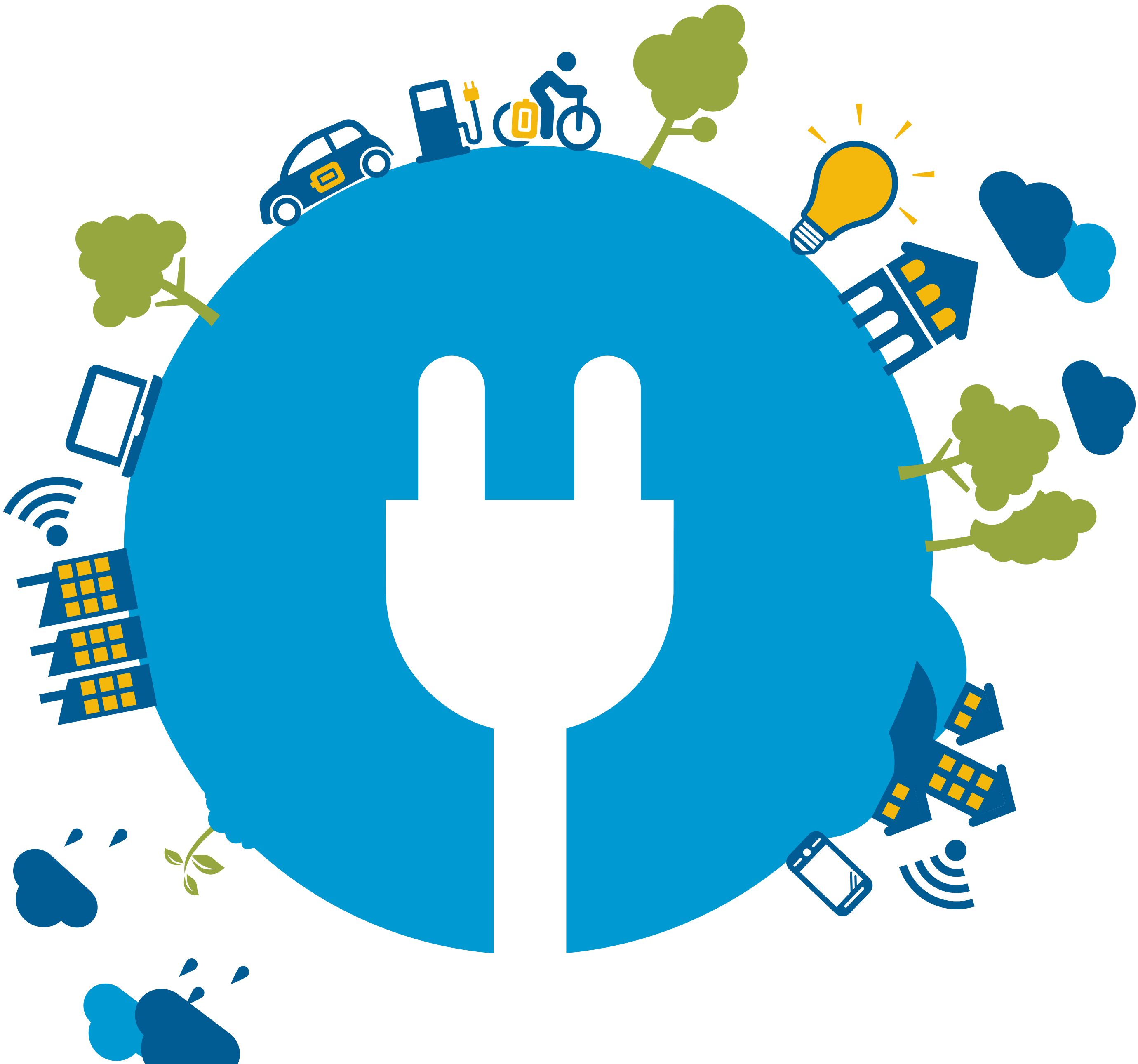
Global Sustainable Electricity Partnership

POWERING INNOVATION FOR A SUSTAINABLE FUTURE

An Electric Industry's Perspective



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GSEP OPEN LETTER TO POLICYMAKERS FOR COP21

We, the undersigned leaders of electricity companies participating in the Global Sustainable Electricity Partnership, believe that electricity can play a major role in responding to the climate challenge. While we recognise our different operating situations, we are aware of the common issues and opportunities we share and believe that optimisation of efficient existing technologies, and especially innovation in new technologies, are the cornerstones on which to build the energy transition.

The world is faced with the challenge of reducing greenhouse gas emissions to address climate change while ensuring economic growth and development.

Electricity is at the heart of this response.

There is an increasing need for electricity. More than 2 billion people either do not have access to any electricity or to the reliable electricity networks needed to use it productively and make meaningful improvements to their quality of life.

Lower carbon electricity represents the most effective vector of all energy systems for providing these benefits and should therefore be prominently ensured worldwide.

To play an ever-larger role in economies worldwide, electricity must be cleaner, safe, affordable, secure and continuously reliable but also efficiently generated, delivered and used. Smart grids, homes and cities will empower customers to be part of this change together with electricity providers. These, as well as global interconnected energy systems, will support the integration of decentralised and renewable sources, along with traditional centralised ones, into the generation, transmission and distribution systems.

Our goal is to promote, develop and deploy electricity technologies now and in the future that perform with all of these characteristics when supporting developing and developed economies and global efforts to address climate change.

We urge Parties when establishing a long-term, international agreement against climate change in the 21st Conference of the Parties (COP21), to enable effective frameworks that channel investments and operations, in all sectors but especially in the electricity sector, to support the development and deployment of reliable and affordable technologies in order to deliver lower or zero carbon emissions.

These frameworks will vary according to local situations be they carbon pricing or regulation or any other way to incentivise investments, operations and innovations that efficiently and cost-effectively reduce the carbon emissions from electricity.

We suggest taking into account four core principles to help secure our commitment to a better climate.

- Establish secure, stable, clear, consistent and long-term policies that address critically important energy, legal/regulatory, economic development, financial and environmental matters with the goal of ensuring an adequate supply of cleaner, secure, reliable, accessible and affordable electricity to tackle climate change
- Develop a systemic approach to electricity systems which takes into account the interrelations and synergies between the various elements of the electricity value chain, in order to enable electricity providers to plan, design, construct and operate the most advanced electricity systems with the goal of providing cleaner, reliable, sustainable, secure, flexible, and resilient electricity infrastructures

- Promote and engage in public-private partnerships that facilitate decision making among electricity providers, government representatives, and private stakeholders and that foster the development and deployment of new commercially available technologies
- Make urgent progress with innovative research, development and demonstrations of advanced economically viable technologies that will reduce greenhouse gas emissions and accelerate the efficient generation, delivery and end-use of electricity.

Our recommendations reflect the technologies that we are currently developing and that have already been developed and implemented by our sector to continuously reduce carbon dioxide emissions throughout the value chain.

These innovations are described in the following report entitled, "Powering Innovation for a Sustainable Future". Of particular note, external technical experts in various parts of the world including the United States, Brazil, China, and India reviewed and ratified each of these technologies.

With headquarters in Brazil, Canada, China, France, Germany, Italy, Japan, Russia, Spain and the United States and serving 1.2 billion customers, our companies generated and delivered about one third of the electricity used in the world last year with a capacity mix of which approximately 60% with no direct carbon emissions.

Together, we are leading the way in the global effort to avoid, and reduce carbon dioxide emissions by optimising technologies in the right mix, amount, time and place. By systematically optimising and applying the full portfolio of advanced technologies as they become commercially available, we believe that sustainable progress can be made over time to help meet global climate challenges.

We collectively hope that you find this report helpful and wish you a successful outcome in Paris.

Nicholas K. Akins
Chairman, President and CEO
American Electric Power

Jean-Bernard Lévy
Chairman and CEO
Électricité de France

José da Costa Carvalho Neto
CEO
Eletrobras

Francesco Starace
CEO and General Manager
Enel

Vyacheslav Solomin
CEO
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Michael D. Penner
Chairman of the Board
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Ignacio S. Galán
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Shosuke Mori
Chairman and Director
Kansai Electric Power Co.

Peter Terium
CEO
RWE

Evgeny Dod
Chairman of the Management Board
RusHydro

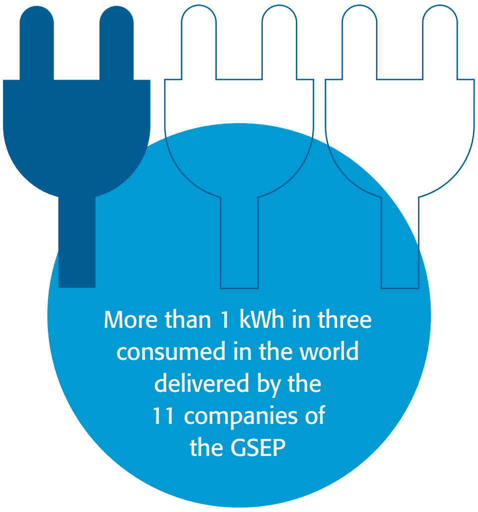
Shu Yinbiao
President
State Grid Corporation of China

GSEP: COMMITTED TO SUSTAINABLE POWER

This report is the product of collaborative work among the Global Sustainable Electricity Partnership members, sharing their wealth of experience in providing clean, safe, continuously reliable, secure and affordable electricity to more than a billion people.

GLOBAL SUSTAINABLE ELECTRICITY PARTNERSHIP:
an alliance of 11 electricity companies worldwide serving more than 1.2 billion customers

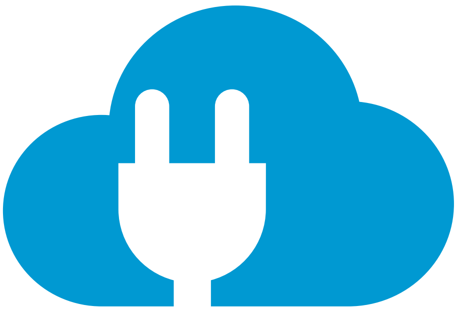
We have the capacity to significantly reduce carbon emissions while supporting our economies through the experience acquired over decades on all electricity technologies and their integration within the power system



- $140 billion in investment per year on generation, transmission, distribution and energy services
- More than 540 GW of installed capacity in all generation technologies (of which 33% hydro, 18% nuclear, 5% other renewables, 17% coal and 17% gas)
- More than 7 million km of transmission and distribution lines, overhead and buried, alternating and direct current; thousands of energy efficiency measures taken by GSEP members and hundreds of smart grid demonstrations under way

A strong commitment to climate and tangible results provide the basis to move forward

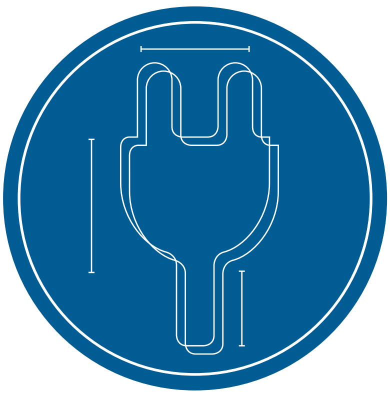
- A mainly CO_2-free energy mix, around 40% fossil-fired and 60% with virtually no direct CO_2 emissions



- A mix that avoids about 1 Gt of emissions a year, equivalent to around 8% of total emissions in the global electricity sector
- A CO_2-intensity 40% lower than the global average

Contributing to building the future by investing in innovation

- 2.4 million employees, of which more than 4,000 are dedicated to in-house R&D



- Around $3 billion a year invested in R&D across the entire spectrum of innovations, including future generation and network technologies as well as new ways of improving our cities, communities and daily life
- Open innovation teams which identify promising start-ups working on new technologies and which foster collaboration with our companies and, when needed, support them financially through dedicated funds

EXECUTIVE SUMMARY

This report has been written to assist country policymakers as they prepare to address ways that carbon dioxide and other greenhouse gas emissions can be stabilized and reduced at the Conference of the Parties in 2015. This Executive Summary and Recommendations section provides an overview of specific technology innovations and enabling public policies for lower- and zero-emitting generating, grid, and efficiency improvements described later in the report. The content of earlier drafts have been shared and confirmed by high-level electricity experts who shared their insights in China, India, Brazil and the United States in 2014 and 2015.

ELECTRICITY IS AT THE HEART OF OUR ENERGY FUTURE

The world is faced with the challenge of reducing greenhouse gas emissions to address climate change while ensuring economic growth and development. Electricity is at the heart of this response. There is an increasing need for electricity in the world. More than 2 billion people either don't have access to any electricity or to reliable electricity networks, to use it productively and to give comfort to people. Electricity represents the most efficient vector for providing these benefits. Last year the International Energy Agency predicted that, on a 2°C pathway, lower-carbon electricity could become the major form of energy worldwide by 2050. It is clear that electricity will play an ever-increasing role in our economies and everyday life. Moreover, as this report shows, this transformation of other forms of energy into electricity provides opportunities to improve the environment, including reducing greenhouse gas emissions using the full portfolio of existing and future technologies.

The electricity sector has been leading the way in the global effort to emit less carbon dioxide equivalent (CO_2eq) greenhouse gases from our sector. Electricity providers understand that the development of an international policy in 2015, that provides a platform for nations to pledge to reduce their CO_2eq emissions from all sectors, including electricity, is very important. Simultaneously, countries are turning to electricity to achieve their economic and social development goals.

Therefore, energy efficiency and technological innovation in the electricity sector are essential, in order to both reduce emissions and improve the quality of life of citizens around the world. COP21 policymakers are well positioned to help accelerating the development and deployment worldwide of energy efficiency measures and of innovative technologies with effective policies.

The value of Integrated System Planning and Operation

As power supply systems are becoming even more complex, national, trans-national and regional policies and regulations, in a longer-term frame, have to consider that planners and operators must consistently design and manage the amount and sources of electricity that will be increasingly placed on electricity systems at any given time. The International Energy Agency predicts that worldwide electricity demand will increase. All generation sources will be needed to sustainably reduce power sector emissions, according to the Intergovernmental Panel on Climate Change (IPCC). More baseload generation will be vital, providing continuously available power, helping make electricity affordable and contributing to a high-performance grid. More renewable generation sources will also be required: they will need to be integrated not only into the grid, but also into the market in order to operate in a level playing field with other sources.

A very high priority for designers and operators in the grid integration process is voltage support for electricity transmission and distribution systems from the proper mix and amount of electrical energy from generation. If the voltage deviates too much from regional, national, and trans-national grid reliability standards, partial or complete grid shutdowns can occur. Power quality, performance, affordability and reliability standards have been established so that changes in generation can be monitored and compliance with these standards can be predicted to prevent decreases in grid performance. Appropriate technologies are already commercially available today and advanced ones are being developed and demonstrated to ensure reliable, secure and affordable electricity will always be available when consumers need it.

Electricity prices are important to households and businesses. Environmental, energy, economic development, and investment policies, as well as legal/regulatory frames and markets all influence the affordability of the electricity produced and delivered. The electricity sector is supporting the research, development and demonstration (R&D&D) of lower- and zero-carbon emitting technology innovations that are not only affordable, but cleaner, safer, more secure and continuously reliable as well. The growing electricity needs in many countries and/or geographical regions of the world can only be satisfied with a comprehensive portfolio of technologies.

TOMORROW: INNOVATION IS THE BRIDGE TO A SAFE CLIMATE

The International Energy Agency has estimated that electricity technology investments of 20 trillion dollars (USD) will be needed between the years 2015 to 2040. Nations and electricity providers will be able to choose combinations of these technologies according to their commercial readiness, market conditions, consumers' ability to pay for them, national energy security and independence priorities, geographical circumstances, resource availability and their role in residential, commercial and industrial, transportation and other sectors.

Developing better generation

Central and distributed generation based on hydropower, wind, solar and other renewable energies are playing an increasing role in markets, helped by careful large scale power systems modeling and planning for energy balancing. Advanced technologies are needed to integrate them with baseload generation complemented with bulk storage and flexible demand linked to transmission and distribution grids. Strong, smart, efficient, flexible, reliable transmission and distribution grids, as well as energy storage in a longer time-frame, are critical to deliver electricity with reduced CO_2eq emissions in the future. Spreading and developing ‘sustainable-hydro’ best practices will enable to tap into the significant remaining hydro potential worldwide. New designs and innovations in materials can increase energy capture and reducing component costs for onshore and offshore wind, in a rather broader wind profile rank. For solar, breakthroughs in semiconductors would boost the efficiency of and make it competitive beyond sunny regions.

Nuclear power has demonstrated its role in significant emissions mitigation, as it provides dispatchable, CO_2-free, affordable baseload energy. Continuous improvement of existing plants and moving down the experience curve on Generation III technologies are key examples of such innovations.

Combined-Cycle Gas Turbines (CCGT) is today the lowest-emitting fossil-fired generation technology. New ultra-flexible Combined-Cycle Natural Gas Turbines can run longer with higher efficiencies and reduced outages.

Coal plants with thermal efficiencies of 40% and higher are becoming the standard. Advanced ultra-supercritical coal plants could reach 50% efficiency with more development against 33% for the existing fleet, thanks to new materials and alloys resistant to very high temperatures and pressures. Technologies to capture CO_2 in flue gas from these plants is being developed and demonstrated.

Rethinking power systems

Stronger, smarter, efficient, reliable and flexible large transmission and distribution grids are being built and developed with the capability to move large amounts of electricity from generation and energy storage sources and to provide electromechanical stability, voltage regulation and other support services to the grid.[1] They are crucial to delivering electricity with increasingly reduced CO_2eq emissions.

Progress in power electronics and the management of a mix of AC and DC lines, and spreading the use of Ultra High Voltage technology, can enable greater power loads on a given grid topology as well as more efficient load distribution across the network. For lower-voltage networks, digitization use of information technologies is facilitating the integration of intermittent and decentralized generation, and empowering “prosumers” to actively participate in the supply-demand balance of the electricity system.

Bulk storage could revolutionize electricity systems, increase the integration of intermittent energy sources and reduce the need to develop or expand power networks. Many types of storage are available. Some are already competitive today, such as pumped storage or electric water heating.

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1. In the coming year, GSEP will investigate further the key role of grids with a joint work led by State Grid Corporation of China, namely on the theme of “Roadmap for Future Energy - Moving from Today's Power Systems to Global Energy Interconnection”

Progress in batteries allows them to provide power in a very short time period (grid frequency regulation, to cope with demand peaks, and provide system services such as voltage and stability control, etc.). However, significant R&D&D on materials and nanotechnologies are needed to develop batteries that can transfer energy over longer time periods which would help greater grid integration of intermittent renewable energy sources.

Optimizing energy use

Improving end-use efficiencies of electro-technologies such as heat pumps and lighting, fostering the uptake of efficient electricity uses in homes, in commercial and institutional buildings, in manufacturing facilities and in the transportation sector are opportunities to optimize energy use and to enable electricity to play its full role in delivering lower end-use emissions.

Innovation of electric vehicles involves three major objectives areas: extending range, reducing costs, and developing charging infrastructure. Lithium-ion batteries are making robust progress: current trends could, make electric vehicles competitive with internal combustion engine vehicles in many regions of the world in the near future.

Developing smart homes and buildings, smarter and more sustainable cities will be also key avenues for innovation; these will entail a systemic approach with lower- and zero carbon electricity and digital technologies at the core.

TODAY: OUR GROUNDS FOR ACTION

While innovation is vital, it takes time. However, as this report demonstrates, the research, development, and demonstration steps in lower and zero carbon technologies have already started. Commercially deployable technologies are ready now that can all contribute to climate change mitigation and global temperature stabilization. Promising technologies, vital to stabilizing and further decreasing CO_2eq emissions, can become market-ready in the not- too -distant future with enhanced RD&D support policies and international collaboration among technology researchers, developers and electricity providers and users.

Not all technology innovations are commercially ready today or produce and deliver electricity at affordable prices, but some already applied technologies are helping to curb emissions now. As the statistics for GSEP illustrate, electricity providers have been working with individual national governments to select and deploy the optimal mix of technologies.

The optimal combination of existing and new technologies will vary from country to country, or even between geographical region, depending on the structure and state of local and regional electricity systems, the availability of energy resources, the development of industry and the speed at which the less mature technologies improve in terms of performance and cost. A systemic approach to the electricity sector will be crucial to tailor stable long-term policy frameworks able to keep electricity costs in check through deep, nation or region-specific assessments of technologies and their potential interactions.

POWERING INCLUSIVE SUSTAINABLE DEVELOPMENT

By optimizing current technologies and adding new ones with supportive policies, investments and markets, emissions can be reduced and the quality of life of billions of people improved, including those who either don't have access to any electricity or who don't have access to enough electricity to use it productively. This is how the electricity sector is implementing the Positive Agenda for economic growth and improving society's well-being.

Local, national, regional and trans-national electricity, economic and financing development plans that factor in appropriate technologies yielding affordable prices will be vital. They will need to be implemented by governance, technical, managerial, and entrepreneurial training.

In addition to reducing CO_2eq emissions, significant efforts and investments to make electricity systems more resilient, secure and reliable are also of great importance, in order to respond to more severe and extreme weather conditions. Planning ahead to adapt is crucial for electricity providers, especially as changing water resource availability can significantly disrupt the operation of some technologies. The water-electricity nexus also needs to take into account rising food production: 60% more food will be needed by the world's population in 2050.

POLICIES TO DRIVE MITIGATION AND INNOVATION

Rising to the challenge of climate change and transforming electricity systems calls for commitment. Electricity companies are ready to contribute, bringing their practical experience of the sector, their expertise in low- and zero- carbon technologies and their capacity for RD&D.

It is through this process and dynamic of cooperation and dialogue that a stable, long-term policy framework should emerge, integrating the following core components:

- Fostering innovation through research and development and demonstration activities (R&D&D) supported by national governments and international collaboration;
- Striving to continuously increase energy efficiency and improve the performance of electricity systems;
- Establishing long-term stable frameworks that are decades long to encouraging better planning, resource use, investment conditions, risk management and cost efficiency;
- Prioritizing cost-effectiveness to accelerate near-term progress on reducing emissions that electricity users can afford;
- Setting clear environmental, energy, economic and social development objectives to create synergies that sustain development; and
- Mobilizing financing for lower and zero-carbon emitting technologies to be deployed and maintained with appropriate CO_2 prices in countries that choose to do so.

RECOMMENDATIONS

The world's population can fully benefit from innovative electricity technologies when a long-term, international carbon emissions agreement is made that enables action along four key principles:

- **Establish secure, stable, clear, consistent and long-term policies that address critically important energy, legal/regulatory, economic development, financial and environmental matters aimed at reducing emissions with the goal of ensuring an adequate supply of cleaner, secure, reliable, accessible and affordable electricity.**

- **Develop a systemic approach to electricity systems which takes into account the interrelations and synergies between various elements of the electricity value chain, in order to enable electricity providers as they plan, design, construct and operate the most advanced electricity systems with the goal of providing cleaner, reliable, sustainable, secure, flexible, and resilient electricity generating and delivery infrastructures.**

- **Promote and engage in public-private partnerships that facilitate decision making among electricity providers, government representatives, and private stakeholders and that foster the development and deployment of new commercially available technologies.**

- **Make urgent progress with innovative research, development and demonstrations of advanced economically viable technologies that will stabilize and reduce emissions and accelerate the efficient generation, delivery and end-use of electricity.**

1

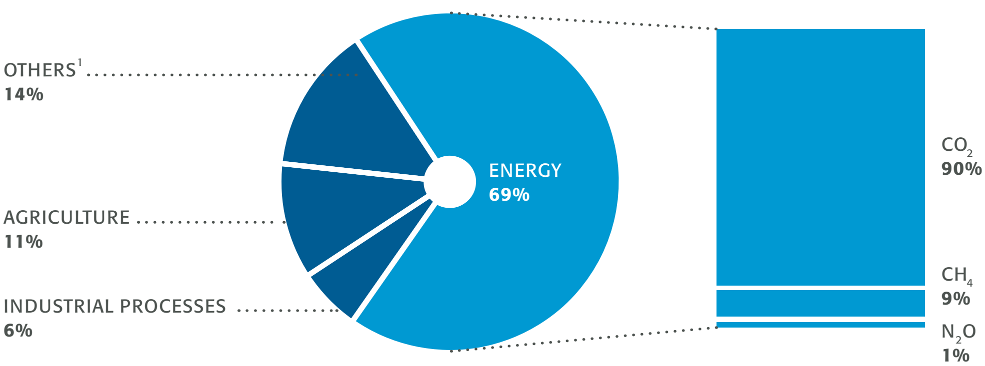
CONTEXT: ELECTRICITY AT THE HEART OF OUR ENERGY FUTURE

At the Climate Change Conference in Copenhagen in December 2009, governments agreed on the long-term goal of limiting maximum global temperature increases to no more than 2°C above pre-industrial levels by 2100.

However, almost six years after Copenhagen the world is not on track: without a greater effort to reduce greenhouse gas (GHG) emissions, global average surface temperatures are likely to rise to 3.7°C above pre-industrial levels by 2100 according to the International Energy Agency.[i]

Climate change mitigation calls for action across many fronts, and electricity will be one of the cornerstones of the world's response. A two-fold dynamic is gathering pace in the electricity sector, with the replacement of more carbon-intensive energy carriers in many uses and at the same time the progressive transformation towards low-carbon generation.

SHARES OF GLOBAL ANTHROPOGENIC GREENHOUSE GAS (GHG) EMISSIONS – 2010



1. Others include large-scale biomass burning, post-burn decay, peat decay, indirect N_2O emissions from non-agricultural emissions of NO_x and NH_3, Waste, and Solvent Use.

Source: IEA, CO_2 Emissions from Fuel Combustion, Highlights 2014

FORGING A 2°C PATHWAY AGAINST CURRENT TRENDS

With GHG concentration levels today approaching 435 ppm CO_2eq, the world is on a trajectory to cross the 2°C threshold before 2100.[ii]

Between 1970 and 2010, global emissions of GHGs increased by 75% from 27 to 49 billion tonnes of CO_2 equivalent (GtCO_2eq). Emissions from the energy sector (mainly electricity generation) and from transport dominate this increase: worldwide, power sector emissions have tripled since 1970 and transport emissions have doubled.[iii]

The growth rate of global emissions went from 0.6%/year in the decade between 1990 and 2000 to 2.2%/year from 2000-10. Yet, according to the Intergovernmental Panel on Climate Change (IPCC), global emissions would need to decrease by 2.2% per year over the period 2010-2050 in order to have a serious chance of limiting the global temperature rise to no more than 2°C by 2100. Moreover, we should bear in mind that the energy system – which accounts for the majority of GHG emissions – can only change relatively slowly, even in the face of concerted mitigation policy efforts.

AFFORDABILITY BACK AT THE TOP OF THE AGENDA

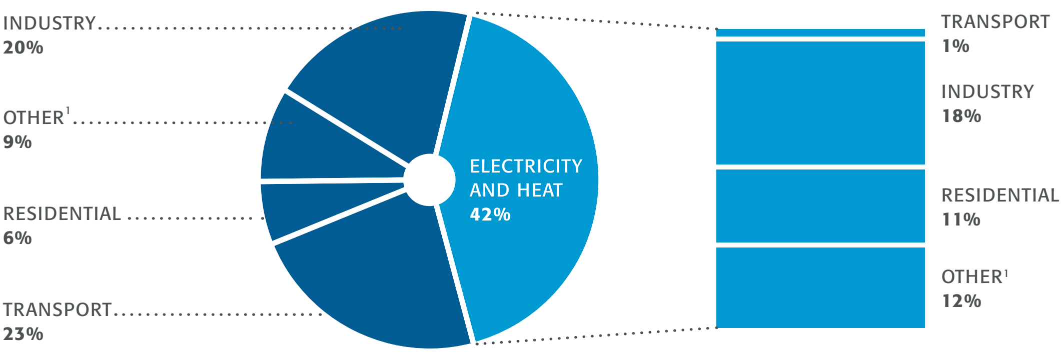
Following the financial and economic crisis, less favourable growth perspectives and weakened public finances have put the costs of mitigation policies adopted in various regions of the world under the microscope.

In a context of lower growth and increased international competition, energy prices are an increasingly sensitive issue for both households and businesses. For example:

- Higher electricity prices have a direct impact on households' purchasing power, especially poorer ones, highlighting the importance of energy efficiency and effective policies against fuel poverty. In developing countries, higher electricity prices are raising the bar to access to electricity, postponing the day when everyone in the world will have a source of reliable energy
- Higher electricity prices are having a negative impact on the competitiveness of industry.

From a macroeconomic perspective, sharp increases in electricity prices could trigger supply shocks similar to oil price hikes, given that the proportions of oil and electricity in GDP are of the same magnitude. In such circumstances, the growth of virtually all sectors (e.g. in terms of productive output and job creation) would be negatively affected.

WORLD CO_2 EMISSIONS BY SECTOR – 2012



Note: Also shows allocation of electricity and heat to end-use sectors.

1. Other includes commercial/public services, agriculture/forestry, fishing, energy industries other than electricity and heat generation, and other emissions not specified elsewhere.

Source: IEA, CO_2 Emissions from Fuel Combustion, Highlights 2014

Both micro and macro impacts are amplified by international distortions in energy (and specifically electricity) prices between Europe, North America and Asia. Increasingly, electricity is becoming a driver in international competition. In a period where wage gaps across regions are diminishing, affordability and competitiveness are therefore being reinforced as central objectives of energy policy.

HARNESSING THE POTENTIAL OF ELECTRICITY TO DECARBONISE THE ENERGY MIX

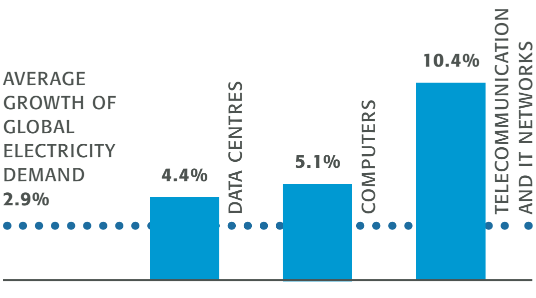
The energy sector is the largest contributor to global GHG emissions, accounting for two-thirds of the total.

The electricity sector itself represents 25% of direct global GHG emissions, followed by forestry and land use (23%), industry (18%), transport (14%) and buildings (6%), illustrating the importance of electricity in tackling climate change.

Despite progress in the deployment of clean energy, continued dependence on fossil fuels is maintaining the high carbon intensity of the power sector. Globally, the CO_2 emissions intensity of electricity generation has improved only slightly over the past 40 years.

In order to significantly reduce CO_2 emissions in the electricity sector, there is a critical need for competitive advanced generation, transmission,

AVERAGE GROWTH OF ELECTRICITY DEMAND IN THE GLOBAL DIGITAL ECONOMY – 2007-2012



Source: IEA, ETP 2014

distribution, storage, and end-use efficiency technologies to be available on time. This will enable countries and electricity providers to optimise for specific circumstances that exist now and in the future and avoid harming economies due to a lack of cleaner, safer, affordable, secure and continuously reliable technologies.

LOW-CARBON ELECTRICITY TO BECOME THE LEADING ENERGY CARRIER

Establishing a 2°C pathway depends on emission reductions across all sectors. For the electricity sector, it will depend on how fast existing advanced technologies can be rolled out and new technologies can be developed, demonstrated and commercialised. Low-carbon electricity has a key role to play in emission reductions in other sectors: it could well become the leading final energy carrier over the course of the century, overtaking oil before 2050.

A range of factors that are transforming our societies and economies are also driving demand for affordable, clean electricity: population growth, improved standards of living, urbanisation, technological development and digitisation, together with more efficient end-use of energy and electricity:

- Global population is expected to grow from 7 billion people today to 9.5 billion people in 2050; the world's urban population – 54% of the total in 2013 – is expected to increase to 66% by 2050
- Today, citizens in developing countries consume up to six times less electricity than those in the OECD. A significant proportion of the 1.3 billion individuals who still lack electricity will have access to it by 2050. By then, average electricity demand growth is expected to reach 145% in non-OECD countries compared to 16% in OECD countries, according to the IEA.
- Computerisation – already common for equipment and appliances in most industries, offices, and homes – is a growing trend.

2

TOMORROW: INNOVATION A BRIDGE TO A SAFE CLIMATE

According to the IEA, global electricity-related CO_2 emissions intensity (g/kWh) needs to be reduced by 90% by 2050 to meet the 2°C target. This constitutes a reversal of recent trends, which have seen overall global emissions from the electricity sector increase by almost 75% between 1990 and 2011, due to rising demand with little change in emissions intensity.[iv]

While significant progress can be made with existing technologies, in the long run deep decarbonisation calls for a commitment to innovation. The field of action is vast. Not only are there multiple promising technologies in various stages of development, but significant innovations are also possible in the management of power systems and in the use of energy. A systemic approach to our power systems will be essential, factoring in the interactions of technology choices from generation to networks and end-uses, and their impact on industry, economies and user behaviours.

Engaging citizens, policy-makers, business, financial investors, and research and higher education institutes on a journey of energy innovation will put at our disposal the solutions that can be progressively implemented (and optimised) to deliver a safe climate over the coming decades. Innovation has the potential to unleash a transformation of the energy sector, generate new jobs and opportunities for growth, and improve the quality of life of citizens around the world.

TYPICAL EMISSIONS FROM ELECTRICITY GENERATION TECHNOLOGIES

	g/kWh	
	DIRECT EMISSIONS	LIFECYCLE EMISSIONS
Coal	750	800
CCGT	350	500
Coal CCS	120	220
Hydro	0	70 – Very site specific
Nuclear	0	20
Biomass	0	200 – High variability
Wind	0	10
PV	0	60
Geothermal	0	40

Source: based on IPCC, AR5, WGIII, Chap 7

INNOVATION: DEVELOPING BETTER GENERATION

Innovation is not simply the search for the "game-changer", one idea that will transform everything. Rather, it is a process of exploring all possible avenues, working to improve the full spectrum of available technologies, planning from the earliest stages for the integration of all technologies into power systems and shaping new ways to engage citizens and communities.

Below we draw on the experience of the companies that comprise GSEP to outline the state of play in energy technologies, and what prospects are in store if innovation dynamics are maintained or strengthened. Technologies are presented in the following way: technologies with no direct emissions such as renewables (according to their current share of the global mix) and nuclear; fossil-fired technologies such as coal and gas-fired plants and carbon capture and storage (CCS).

TECHNOLOGIES WITH NO DIRECT EMISSIONS

HYDROPOWER

GLOBAL INSTALLED CAPACITY	1,172 GW
GLOBAL PRODUCTION	3,900 TWh
SHARE OF GLOBAL ELECTRICITY GENERATION	17%

Why innovate?

Hydropower is currently the world's leading renewable technology with virtually zero emissions. It met around 17% of the world's electricity needs in 2014 (~ 3,900 TWh) from an installed capacity of 1,172 GW.[v] Four countries – China, Brazil, Canada and the United States – together represent 50% of global hydropower output.

However, current global production only exploits one-third of economically viable hydropower, with several regions (for instance sub-Saharan Africa) only using a fraction of their potential.

Hydropower provides the power system with a number of tools in addition to power generation: gravity energy and pumped storage improve system regulation (enabling voltage and frequency regulation, black start, reserves) and can facilitate the integration of intermittent renewable energies. Hydropower also enables the management of the multiple uses of water resources, such as transportation, irrigation, flooding control, leisure activities, etc.

What innovations?

The future of hydropower depends on geographical context.

HYDRO: TODAY'S LEADING RENEWABLE GENERATION HAS SIGNIFICANT COMPETITIVE POTENTIAL

The Krasnoyarskaya Hydropower Plant on the Yenisei River in Eastern Siberia, Russia, has an installed capacity of 6,000 MW (EuroSibEnergo).

Europe and Japan's hydropower resources are already largely exploited, so future projects will mainly involve renovating and upgrading existing infrastructure, developing hydropower's role in regulating and balancing the power system, and addressing the issue of competition for water use in drier regions.

In Asia, Canada, Russia, South America and Africa, hydropower has a major role to play in generating electricity while contributing to sustainable development.

From a technological standpoint, the main challenges are to:

- Deploy command and control systems to boost the role facilities can play in regulating the power system
- Coordinate the management of thermal and hydropower facilities to optimise water usage while enhancing system flexibility
- Design and build turbines with very high unit capacity adapted to very large facilities
- Boost operating flexibility, especially by speeding ramp-up rates.

Sustainability is the cornerstone of hydropower development. In the past, projects of intrinsic quality have foundered because the public or other stakeholders did not consider that the benefits outweighed the multidimensional impacts that a hydropower facility might entail. Accordingly, hydropower developers need to address issues relating to land use, impacts on fauna and flora, biodiversity and the displacement of populations. There are good examples of successful impact mitigation and environmental management available from the implementation of hydro projects in the past two decades.

More recently, concerns have been raised about methane emissions from large dams in tropical areas. Better understanding of reservoir behaviour in terms of GHG emissions, factoring in the importance of soil composition or the ratio between flooded area and the capacity of the facility are key elements, as is employing best practices (such as the Hydropower Sustainability Assessment Protocol developed by the International Hydropower Association).

HARNESSING HYDRO POTENTIAL ACROSS THE WORLD BY SPREADING SUSTAINABLE HYDRO BEST PRACTICES

The Volzhskaya Hydropower Plant is the largest European hydropower plant with an installed capacity of 2,639 MW and 23 hydro units of various capacities. It is the last downstream power plant of the Volga River in Russia (RusHydro).

ONSHORE WIND POWER

GLOBAL INSTALLED CAPACITY	361 GW
GLOBAL PRODUCTION	700 TWh
SHARE OF GLOBAL ELECTRICITY GENERATION	3%

Why innovate?

Onshore wind is a carbon-free renewable technology for generating power. Its output reached around 700 TWh in 2014, from an installed capacity of 361 Gigawatts (GW). China led the way with 115 GW of installed capacity, followed by the United States (66 GW), Germany (38 GW) and Spain (23 GW). In total, wind power supplied around 3% of the electricity consumed worldwide.

Thanks to a consolidated manufacturing base and progress on operation and maintenance, onshore wind power is already competitive in high-wind regions, where it can be rolled out without any direct support mechanism.

In other regions, large diameter turbines have enabled an increase in the load factor of wind generators in medium and low-wind areas. This has enlarged the potential for development while keeping the level of support constant.

In order to boost onshore wind potential, innovation can contribute to:

- Progressively decrease turbine costs
- Adapt turbines to harder climate conditions (cold, extreme winds, etc.)
- Further optimise impact management (resolving conflicts with radar zones, acceptability of larger and taller machines, impacts on wildlife, etc.) and improve generation forecasts and integration into the grid.

What innovations?

In the short run, incremental innovation such as larger turbines can bring onshore wind forward. As of today, onshore turbines of 2 to 3 megawatts (MW) represent a large majority of the capacity installed worldwide. Larger machines (5-6 MW) are available and further development could see a progression to very large turbines (8 MW and over); this will reduce costs and open the way to developing wind power in areas with weaker wind resources. Developing optimised repowering solutions is also high on the agenda in countries or regions with significant existing plants.

Turbines that do not interfere with radars would allow installation in radar exclusion zones, while those with hot air circulation systems or electric heating to prevent ice from forming on the blades would open up development in colder regions with significant wind resources.

Innovations in materials (like neodymium turbines), electrical engineering, and aerodynamics – as well as enhanced operation and maintenance practices – could also increase the lifetime of wind turbines.

In the medium term, the emergence of a more integrated global market for wind turbines could help bring the costs further down. Better wind forecasting should allow for better generation plans and better integration into the grid, helped by turbines that provide direct reserve services to the grid (such as frequency control and primary reserves).

Longer term, wind technology could benefit from the development of superconductor materials or breakthroughs such as extra-large blades assembled from parts.

A foldable helicopter with cameras and sensors designed for inspecting wind turbine blades in order to reduce O&M costs (Iberdrola).

ONSHORE WIND: LARGER TURBINES WILL EXTEND COMPETITIVENESS TO LESS WINDY AREAS

OFFSHORE WIND POWER

GLOBAL INSTALLED CAPACITY	9 GW
GLOBAL PRODUCTION	40 TWh
SHARE OF GLOBAL ELECTRICITY GENERATION	<0.5%

Why innovate?

Offshore wind power is at an early stage of deployment with a rapid pace of development. In 2014, global installed capacity was around 9 GW with more than 4 GW installed in the United Kingdom.

Building wind farms offshore expands the number of available sites. In addition, offshore sites benefit from higher and more regular wind resources. The cost of offshore wind remains typically 1.5 to 2 times higher than onshore wind with a potential for cost reductions as the technology gains a critical industrial mass.

In order to capitalise on the potential of offshore wind, innovation is key to keeping construction costs in check and optimising operation and maintenance.

What innovations?

Cost reductions can be achieved in several areas:

- In the development phase, by improving the knowledge of sites (detailed knowledge of the seabed, wind resources and wave and sea profiles) in order to de-risk projects

The Fécamp offshore wind farm project in France reduced installation costs by using 83 innovative gravitational floating foundations transported by trailer, rather than by costly traditional shipping (EDF).

OFFSHORE WIND POWER: HARNESSING POTENTIAL THROUGH INNOVATION ALL ALONG THE VALUE CHAIN

- In the planning phase, for instance through the optimisation of foundations. Current foundation design is derived from offshore oil rigs and represents 40% of costs. Alternatives to the standard monopole design include new concepts like gravity-based systems and optimised jackets, which could be adapted for some sites after tests and validation. Increasing the size of the turbines would reduce the number of machines per farm and thus the related foundation work. Most offshore turbines installed to date were modelled on onshore wind technology. From capacity levels of 2 to 3 MW, commercially available size has increased to 7 to 8 MW and 10 MW turbines are expected in the coming years, while the technology is becoming more and more tailored to offshore conditions.
- In the construction phase, by minimising work at sea or developing faster installation
- During operation, for instance by reducing onsite interventions through e-monitoring and by increasing knowledge of component ageing, especially for larger turbines.

In the longer term, floating turbines without foundations are a promising technology that could radically change the future of offshore wind, massively enlarging potential sites (including those in even more windy zones and greater depths), increasing installation speeds, eliminating the need for special installation ships, and facilitating maintenance (which could be carried out onshore). Pilot research programmes would help identify the right float systems and the best-adapted turbines and optimise the anchoring system.

The Nordsee Ost offshore wind farm in Germany has an installed capacity of 295 MW and uses 48 multi-MW wind turbines in water depths of up to 25 metres (RWE).

OFFSHORE WIND: LARGER TURBINES, BETTER FOUNDATIONS AND ENHANCED O&M ARE MAIN AVENUES FOR COST REDUCTIONS

BIOMASS

GLOBAL INSTALLED CAPACITY	95 GW
GLOBAL PRODUCTION	430 TWh
SHARE OF GLOBAL ELECTRICITY GENERATION	2%

Why innovate?

Electricity from biomass is the third largest contributor of renewable electricity in the world, after hydro and wind power. In 2014, generation reached 430 TWh, for an installed capacity of around 95 GW worldwide, representing 2% of global electricity generation.

Electricity from biomass can be generated from a wide range of resources, which can be categorised into four main types: solid biomass (mainly forestry and agricultural products and residues), which accounts for 75% of biomass generation; wet biomass converted to biogas through methanation (18%); the renewable portion of incinerated waste (7%); and liquid biomass (1%).

The Biomass Platform of Velaine en Haye, France prepares and stores wood biomass from local resources that feeds several cogeneration systems located within 60 km from the facility, ensuring the traceablity of the biomass supply through an IT system (EDF - © EDF – Stephane Harter)

BIOMASS: INNOVATION IN SUSTAINABILITY, PRE-TREATMENT AND COGENERATION CAN BOOST POTENTIAL

A number of technical processes for producing electricity from biomass have reached maturity. The main methods for solid biomass are combustion inside a dedicated boiler and co-combustion in thermal power plants. Gasification, in which dry biomass is converted into a combustible gas, is still being developed. As for wet biomass, methanation involving the conversion into biomethane of wet biomass by a biological process is the main solution in use.

In order to enhance efficiency and ensure competitiveness, electricity generation can be combined with the production of usable heat (cogeneration).

Small generation plants, while not benefiting from the economies of scale of larger facilities, allow low-cost local biomass, with short supply chains, to be used and thus avoid the sustainability challenges that come with larger resource requirements. In addition, smaller plants are more likely to find markets for heat as well as electricity, and hence use their resources optimally.

To fully exploit the potential of this technology, there is further scope to both bring down production costs (for instance, through modular replicable and scalable solutions) and to optimise the management of biomass resources, integrating demands from other end uses (heat, biofuel, biomethane).

What innovations?

Innovation can contribute across three broad fronts:

- Sustainability: Electricity from biomass depends on the sustainable use of resources, for which lifecycle assessments taking into account local situations, production of waste, changes in land use and interactions between energy, water and food will be key.
- Pre-treatment: Biomass is pre-treated to create a fuel that is more compact and homogeneous, and therefore easier to burn. Some pre-treatment processes are advanced, such as roasting, pyrolysis and biogas, while others are less mature, such as hydrothermal treatment. When properly treated, biomass can replace coal in coal-fired plants with only minor modifications to facilities, while untreated biomass can replace up to 15%.
- Cogeneration: Generating electricity and heat at the same time enhances overall energy efficiency, although the heat produced needs to be used close to the facility. In practice, combined heat and power plants running on biomass generate little electricity due to the low temperature of the heat source. Processes based on the Organic Rankine cycle, using organic fluids that vaporise at 70°C, rather than water, could help improve the electricity output of these plants.

SOLAR PHOTOVOLTAIC (PV)

GLOBAL INSTALLED CAPACITY	177 GW
GLOBAL PRODUCTION	170 TWh
SHARE OF GLOBAL ELECTRICITY GENERATION	0.7%

Why innovate?

Solar PV has a considerable potential. It has experienced massive growth over the past ten years, with installed capacity increasing by a factor of more than 40 since 2004. Installed capacity reached around 177 GW in 2014 for around 170 TWh produced, amounting to 0.7% of global power generation. The European Union remains the leading market so far, with more than 80 GW of installed capacity. The centre of gravity is, however, moving to Asia. With a production exceeding 40 GW of panels per year, and a manufacturing capacity of around 70 GW, the solar PV industry has now entered industrial maturity.

This momentum has been driven by considerable technological progress. In the past 15 years, module conversion efficiency has risen by more than 50%, from less than 10% to 15% for industrial modules. Efficiency enhancements have been achieved across the spectrum of existing PV technologies: crystalline silicon (c-Si), including both multicrystalline or single crystal technology, with an estimated market share of 80%; and "thin-film" cells made with cadmium telluride (CdTe) or copper indium gallium selenium (CIGS).

Increased efficiency of modules, together with the upscale of manufacturing and its transfer to countries with low labour costs, has driven module prices down by a factor of five since 2008, while better solar power plant efficiency has translated into a lower footprint, thereby reducing the "balance of plant" cost.

As a result, today, electricity from ground-mounted solar PV (PV farms) has almost reached competitiveness in countries with high levels of sunlight and where peak demand correlates with sunlight, as long as volumes are kept in check to maintain a high enough market value for the kWh produced by PV.[1] In those regions, the presence of storage capacities such as hydro reservoirs can significantly enhance the competitiveness and penetration of PV generation. In regions with less sunshine, the total cost can be two to three times higher. Today, roof-mounted PV panels can typically be 1.5 to 2 times more expensive than ground-mounted panels.

Pursuing the dynamic of research and development has the potential to reduce costs further and enable solar PV to take hold beyond existing markets.

What innovations?

Incremental progress on existing technologies can put the PV performance target of 25% efficiency for industrial modules within reach, by:

- Bringing the performances of multicrystalline silicon cells, which are less expensive, towards the level of monocrystalline cells

1. This refers to the fact that the value of each kWh produced by PV (i.e. "the market value") decreases with higher installed capacity. The first GWs of PV displace peaking plants with high variable costs. Increasing installed capacity displaces mid-merit units with lower variable costs and, ultimately, displaces baseload units with very-low variable costs. This effect is described in more length in IEA, WEO 2014, pp. 268 and 269.

SOLAR PV A SOLUTION FOR HIGHLY SUNNY, REMOTE OFF-GRID AREAS

This solar PV (200 kWp) facility, together with a mini wind turbine (30 kW), and electrochemical batteries (520 kWh) covers the electricity needs of the remote village of Ollague, Chile, at 3,700 m altitude (Enel).

- Controlling impurities in semiconductors to avoid the excessively fast recombination of charge carriers that limits the number of electrons that can be used to generate power
- Optimising plant design and progressing in converters to enhance the performance of PV plants and reduce the "balance of plant" cost. Innovative converters and module designs can also be used to repower existing plants.

These developments could bring the cost of ground-mounted PV systems down to $1 per Watt-peak (Wp), substantially enlarging the scope for the development of PV power.

For solar PV electricity to develop in regions with lower solar irradiation and where peak power demand does not coincide with peak sunlight, the target is R&D on breakthrough technologies to reduce the cost of PV systems below the $1/Wp target. However, with current PV cells, that would entail achieving higher efficiencies than is theoretically possible. Breakthroughs in hybrid multi-junction technologies and thin-film/crystalline silicon are potential high-efficiency solutions as long as cell costs are successfully kept in check. In the long term, new concepts still at the lab stage, such as hot carriers and intermediate band cells, are examples of research avenues that could deliver significant efficiency increases in the coming decades subject to a strong commitment to R&D.

GEOTHERMAL

GLOBAL INSTALLED CAPACITY	12 GW
GLOBAL PRODUCTION	73 TWh
SHARE OF GLOBAL ELECTRICITY GENERATION	<0.5%

Why innovate?

Installed geothermal capacity stood at 12 GW in 2014 with around 73 TWh produced, divided between two distinct technologies:

- Conventional geothermal electricity in volcanic environments
- Unconventional geothermal electricity in sedimentary environments.

Geothermal electricity is carbon-free and does not pose any intermittency challenges.

Conventional geothermal electricity produced from volcanic environments is a mature technology, and facilities with capacity of up to 1,500 MW are in operation. The United States, the Philippines and Indonesia are the most advanced markets, with 3,500, 1,900 and 1,400 MW of installed capacity respectively. Latin America has significant potential; however, environmental impacts have to be managed as geothermal resources are largely located in protected natural areas.

Unconventional geothermal electricity in sedimentary environments, with small facilities (a few MW), is in the pre-industrialisation phase.

The Stillwater hybrid power plant in Nevada, USA, is comprised of a 33MW geothermal plant and a 26 MWp PV plant, allowing optimal fit between production and consumers' power needs (Enel).

CONVENTIONAL GEOTHERMAL ELECTRICITY PRODUCED FROM VOLCANIC ENVIRONMENTS IS A CO_2-FREE, MATURE TECHNOLOGY. R&D IS NEEDED TO DEVELOP UNCONVENTIONAL GEOTHERMAL ELECTRICITY

What innovations?

Speeding up the development of conventional geothermal electricity will involve:

- Stepping up exploration programmes and the characterisation of deposits
- Adopting exploration protocols that focus more on the productivity of the resource
- Improving exploration, drilling and reservoir simulation techniques.

Prefabricated, modular small-size equipment could allow for early exploitation of new or remote sites.

Making greater use of unconventional geothermal electricity involves building larger facilities, standardising thermal, chemical and hydraulic stimulation processes, developing equipment specifically adapted to geothermal electricity production conditions, and optimising the combined generation of electricity and heat.

The Mutnovskaya geothermal power plant – the largest geothermal power plant in Russia (2 x 25 MW) – is located in the Kamchatka region and covers more than 30% of electricity consumption in the regional grid (RusHydro).

ENHANCING THE POTENTIAL OF GEOTHERMAL ELECTRICITY WILL INVOLVE IMPROVING EXPLORATION, DRILLING AND RESERVOIR SIMULATION TECHNIQUES

CONCENTRATED SOLAR POWER

GLOBAL INSTALLED CAPACITY	4 GW
GLOBAL PRODUCTION	<10 TWh
SHARE OF GLOBAL ELECTRICITY GENERATION	<0.5%

Why innovate?

Concentrated solar power plants use mirrors to concentrate the sun's rays on a heat transfer fluid that enables electricity generation. Facilities can be divided into two main categories: parabolic troughs and power towers.

With 4,300 MW of capacity installed in 2014 and more than 10,000 MW in development worldwide (notably in the United States, Middle East, India, China, South Africa and Morocco), the technology holds substantial development potential in countries with sufficient sunlight (more than 2,000 kilowatt hours (kWh)/m²/ year of direct normal irradiance) and low cloud cover, such as arid and desert regions, provided that investment costs are kept in check.

What innovations?

Key innovations over the medium term will involve:

- Equipping facilities with storage systems to address intermittency-related problems. Molten salt power tower systems seem to be best suited to integrating storage systems

- Combining concentrated solar power units with conventional plants, such as combined-cycle gas turbine (CCGT) facilities. Parabolic trough plants are a promising technology for hybrid facilities. Innovations to bring down the cost and performance of air-cooling systems will expand the scope of trough plants by reducing their dependence on water resources.

Over the longer term, breakthrough innovations have the potential to bring costs down thanks to:

- Adoption of innovative thermodynamic cycles at high temperatures: supercritical steam cycles, combined cycles similar to CCGT systems and supercritical CO_2 cycles
- New concepts for solar receptors and storage adapted to high temperatures.

MARINE ENERGIES

GLOBAL INSTALLED CAPACITY	0.5 GW
GLOBAL PRODUCTION	<5 TWh
SHARE OF GLOBAL ELECTRICITY GENERATION	<0.5%

MARINE ENERGIES NEED R&D IN ORDER TO INCREASE RELIABILITY, COMPETITIVENESS AND ROBUSTNESS IN HOSTILE ENVIRONMENTS

A 10MW tidal project using Andritz Hydro Hammerfest technology with turbines fully submerged on the seabed off the west coast of Scotland (Iberdrola).

Why innovate?

Renewable marine energies harness energy from the sea to generate power without carbon emissions. There are several technologies:

- Tidal power, which generates electricity by harnessing sea level variations due to tides
- Marine current energy, which harnesses the kinetic energy of marine currents
- Wave power, which harnesses energy from waves
- Ocean thermal energy, which exploits temperature differences between surface and deep-sea waters.

Thus far tidal power has already seen some deployment, while the other technologies are at the R&D or prototype stage. All offer great potential.

What innovations?

The main technical challenges, which innovation can contribute to solve, relate to cost reduction and the use of machines in the marine environment, which poses specific problems in terms of corrosion, operation, and acceptance.

Tidal power accounts for 518 MW of capacity installed worldwide in 2013 (compared to just a few megawatts for wave and marine current energy), and for which availability of sites and acceptability are the main challenges moving forward. Ocean thermal energy is only in the experimental stage for now.

For marine current and wave power turbines, the roadmap involves overcoming significant obstacles in terms of robustness in hostile environments, reliability and, ultimately, costs. Today, the goal is to gather feedback from initial projects and create more demonstrators to advance on mechanics (resistance to storms), electrics (conversion, transmission and connection), installation in marine environments and control of machines.

Issues relating to acceptance, and particularly sharing the marine environment with other types of activities, for instance fishing, will be all-important.

The Kislogubskaya Tidal Power Plant in Russia has an installed capacity of 1.7 MW and uses an experimental site for testing new turbines and auxilliary equipment (RusHydro).

MARINE ENERGIES: HIGH POTENTIAL WITH SOME EXISTING TIDAL POWER INSTALLATIONS AND A NEED FOR R&D IN OTHER MARINE TECHNOLOGIES

NUCLEAR POWER

GLOBAL INSTALLED CAPACITY	394 GW
GLOBAL PRODUCTION	2,460 TWh
SHARE OF GLOBAL ELECTRICITY GENERATION	11%

Why innovate?

A total of 434 nuclear reactors are in service in 30 countries, representing an installed capacity of 394 GW, or 11% of global electricity generation. Currently, most installed nuclear power plants are competitive in relation to coal- and gas-fired generation.

OECD countries are home to 80% of installed capacity. However, of the 69 reactors being built worldwide (76 GW), more than three-quarters are outside the OECD, demonstrating that the technology is attractive to large emerging economies (e.g. China, India, Turkey).

Generating high volumes of stable power with no CO_2 emissions while contributing to security of supply, nuclear power has a key role to play in long-term decarbonisation, provided that the countries that wish to develop it can establish an adequate institutional and industrial framework.

The majority of the nuclear reactors in service today are second generation, built starting in the 1970s. Innovation is a continuous process in the nuclear sector, with emphasis placed on safety and efficiency improvements. The main areas which have undergone or are undergoing progress are:

- Safety culture, with regular integration of feedback, greater personal accountability and sharing of best practices among operators under the oversight of the World Association of Nuclear Operators (WANO).
- Evolution of command and control systems, transitioning from analogue to digital for plants built within the past 20 years to simplify operations and aid engineering and training.
- Metallurgy, with improvements in the materials of primary components (steam generators) has boosted plant performance.
- The more efficient use of fuel.

Safety is a central, defining responsibility for nuclear power plant operators. Safety can be optimised through plant design, the technical capacity and safety culture of the operator (the primary responsible agent for plant safety), and the quality of oversight by public authorities.

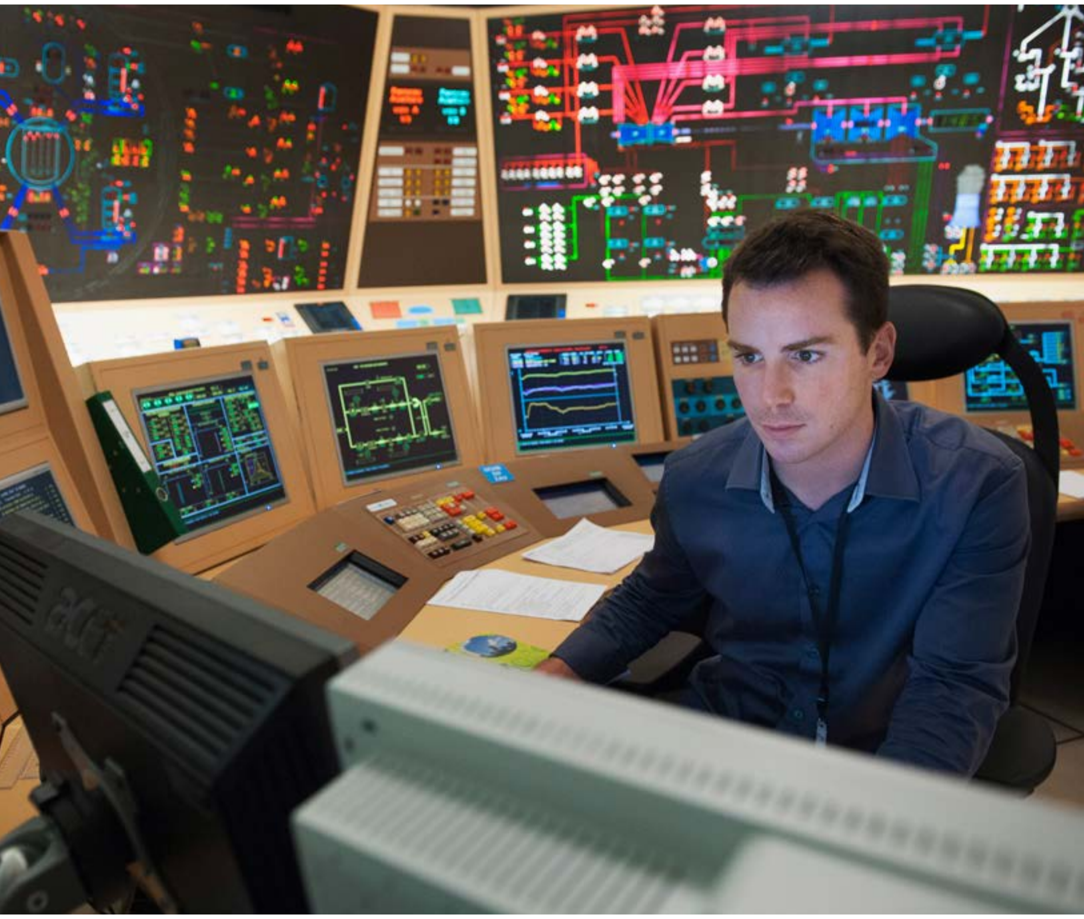
For the successful development of nuclear power stable technical standards, allowing reactor standardisation and thus cost optimisation thanks to series effects, are key. Other enabling factors include

- Qualified executives at government, safety authority and operator level.
- A governance system that clearly delineates the responsibilities of public authorities, the safety authority and the operator, underpinned by a collective safety culture.
- An industrial fabric capable of providing the components and services to build and maintain the plants.
- The long-term prospect of markets that will sustain demand for the power generated.

What innovations?

Performance and safety can be optimised through an ongoing process of continuous improvement at existing plants. The main targets are:

- Increased safety redundancies if coolant is lost (backup diesel generators, sand filters, H2 recombiners, on-site intervention in the event of an accident, increased resilience of facilities)
- Extending the lifespan of existing reactors



NUCLEAR: THE EVOLUTION OF COMMAND AND CONTROL SYSTEMS, TRANSITIONING FROM ANALOGUE TO DIGITAL, HAS ENHANCED O&M AND SIMPLIFIED OPERATIONS

The Civaux Nuclear Power Plant in France has an installed capacity of 2,900 MW and a fully digital control center (EDF).

- Waste management. Although technical solutions exist (burial within stable geological formations, vitrification) and sites have been identified in some countries (Sweden, Finland, France), winning local acceptance remains a challenge.

For third-generation reactors (some 30 from 69 currently under construction), the nuclear sector is still moving down the experience curve. Third-generation reactors include major safety innovations (drastic reduction in release of waste in the event of accidents, protection against airplane crashes, modular construction and enhanced active and/or passive safety systems). The reactors under construction are intended to be models for standardised series.

Further out in the future, fourth-generation fast neutron reactors, which use fuel far more efficiently, will supplant the current technologies. Fast neutron reactors could be ready for industrial deployment by 2040. As these reactors can use natural uranium or thorium as a fuel, resources would jump to well over 1000 years at today's consumption levels.

Small modular reactors (SMRs), designed from the small mobile reactors developed for ship propulsion, are currently in the experimental phase. Modularity, standardisation and series effects could make SMRs an efficient solution for bringing power to remote sites or for combined heat and power generation in urban areas.

GAS-FIRED POWER GENERATION

GLOBAL INSTALLED CAPACITY	1,460 GW
GLOBAL PRODUCTION	5,100 TWh
SHARE OF GLOBAL ELECTRICITY GENERATION	20%

Why innovate?

Natural gas is currently the lowest-emitting fossil fuel source for power generation with CO_2 emissions per kWh typically half of those from coal plants. It currently supplies more than 20% of global power demand. In the past 20 years, the quantity of electricity produced from natural gas has risen at an annual rate of 5%, the highest rate of any non-renewable generation technology.

Fuel accounts for a significant share – 70% on average – of production costs at CCGT plants. In regions where natural gas can be sourced at competitive prices, CCGT plants are used for baseload generation, competing with coal-fired or nuclear power plants. In regions where natural gas is more expensive, CCGT plants cycle as necessary to complement baseload generation, back up intermittent renewables as needed and compensate for the overall fluctuations in electricity demand.

CCGT technology is widely used in countries with competitively priced gas resources and appropriate gas infrastructure because it offers lower emissions (350 grams of CO_2 per kWh for the most efficient technologies), dispatchability, flexibility, and short construction lead times.

With an installed capacity of 2,919 MW, the Himeji Power Station in Japan uses a gas turbine which reaches a temperature of 1600°C. It has a thermal efficiency of 60% and a CO_2 efficiency of 0.327 tCO_2/MWh (Kansai).

CCGT: INNOVATION TOWARDS HIGH EFFICIENCY AND ULTRA-FLEXIBLE PLANTS COULD REDUCE EMISSIONS AND FACILITATE THE INTEGRATION OF INTERMITTENT SOURCES

Within the context of the energy transition, CCGT plants can:

- Help reduce CO_2 emissions due to the plants' relatively low carbon intensity, assuming that the full cost of gas for baseload generation can compete with the baseload costs of the most competitive technologies, notably coal-fired plants
- Contribute to the regulation and stability of the electricity supply-demand balance, due to their flexibility, and support the integration of intermittent renewables. This factor is especially relevant to Europe and could become more prevalent in the US as renewable energy standards are contemplated and implemented.

What innovations?

The thermal efficiency of CCGT plants operating at full capacity has risen from around 50% in the 1990s to almost 60% today. The potential for further gains is shrinking. Moving beyond 65% requires R&D breakthroughs in materials and components to enable higher operating temperatures.

R&D is currently focused on improving plant flexibility as CCGT plants are increasingly being used for load-following applications. This calls for greater kinetic capacities (rapid stop and restart, partial load operations, fast-ramping to accommodate load changes, etc.). The ability to maintain high thermal efficiency, low emissions, robust equipment performance, cost and environmental impact when operating in this manner is a high priority for the industry.

Natural gas-fired internal combustion engines can provide small scale and modular solutions, especially where flexibility needs are increasing. The potential of Stirling engines is being explored, while fuel cells need further improvements to decrease investment and maintenance costs for wider utilisation.

COAL

GLOBAL INSTALLED CAPACITY	1,800 GW
GLOBAL PRODUCTION	9,200 TWh
SHARE OF GLOBAL ELECTRICITY GENERATION	40%

Why innovate?

Coal-fired plants account for 40% of global electricity generation and remain the most competitive form of generation in many countries. Coal is an abundant resource, even though large countries like India could potentially become importers if their domestic needs continue to increase.

Improving the thermal efficiency of existing coal-fired generation units (which is 33% on average) while developing and deploying innovative coal plant technologies with even higher efficiencies will be key to reducing carbon emissions as coal will remain a major primary energy source for new electric power generation in many countries, notably Asia, over the next decades.

The process of phasing out less thermally efficient, older, smaller coal-fired generating units has already started, in particular in industrialised countries. For example, sub-critical coal-fired plants are being retired in Europe and the United States due to market forces and/or environmental regulations, leaving relatively newer, more thermally efficient supercritical plants in operation. In this respect, innovative and cost-effective mothballing processes are a priority in regions like Europe.

Large pulverised coal plants are becoming the technological standard, with efficiencies of around 40%. Circulating fluidised bed combustion is for now mostly a niche technology, which has high flexibility in terms of

MOVING FORWARD TO MORE EFFICIENT COAL PLANTS: ADVANCED ULTRA-SUPERCRITICAL COAL-FIRED PLANTS COULD REACH 50% EFFICIENCY

BoA 2&3, a lignite-fired power station with optimised plant engineering, operates at an efficiency rate of 43% in Neurath, Germany (RWE).

fuel and can use – besides poor quality coal – industrial waste and biomass at medium-sized facilities.

What innovations?

The bulk of research and development is focused on improving thermal efficiency.

Ultra-supercritical coal-fired plants, which first appeared in the mid-1990s, operate at very high temperatures and pressures (typically 600°C and 300 bar) to generate power at about 42% efficiency and higher. Recent improvements to components can drive efficiency up to 46%.

Going beyond this level to advanced ultra-supercritical systems involves increased R&D and use of high-nickel alloys capable of withstanding even higher temperatures and pressures (700°C and 350 bar). The ultimate goal is for advanced ultra-supercritical units to generate power at thermal efficiencies upwards of 50%.

Integrated gasification combined-cycle (IGCC) plants represent another avenue for innovation. IGCC plants use a gasifier to convert coal (or other carbon-based energy sources) to synthesis gas (syngas), which then drives a CCGT. At demonstration phase, this technology can generate power at 42% efficiency. It could achieve thermal efficiencies of up to 50% as gasifier and turbine technologies continually evolve and improve.

Such technologies would result in coal plants 50% more efficient than the existing fleet, thus emitting around one third less CO_2 per kWh.

With certain modifications, pulverised coal power plants can utilise fuel with a 10% to 15% biomass blend, enabling a proportionate decrease in carbon footprint. Additional demonstrations to determine performance, operational and economic impacts are necessary. The need for a robust and sustainable biomass supply chain, both in terms of resources and logistics, is a significant factor for the successful development and widespread deployment of this type of technology.

CARBON CAPTURE AND STORAGE

Why innovate?

Carbon capture and storage (CCS) has the potential to make a profound contribution to decarbonisation, transforming emitting fossil-fired plants (in particular coal-fired units) into very low to virtually zero-carbon generation units. The International Energy Agency (IEA) estimates that CCS could represent between 3 and 5 $GtCO_2eq$ of carbon reductions by 2050.[vi]

Furthermore, stabilising a 2°C pathway for 2100 may require negative carbon emissions during this century. This would mean, for instance, combining CCS-based technologies with electricity generation from biomass – subject to a sustainable management of biomass resources – to maintain a favourable carbon balance.

While there has been strong momentum in CCS development in the past, this appears to have waned more recently. Several small industrial pilot trials are under way. Larger scale demonstrators are ready to come on line. One large-scale unit is in operation today in Saskatchewan, Canada, where SaskPower's 110 MW coal-fired Boundary Dam Unit 3 power plant includes post-combustion CO_2 capture. The captured CO_2 is used for enhanced oil recovery.

To reduce the gap in competitiveness between coal-fired plants with CO_2 capture and storage and conventional units, action has to be taken at different levels of the value chain (materials, compressors, pumps, air separation units, amines, breakthroughs in capture process technology), all of which imply significant R&D in terms of design, materials and process optimisation.

Adsorptive filter at a scrubber pilot plant, located at the Niederaussem Coal Innovation Centre in Germany (RWE).

CCS: THE CHALLENGE IS TO RAMP UP TO AN INDUSTRIAL SCALE WITH A CLEAR ROADMAP ON CAPTURE TECHNOLOGIES AND STORAGE

What innovations?

Existing carbon capture technologies are being tested in a number of small pilot projects:

- Post-combustion is the most mature technology. The CO_2 captured from flue gas after combustion is absorbed in a chemical solvent to separate it from other exhaust gases. A similar technology is already being used in the oil and gas industry to separate the CO_2 present in natural gas at wellheads (although treating the available volume of flue gases during electricity generation is a considerably more complex process, with scalability challenges).
- Oxy-fuel combustion involves burning coal using pure oxygen (rather than air) so that flue gas only contains CO_2 and water, making it easier to separate the CO_2. The oxygen used is isolated by removing nitrogen cryogenically, which is both energy-intensive and costly.
- Pre-combustion involves prior coal gasification, producing a mixture of carbon monoxide and hydrogen, and then the conversion of this mixture in the presence of steam to obtain CO_2 and hydrogen, followed by the separation under pressure of the CO_2. Southern Company's 582 MW Kemper County Integrated Gasification Combine Cycle (IGCC) plant is being constructed to demonstrate one type of this technology. The plan is not operational and has experienced delays and accumulated nearly $4 billion in additional costs above its original 2004 estimate of $2.2 billion.

The challenge today is to move to power-plant scale demonstrations that can better inform the upscaling and optimisation required to eventually commercialise CCS technology. For instance, computer simulations for the design of a 1,000 MW oxy-combustion boiler are best validated with data from a reasonably scaled demonstration (in the hundreds of megawatts), rather than from a 10 MW pilot (which is best suited to inform the design of the demonstration unit).

The technologies that enable the transport of CO_2 and its injection into storage sites are relatively mature, but storage characterisation, maintenance and monitoring require more R&D. Reliable technologies exist for using CO_2 in enhanced oil recovery (EOR), but the storage potential remains limited and uncertain.

Provided that the related technologies are developed and approved, and adapted regulatory and legal frameworks are put in place, injecting supercritical CO_2 into deep underground rock formations, via wells in permeable rocks situated under airtight formations, could provide sufficient means for the sequestration of anthropogenic CO_2.

Deep saline aquifers hold the most potential in terms of storage capacity. Although more evenly spread out across the globe than hydrocarbon deposits, their structure and capacity to permanently trap CO_2 need testing and monitoring across a variety of geological formations. Such R&D on long-term storage is a key element for public acceptance.

INNOVATION: RETHINKING ENERGY SYSTEMS

Above and beyond the specific merits of individual technologies, the value they provide to the power system – and, ultimately to consumers – will depend on how they can be integrated into the grid. It is essential to take into account interactions, positive or negative, at the system level, identify and mobilise solutions to overcome potential issues and capitalise on the multiple synergies that rethinking energy systems will unleash. Many of these interactions have an impact at the level of the power grid – the purpose of which is to precisely balance generation and consumption as power input and output must be equalised at every moment to ensure system stability, reliability and security of supply. From this standpoint, electricity networks are key enablers of the energy transition and the crossroads of the digitisation of power systems from smart grids to smart homes and cities.

NETWORK TECHNOLOGIES

Why innovate?

The IEA forecasts that over the next decades, for every dollar invested in generation, close to one dollar will need to be invested in networks. In OECD countries, the cost of delivering electricity to consumption sites over transmission (high voltage) and distribution networks (medium and low voltage) typically represents 40 to 50% of the price residential consumers pay for electricity (excluding taxes and levies).

Networks serve a variety of functions within power systems, such as:

- Delivering electricity to consumption sites.
- Ensuring system adequacy, stability, reliability, security and quality of supply.
- Utilising regional diversity of load and supply resources to reduce generation reserve margin and minimise generation costs.

The network infrastructure in OECD countries is ageing and much of it will be upgraded, rebuilt or replaced over the coming decades: this upgrade will be driven by technology, in particular by the digitalisation of distribution grids. In emerging countries, rising consumption entails the expansion of networks to keep up with demand while enhancing the level of interconnections among countries or geographical areas can foster synergies and flexibility. To meet needs, whether with new infrastructure or by replacing equipment at the end of its useful life, innovative ways to make infrastructure more productive should be pursued to limit capital expenditure and enhance cost-effectiveness.

Increasingly, the integration of intermittent renewable resources and development of distributed generation are creating new challenges for networks. In many situations, renewable resources are located far from demand centres, requiring new transmission grid development. The incremental grid cost related to the integration of the renewable resource will depend on distance relative to demand centres, the capability of the existing grid, and the volume of new capacity to be delivered.

Intermittency issues are negligible as long as the penetration of intermittent generation remains limited. Most electricity systems can "absorb" some volume of intermittent generation at low or no cost. However, when penetration rates increase and intermittency stops being of secondary magnitude several challenges arise:

- Balancing (i.e. matching supply and demand on a real-time basis): High penetration of intermittent energy increases balancing needs since output from the intermittent energy sources is volatile and more difficult to predict. The extent of balancing costs depends on penetration level, flexibility and storage capacities, quality of weather forecast and interconnections.
- Adequacy (i.e. ensuring backup generation to maintain system reliability): In electricity systems that rely heavily on wind or solar energy, backup generation is needed to satisfy demand when there is no wind or no sun and demand is high.
- Grid enhancement, in particular for voltage quality control (i.e. ensuring that the voltage is maintained at the desired level with minimum distortion): Enhancement involves transmission (for large facilities) and distribution lines (for distributed generation). The nature and scope of grid enhancement will depend on the strength of the grid, quantity of intermittent renewables as well as the breakdown of flexible loads on the network.

Finally, public acceptance of network extension projects is a very real challenge in many countries. Opposition to transmission lines can be very significant and result in long delays, additional costs and even cancellation. Stakeholder engagement is a priority to achieve public acceptance of network extension projects.

What innovations?

Widespread roll-out of real-time data integration systems will provide utilities with more timely and actionable information on the health of critical transmission network assets.

Rebuilding an existing 138-kV line in Indiana, USA with a newly patented, higher capacity and efficiency extra-high voltage 345-kV crescent-shaped crossarm line, called BOLD™ (Breakthrough Overhead Line Design) (AEP).

NETWORKS: WORLDWIDE, FOR EVERY $1 INVESTED IN GENERATION, A SIMILAR AMOUNT NEEDS TO BE INVESTED IN NETWORKS

This information can be used to help drive performance-based maintenance practices rather than rely on time-based practices, helping inform prioritisation decisions on asset renewal and provide insights to the real-time status of equipment, possibly preventing equipment failures. These types of systems will be critically important to the management of aging infrastructure.

Innovations in the area of power electronics could boost the efficiency of grid infrastructure. New generations of FACTS (flexible alternating current transmission systems) optimise the use of power lines by actively managing electricity flows on the network. They regulate voltage and frequency on the AC network and control reactive power to enhance power transfer capacity, and could help boost the transmission capacity of some high-voltage lines by 40-50%.

Developing more efficient ways to transmit electricity over long distances, notably when renewable energy sources are located far from demand centres, will be very important to the development of renewables. Moving forward, the integration of DC lines (which reduce losses over long distances) with AC transmission systems is key.

Two technologies can be used for DC connections:

- Line-commutated converters (LCCs) are used to transmit high or very high power at high voltage over long distances
- Voltage source converters (VSCs), which are more controllable and compact, are suited for transmitting electricity from offshore wind turbines. Their rating is limited to 1 GW.

The main avenues for technological improvements relate to:

- Circuit breakers and the complexity of operating a line that interfaces at several points with the AC grid for LCCs
- Insulators and disconnectors for VSCs.

The acceptance problems that network expansion plans have faced suggest that one option is to use existing transmission line routes with advanced line designs.[2] Another option is burying very high voltage lines. This, however, requires additional R&D as existing solutions, such as gas-insulated lines, are not yet competitive for transmission over long distances.

NETWORKS: SMARTER AND MORE EFFICIENT NETWORKS ARE KEY TO ENSURE THE RELIABILITY OF ELECTRICITY SUPPLY AND BETTER INTEGRATION OF INTERMITTENT SOURCES

The 1,000 kV Jindongnan Nanyang-Jingmen UHV AC Pilot Project in China is 640 kilometres long and has a transforming capacity of 6,000 MVA, with a nominal voltage of 1,000 kV and the highest operation voltage of 1,100 kV (SGCC).

Superconductivity could allow power cables to carry as much as 100 times more electricity than conventional lines, with zero losses if they are delivering DC power. For now, superconductivity is only seen at very low temperatures (below 150°K), such that liquid nitrogen refrigeration units are needed, resulting in high costs. Room temperature superconductivity is thus an important area for further R&D.

2. Another option for moving power over long distances while avoiding the introduction of new voltage classes is through the use of new advanced line designs that allow higher delivery capacity while keeping voltage level constant. One example of such innovation is the new BOLD™ transmission line technology with a power delivery capacity that can exceed a conventional 345-kV line by up to 60%, surpassing the capacity of a traditional 500-kV line.

SMART GRIDS

SMART GRIDS, TOGETHER WITH CONNECTED HOMES, CAN ENHANCE SYSTEM RELIABILITY AND DEMAND RESPONSE

With 50 million installed worldwide, smart meters provide remote controlled energy supplies and promote power network efficiency, reliability, free market competition and consumer awareness (Enel).

Why innovate?

Rolling out the hardware and software to enable power system stakeholders to view the state of the network and exchange information and instructions in real time opens the door to major improvements in utilising existing grids, thus boosting security of supply, reducing investment needs, helping integrate intermittent renewable energies at least cost and enabling consumers to participate in the regulation of power systems.

Combined with digitisation at the user end, smart grids will mean better service for customers as they become "prosumers" (i.e. producing, storing and managing energy as well as consuming it) and more efficient use of energy in the system as a whole.

What innovations?

Transmission grids are already well equipped with supervision and command and control systems, so innovation will mainly involve developing new management systems for dispatching, grid monitoring and enhanced maintenance prevention as well as increasing the insertion of direct current lines in alternating current networks to carry more power over long distances thanks to progress with power electronics.

Unlike very high-voltage networks, medium- and low-voltage grids are predominantly "blind" low-flexibility networks designed to carry energy flows in one direction, from transformer substations to customer sites.

Until now, the topology and predictability of flows on low-voltage grids has been such that the massive rollout of smart technologies was not economically efficient. The development of distributed generation, and notably intermittent distributed generation, calls for innovations that can help build new business cases for the rollout of smart distribution grids which optimise the supply-demand balance at the local level.

Innovation will generate progress in:

- Systems for protecting distribution grids that are adapted to high penetration rates for distributed and intermittent generation in order to monitor and control electricity generation according to the requirements of the grid in order to ensure the security of supply.
- Decentralised storage systems that are adapted to the operating constraints of distributed generation sites and their insertion in distribution networks.

- The development of network automation (consisting of centralised systems as well as distributed equipment provided with local intelligence) in order to improve the network operations, in particular to rapidly and efficiently identify network failures and isolate faults, providing an even higher quality of service to final customers.
- The development of smart meters (allowing customers to increase their own consumption awareness and to optimise their price/consumption profile) and of management systems in smart buildings as well as the development of systems to manage new energy uses efficiently, particularly when it comes to new applications like electric mobility (i.e. smart charging infrastructures are able to reduce and control the grid-impact of a widespread roll-out of such technologies).
- Systems to ensure the highest level of cybersecurity.

Smart home applications in conjunction with the development of connected home equipment will be the next step in grid digitisation, simultaneously improving comfort and the flexibility of uses for customers and enabling them to help better regulate the electricity supply-demand balance.

Developing smart grids involves the adoption of standardised communication and interface protocols (power line communication and wireless) across the entire technical chain, and the development of inexpensive and programmable sensors and machines for use on low-density medium voltage networks and buildings.

In time, the “Internet of Things” will drive up the range of uses and effectiveness of smart grids, and make them more widely available and profitable.

STORAGE

Why innovate?

A wide array of stationary electrical energy storage technologies is available today:

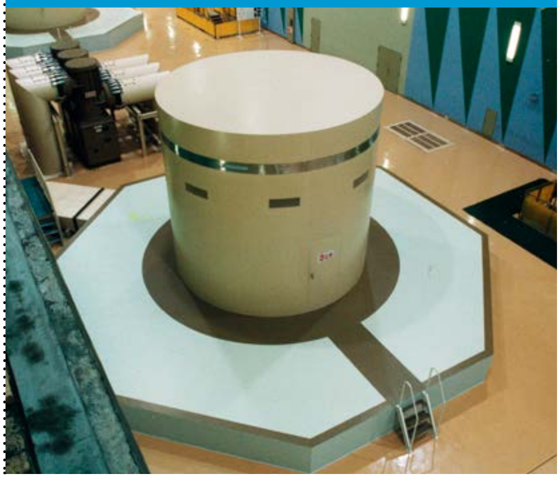
- Gravity energy storage from pumped storage plants (the most mature technology)
- Mechanical energy storage from flywheels
- Pneumatic storage from compressed air energy storage
- Chemical storage from batteries.

The degree to which these technologies are competitive depends on what they can provide to the system:

- For frequency regulation, which involves very short discharging periods, batteries, flywheels and compressed air storage systems are competitive

The Ohkawachi Pumped Storage Hydro Power Station in Japan has an installed capacity of 1,280 MW and is equipped with a Variable Speed Pumped Storage System enabling frequency regulation (Kansai).

PUMPED STORAGE HYDRO: A MATURE TECHNOLOGY FOR STORING ELECTRICITY



STORAGE: POTENTIALLY A GAME-CHANGING INNOVATION IN THE ELECTRICITY SECTOR. R&D ON ELECTROCHEMICAL BATTERIES IS NEEDED FOR AN INDUSTRIAL DEPLOYMENT IN NETWORKS TO MANAGE INTERMITTENCY

The Zhangbei National Demonstration Project in China combines 140 MW of wind and solar generation, 36 MWh of energy storage and a smart power transmission system relieving intermittency challenges (SGCC).

- For secondary reserve, which involves longer discharging periods (generally a few minutes), batteries (e.g. Li-Ion and NaS) are nearly competitive, especially in isolated zones (e.g. islands, mini-grids)
- For energy transfers over longer periods (tertiary reserve) or substitutions for intermittent renewable sources in the absence of wind or sunlight, pumped storage power stations alone are competitive today. Batteries still have a competitiveness gap to overcome.

Innovation should expand the field of low-cost technologies, facilitate the integration of intermittent renewable sources and keep grid investments costs in check.

What innovations?

Innovation can contribute to all forms of storage.

Although pumped storage technologies are very mature, the main challenge is to develop variable speed pump turbines that allow pumped storage to contribute to real-time regulation of the power system even during pumping. In addition, because they are highly location dependent, the development of pumped storage plants on the seashore with the sea as the lower reservoir could ease the issue of site scarcity. From a technological standpoint, the challenge will be to ensure the perfect water-tightness of the upper reservoir, which is usually artificial and on the coast, in order to keep seawater out of the water table and the soil.

Compressed air energy storage holds compressed air in rock cavities. Currently, there are two sites in the world, one in Germany and one in the United States, both diabatic. R&D should focus on adiabatic processes, where the heat generated by the compression of air is reused, meaning natural gas would no longer be required during the compression phase. It could also make the technology less dependent on geological conditions, which is currently holding back development.

With regard to batteries, there is significant scope for costs to come down thanks to serial production and feedback from the mobility sector. The key innovations on the horizon should enable:

- An increase in electrolyte purity to improve efficiency
- An increase in the surface area for exchange of the anode and cathode electrodes, for instance thanks to developments in nanotechnologies
- The replacement of the rare metals used in battery manufacturing with less expensive materials
- Continued development of power electronics
- Improvements in battery packaging.

CENTRALISED AND DECENTRALISED POWER GENERATION

Why innovate?

Since the discovery of how to move power over long distances, power systems have historically developed in a centralised fashion. With the expansion of the grid, it has become possible to build ever-larger electricity generation facilities, with larger unit sizes reducing production costs and offsetting grid costs (investments and Joule losses). The grid has also enabled the growth of electricity demand over greater areas, covering risks associated with the potential unavailability of generation plants.

Today, power thus mainly flows "down" networks from generation plants towards demand. The development of competitively priced distributed generation is forcing us to rethink this paradigm. Going forward, power systems will be accommodating not only large generation plants but also smaller on-site generation units, the production from which will be consumed on-site (i.e. self-consumption), at least in part.

Such systems call for grids that can accommodate two-way energy flows, as well as the rethinking of grid management practices.

The new combination of centralised and decentralised power generation may have additional benefits, for example by increasing the resilience of power systems:

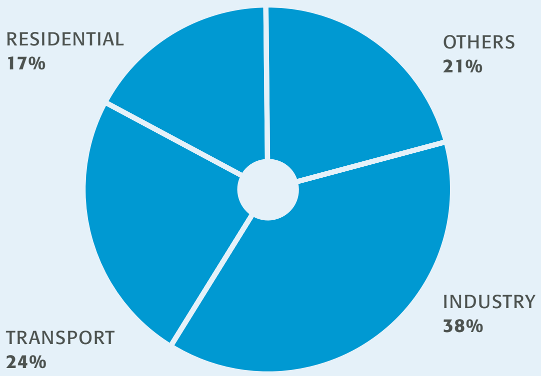
- Decentralisation will make electricity systems less prone to large-scale failure, through the integration of distributed generation, distributed storage in buildings and new forms of matching supply and demand
- Centralisation creates technical solidarities between local areas and is indispensable to allow generators to procure black-start capabilities to restore power after a blackout.

In order to enable this combination in a sustainable manner, an adapted regulatory framework is needed that ensures that each consumer or producer connected to the grid contributes their fair share of both grid costs and taxes/levies in order to avoid cross-subsidies between users.

INNOVATION: OPTIMISING ENERGY USE

End-uses are a major source of innovation, particularly in the fields of lighting, thermal uses (like heating and cooling), motors, mobility and new energy carriers like hydrogen. Smarter homes, buildings and cities that are more sustainable and energy efficient will be key aspects contributing to a systemic approach that integrates low-carbon power, digital technologies and innovation at its core. End-use innovation will help replace fossil fuels with decarbonised electricity in buildings and transport in our cities and is a crucial driver of decarbonisation.

DIRECT AND INDIRECT WORLD CO_2 EMISSIONS BY SECTOR – 2012



Source: based on IEA, CO_2 Emissions from Fuel Combustion, Highlights 2014

ELECTRIC BOILERS

Why innovate?

Electric storage water heaters are mature systems widely used to produce domestic hot water. The biggest advantages for users are that they are inexpensive and easy to install and maintain.

For the power system, these heaters are a regulation instrument: hot water is produced at night, when power demand is lower, and can be used during the day.

Tanks have an average capacity of 200 litres and typically last 20 years. Electric storage heaters have become the main technology for producing domestic hot water in many countries.

Going forward, water heaters will play an increasing role in thermal energy storage as smart grids develop. Controlled by and connected to smart meters, water heaters will be able to provide the power system with flexibility, notably to facilitate the insertion of intermittent renewable energies.

What innovations?

The main innovations will relate to command and control systems and coupling with heat pumps.

"Smart control" electric storage water heaters feature a smart regulator that optimises the production of hot water and only heats as much water as is necessary. It adapts through self-learning to the lifestyle of users and can reduce the electrical energy consumed by 20%.

With thermodynamic water heaters, temperatures are raised in a heating circuit by a small heat pump rather than electrical resistance. Backup resistance heating elements allow water temperatures to be kept constant in cold climates. Thermodynamic water heaters are now suited for use in individual homes and should soon be ready for use in apartment buildings.

LIGHTING

Why innovate?

Throughout the world, there are just over 30 billion lightbulbs in use, accounting for 20% of total electricity consumption and emitting around 2 $GtCO_2eq$. Sources of electric lighting can be divided into three categories:

- Incandescent bulbs, the oldest and least expensive technology, but also the least efficient, at 15-25 lumens per Watt (lm/W)
- Discharge bulbs (e.g. fluorescent lights), which offer an intermediate level of efficiency of about 100 lm/W. The purchase cost is higher and the quality of light produced is not always deemed acceptable
- LED bulbs, which became available in the 2000s and are very efficient (130 lm/W), but remain expensive to buy.

As of today, LED bulbs account for an estimated 10% of the market, but their share should increase to 70% by 2020, helping reduce lighting-related electricity consumption by 50%.

What innovations?

LED technologies are not yet fully mature. Research and development is focusing on:

- Improving efficiency, with a target of 200-240 lm/W by 2025
- Lowering costs. An LED bulb costs between $5 and $10 compared with $1 for an incandescent bulb. Purchase prices are a barrier for consumers, despite the fact that the bulbs consume less power and last longer than traditional ones.

Combining street furniture with design innovation and energy efficiency for urban landscapes: more than 190,000 Archilede LED light fixtures that provide up to 70% in energy savings have been installed in Italy and Spain (Enel).

LEVERAGING INNOVATION AND SMART MANAGEMENT SYSTEMS, LED BULBS COULD REDUCE ELECTRICITY CONSUMPTION FROM LIGHTING BY 50%

ELECTRIC VEHICLES

Why innovate?

Oil is still the predominant primary energy source for the transport sector (90%). The share provided by electricity has remained constant at about 1% since the 1970s.

Transport accounts for 14% of global CO_2 emissions. The variety of means of transport and the fact that energy consumption sources are so spread out are factors to take into account. Reducing emissions in the sector could involve:

- Introducing actions targeting demand for transport
- Adapting the modal share (i.e. increasing the share of journeys by electric-powered means of transport)
- Developing electric vehicles and electric mobility
- Developing biofuel- and gas-powered vehicles
- Making vehicles more energy efficient (lighter vehicles, hybrid engines).

Electric mobility is a key lever to reduce emissions in transport and improve air quality and quality of life in cities (which will host 80% of the world population by 2050).

In regards to electric vehicles specifically, innovation is focused on three areas: extending range, reducing costs and developing charging infrastructure.

What innovations?

Progress in the areas of range and costs is being driven by advances made or expected to be made in batteries used for electricity storage.

Lithium-ion battery storage is making robust gains and storage capacity could double by 2020 while costs could be halved (to $250/kWh for passenger vehicles), making electric vehicles competitive with internal combustion engine vehicles in many regions of the world.

Other technologies are also being developed: lithium-air batteries and zinc-air batteries for passenger vehicles and super-capacitors for public transport. These technologies should move to industrial scale within the next 10-15 years.

At Hydro-Québec's Research Institute energy storage laboratory, an automatic stacker is used to manufacture large-format soft-package lithium-ion batteries (Hydro-Québec).

ELECTRIC VEHICLE BATTERIES: LITHIUM-AIR AND ZINC-AIR BATTERIES FOR PASSENGER VEHICLES AND SUPER-CAPACITORS FOR PUBLIC TRANSPORT COULD MOVE TO AN INDUSTRIAL SCALE WITHIN THE NEXT 10-15 YEARS

ELECTRIC VEHICLES: ANALYSIS OF USER BEHAVIOURS AND NUMBER OF VEHICLES HELPS OPTIMISE SITING OF CHARGING STATIONS

The Electric Circuit is Canada's first public charging network providing the charging infrastructure required to support the adoption of plug-in electric vehicles (Hydro-Québec).

Developing charging infrastructure is the other area of development for electric transport. Rapid charge stations are available but are less competitive than slow charging, so promoting the use of electric vehicles involves striking the right balance between convenience and cost, based on an in-depth analysis of user behaviours and the number of electric vehicles. Adapted regulatory frameworks are also necessary to trigger investment at the right level and pace.

From a technical standpoint, inductive charging could help resolve range issues.

Lastly, the integration of electric vehicles and smart grids will allow electric vehicles to be utilised as a backup energy source when not in use, and could be combined with renewable energies (electricity drawn from vehicles when necessary and injected when supply permits).

HYDROGEN

Why innovate?

Hydrogen is a high-density energy carrier that can be used in a variety of fields (industry, transport, heating); it is storable, and does not release CO_2 when burned.

Hydrogen production, which is limited for now (about 60 million tonnes a year, which is the equivalent of the hydrogen that would be consumed annually by 50,000 vehicles), mainly relies on steam reforming to meet the needs of the chemicals industry.

As it uses methane as a feedstock, steam reforming produces large quantities of CO_2. If hydrogen is to play a role in decarbonisation, electrolysis capacity powered by carbon-free electricity will be necessary.

After production, hydrogen is stored and transported in a gaseous and compressed form or in liquid form.

What innovations?

Innovation is expected at all levels of the technical chain.

Alkaline electrolysis is a mature process though not very scalable. Other technologies are being developed:

- Proton exchange membrane electrolysis, which is in the industrialisation phase, and which offers higher efficiencies and could be powered by intermittent energy sources
- High-temperature electrolysis is not as advanced; efficiency is very high but steady power supply is needed.

As for fuel cells, costs should be driven down by a reduction in component costs (stack, materials substituted for platinum to make membranes, use of nanomaterials) and mass industrialisation.

Where storage is concerned, high-pressure tank technology has become reliable thanks in part to feedback from the space industry on rocket fuel tanks. The goals now are to reduce costs and enhance security.

HEAT PUMPS

Why innovate?

There are more than 500 million heat pumps in service worldwide, with those in residential and tertiary buildings comprising 90% of the installed base.

Heat pumps capture heat from external air, the ground, groundwater or industrial liquid effluents to provide heating, cooling or hot water services, with performances surpassing those of any boiler. In industry, they are used in sectors that generate heated effluents and which require large amounts of heat (paper, food processing, and chemicals).

Thus heat pumps operate like a renewable energy source, producing thermal energy with a high performance coefficient: each kWh of electricity used to drive the heat pump produces typically 3 to 4 kWh of thermal energy.

What innovations?

Heat pumps are a mature technology but still harbour significant potential for improvement, which could radically expand their use, namely:

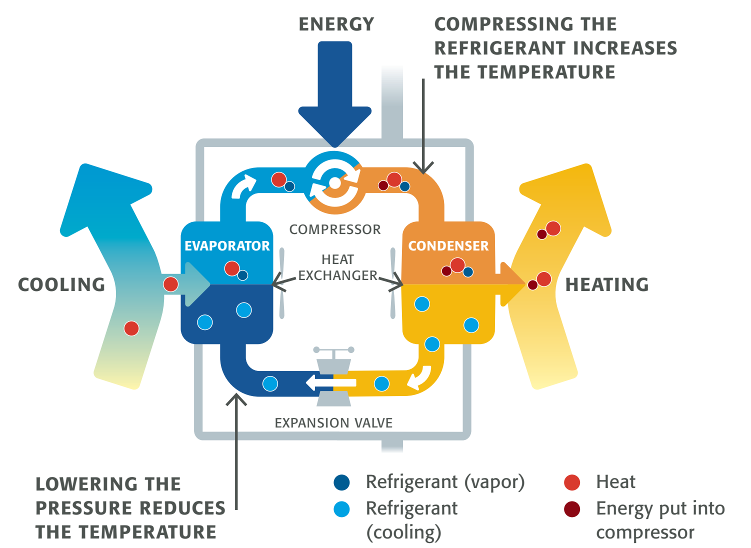
- 20-30% in heating performance, with 30-40% in cost reductions
- 30-50% in cooling performance, with 5-20% in cost reductions.

Increasing condensation temperatures from 70°C to 140°C would increase the potential for heat pumps in industry by a factor of five, and would moreover create an inroad to the district heating market.

Hybrid systems, for instance heat pumps plus gas furnaces, are integrated, dual-fuel systems. A regulation system optimises heat generation based on external conditions, using the furnace when it is very cold and the heat pump when temperatures are milder. Such systems, which can be operated in line with weather forecasts, create additional demand-response potential.

The Eco Cute (CO_2 heat pump water heater) offers energy savings by utilising atmospheric heat as well as an environmentally friendly CO_2 refrigerant as a CFC substitute (Kansai).

HEAT PUMPS: A RENEWABLE SOURCE FOR HEAT GENERATION. R&D COULD INCREASE EFFICIENCY FURTHER



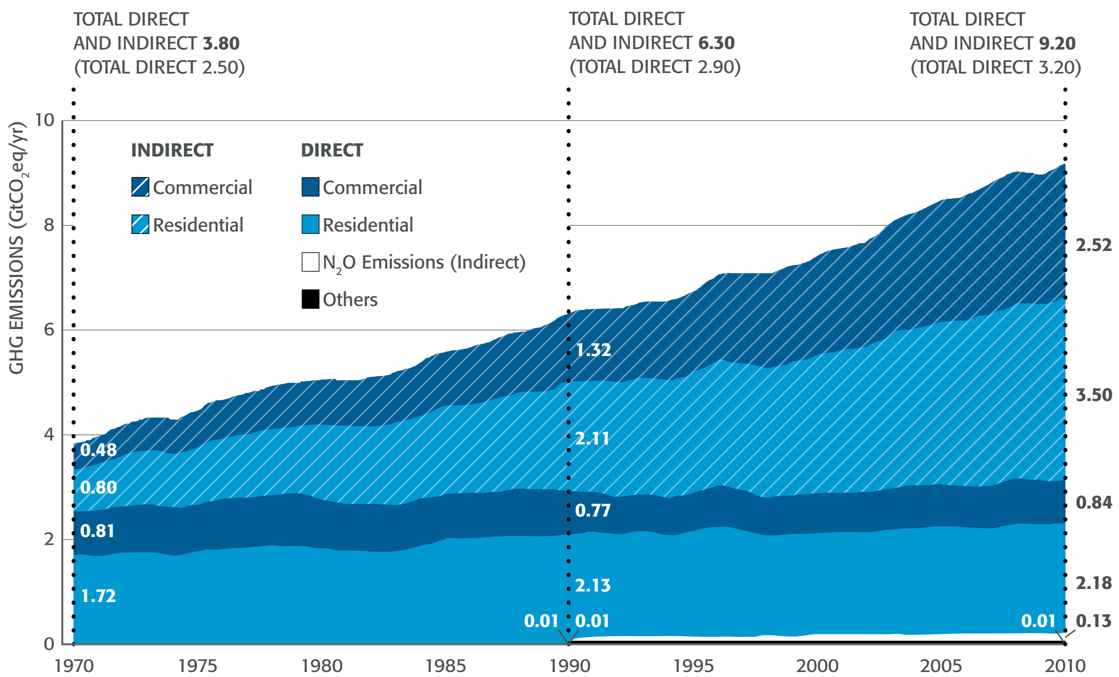
3

TODAY: OUR GROUNDS FOR ACTION

There is no "silver bullet" that can resolve the climate question overnight. Nonetheless, there is a wide range of technologies at our disposal that can set us on a path towards deep decarbonisation starting now.

The optimal combination of technologies will depend on the structure and state of local electricity systems (which is also the product of the political, economic and social history of each country) and the speed at which the less mature technologies improve in terms of performance and cost.

DIRECT AND INDIRECT EMISSIONS FROM ELECTRICITY AND HEAT PRODUCTION IN THE BUILDING SUBSECTORS – 1970-2010



Source: IPCC, AR5, WGIII, Chap 9

START CURBING EMISSIONS NOW

The stabilisation of CO_2 concentrations at low levels implies a transformation of electricity systems, which in turn calls for stable and long-term energy and climate policies. While innovation is vital, we should not wait before acting. The status quo should be moved and can be moved with existing, affordable technologies in order to put ourselves on a more sustainable pathway.

The cost-effectiveness and affordability of climate and energy policies are essential preconditions for the long-term stability of institutional frameworks. Experience teaches that only cost-effective policies can ensure the durable commitment of businesses and communities: energy policies that result in non-affordable energy prices are generally challenged and abandoned. A more consistent, continuous policy dynamic helps build up and maintain the needed skills and experience over time, resulting in the more effective development and deployment of low-carbon solutions.

LEVERAGE THE POTENTIAL OF TODAY'S TECHNOLOGY

There are solutions today that can contribute to climate change mitigation and global temperature stabilisation. These can be categorised under three actions:

- Improve end-use energy efficiency
- Produce more electricity with technologies without direct GHG emissions
- Mitigate GHG emissions from fossil fuel power generation through increased efficiency and fuel switching.

IMPROVE END-USE ENERGY EFFICIENCY

Improving end-use energy efficiency will make a vital contribution to mitigating emissions.

Fostering energy efficiency in buildings

GHG emissions from buildings have doubled since 1970, with building energy consumption representing around a third of the global total and 50% of electricity consumption.

The EDF office building in Toulouse, France features building-integrated PV panels. The office building is labelled as a High Environmental Quality and Low-Energy Building (EDF).

BUILDINGS: THE MOST EFFICIENT TECHNOLOGIES CAN BE SPREAD BY WELL-DESIGNED REGULATION AND BOOSTING SKILLS IN THE BUILDING SECTOR

Policies supporting energy efficiency depend on the context within which they are implemented.

Construction rates in emerging countries are such that new building technologies (in design, materials, heating, cooling and lighting) can be incorporated rapidly. Because of the lifespan of buildings, there is a major lock-in risk when poor choices are made in the construction phase. As long as enforcement and monitoring are ensured, energy efficiency building codes can make a major contribution.

In OECD countries, beyond standards for new buildings, the main target is to improve energy efficiency in the existing building stock, carrying out those renovations which are economically efficient. Thus the focus should be on the measures best suited to each type of building.

In all countries, the spread and adoption of the optimal technologies will involve boosting the installation and technology management skills of workers in the building sector, ensuring regular use of reliable energy audits and creating labels (for insulation as well as more efficient appliances) to inform investors and allocate investment efficiently.

Fostering energy efficiency in industry

Improving energy efficiency in industry is key given its weight in global electricity consumption and the fact that energy consumption is more concentrated (in terms of the number of sites) than in buildings.

Significant progress has been achieved in many countries, with large corporations taking a variety of steps to lower their energy intensity, notably for electricity. However, while energy productivity as a factor of production has improved over the past 20 years, bigger gains have been seen with labour and capital productivity, which have been a focus of lean production strategies.

In energy-intensive industries, an important portion of the savings potential relates to steam systems and waste heat recovery. As far as electricity is concerned, motor systems and buildings are major sources of potential savings.

In non-energy-intensive industries, there are potential savings in motor systems and electricity consumption monitoring.

In both sectors, changes in industrial processes, involving the electrification of sub-processes, could bring significant energy savings. Energy management systems that aim to boost energy efficiency (for instance, systems based on ISO 500001 standards) through plant instrumentation and performance indicator control also have strong potential.

PRODUCE MORE ELECTRICITY WITH TECHNOLOGIES WITHOUT DIRECT GHG EMISSIONS

By 2025, hydropower, nuclear and wind will still be supplying most of the world's carbon-free electricity. Even by 2040, according to IEA predictions, they will provide 80% of carbon-free electricity.

Among the different renewable technologies (other than hydropower), wind power is seeing the most robust energy increase, followed by biomass and solar PV electricity. This ranking reflects the pace at which these technologies are closing the competitiveness gap.

Looking at the prospects for the coming years, the technological choices will be heavily influenced by regional contexts. The following paragraphs provide some examples of those local perspectives, based on workshops organised and run in various parts of the world for the purpose of this report.

Trends in **China's** energy mix reflect the priorities assigned to its energy policy: decrease the relative share of coal, reduce air pollution, enhance security of supply, and create new national industries around carbon-free technologies. China will draw on all low-carbon technologies, as each one offers specific challenges that may hinder exploiting its full potential. Overall, nuclear and hydropower will increase their shares of the mix, as will other renewable energies (thus necessitating careful management of intermittency, grid expansion and flexibility).

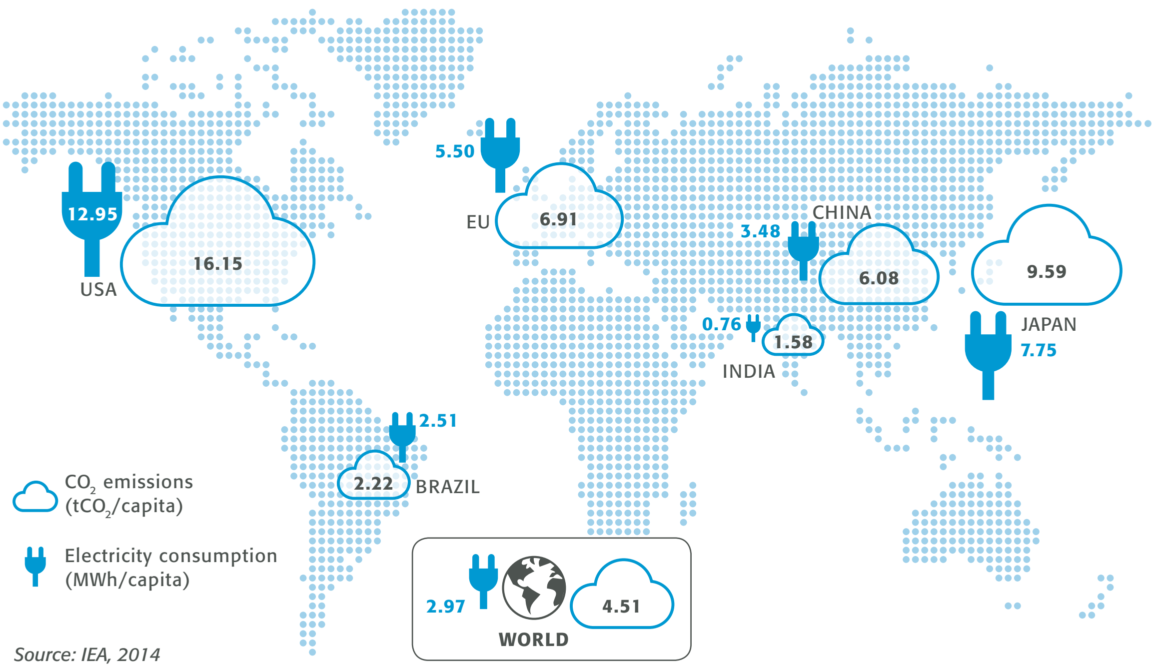
Renewable energy sources are often situated far from demand centres in China: in the North and West for wind and solar power, and in the Southwest for hydropower while consumption mainly takes place on the coasts, in the East and South. Their successful development involves expanding the transmission grid and resolving the intermittency-related issues that are already appearing even though renewables only cover a small fraction of China's electricity demand.

In winter, large-volume generation from multi-GW wind and solar power farms is curtailed, so that coal-fired plants located near large urban centres can be run in priority, as they deliver both electricity and heat to urban residents. Thus giving priority to renewable generation would mean depriving those living in large cities of heat.

To better tap wind and solar power potential, rolling-out those technologies closer to demand centres is an important option: for instance, offshore wind farms in the Eastern regions of the country or distributed PV which is currently under discussion. Higher flexibility going forward will also be key, for example through smart and strong grids, or demand-side initiatives, such as improving building energy efficiency to reduce heating-related demand and promoting electric and gas heating.

Where nuclear power is concerned, China boasts the necessary industrial fabric and skills and, given the size of its domestic market, series effects can take hold. Second-generation nuclear plants are competitive in relation to coal-fired units. Developing nuclear power in China going forward will involve moving down the experience curve for third-generation plants and managing acceptance issues for plants located in inland regions.

CO_2 EMISSIONS LINKED TO ENERGY (tCO_2/CAPITA) AND ELECTRICITY CONSUMPTION (MWh/CAPITA)



Source: IEA, 2014

Europe is facing different challenges:

- In the long term (i.e. by 2050), Europe has committed to massively decarbonise its power system, with a goal of reducing CO_2 emissions by 80%
- In the medium term (from 2030 on), Europe will be mobilising huge investments to overhaul its ageing generation capacity and networks, with a commitment to a 40% emission reduction in 2030
- In the short term, Europe is contending with excess capacity and a loss of competitiveness in the energy arena vis-à-vis regions like North America and Asia.

Hydropower potential has largely been tapped except in Eastern Europe, where there is real scope for development. In other regions, the main challenges are to improve existing infrastructure, make optimal use of water resources by balancing the range of usages, and enhance the combined management of hydro and thermal power plants to increase system flexibility and provide more efficient back-up for intermittent generation.

In most European countries, renewable energy has developed thanks to financial aid mechanisms introduced without corresponding volume controls. This has resulted in significant cost increases and excess capacity, which have been amplified by the economic and financial crisis, leading several countries to backtrack on renewable energy support. Such stop-and-go phenomena are detrimental to the long-term development of renewable energies.

Integrating intermittent renewable energy into the grid is also increasingly a challenge. As in China, although over shorter distances, renewable energy sources are often not near demand centres, which means that bolstering transmission grids and interconnection capacity between networks is a priority. Unlike in China, installations are small-scale and dispersed, putting the emphasis on developing and reinforcing distribution grids as the topology of flows on medium- and low-voltage networks is being modified.

The situation for nuclear power varies across Europe: while some countries have decided to gradually phase it out, many others are planning to retain or develop it. In these latter countries, the key challenges are extending the lifespan of existing units and descending the learning curve on third-generation reactors.

As regards the **United States**, there is significant wind and solar power potential.

The highest quality wind and solar power resources are located in the Great Plain states and the sunny zones of the Southwest. However, wind and solar resources have been developed virtually everywhere in the country. Utility-scale project capacity has increased, with an expanding transmission grid. Homeowners and businesses have been adding small solar power systems to their properties. This distributed generation has been backed by expanding distribution grids, supported by new policies and tariffs, so that owners also pay for the grid to back up their generation.

The Edison Electric Institute estimates that the total of all transmission project investments by its members between 2008 and 2014 is almost $100 billion. Approximately $50 billion more is planned for transmission projects through the year 2025, but this figure could evolve due to possible changes in baseload generation and increasing risks to grid reliability. About half of the transmission projects are planned to integrate renewable generation and 66% of all transmission projects will be for more efficient, 345 kV and higher voltage lines. Sixty percent of the projects will be limited to within one state while 40% will cross two or more states.

Where nuclear is concerned, the immediate objective is to extend the current fleet's lifespan where there is an economic case for doing so. In the longer term, the potential for the construction of new plants will be determined by competitiveness relative to gas prices.

Japan faces difficult conditions after the Great East Japan Earthquake in 2011.

While some nuclear plants have been mothballed, other nuclear units are still waiting for their compliance with new safety standards to restart. Although electricity companies have made significant efforts and spent much time to restart commercial operations under new safety standards, only a limited number of nuclear power plants have been able to restart commercial operations so far. As a result, the supply share of nuclear power has been much less than before the Great East Japan Earthquake.

As in Europe, renewable energy, especially solar PV, has been heavily incentivised with support mechanisms introduced without volume checks. As a result, some electricity utilities have been led to suspend applications to connect solar PV projects as supply volumes from PV exceed total electricity demand in some regions.

Brazil, as well as most of Latin America, has considerable untapped renewable energy potential, particularly for hydropower.

The trend will be to continue to exploit hydropower potential, with particular attention being paid to sustainability, notably in tropical regions, by spreading best practices in terms of stakeholder dialogue and involvement. Nonetheless, in the medium term, demand is set to rise faster than new hydropower, leaving a gap for other forms of generation to fill.

Wind power is already competitive in areas with high resources such as the Northeast. Tapping wind potential while leveraging the complementarity of hydro and wind (there is more wind in dry periods), will make Brazil's power system more resilient. More wind power and more remote hydro plants will call for the development and further enhancement of long transmission lines to carry the energy produced to consumption centres. Expanded interconnections between

The Trent Mesa Wind Farm near Abilene, Texas, USA has 150 MW of installed capacity (AEP).

WIND: INNOVATION IN MATERIALS, ELECTRICAL ENGINEERING AND O&M CAN INCREASE WIND TURBINE LIFESPAN

countries within Latin America should allow for greater geographic diversification of renewable generation sites, synergies between renewable resource regimes and limited use of thermal generation facilities during drought periods.

Solar PV (in particular at farm scale) is being developed thanks to significant resources and large existing hydro reservoirs that ease the insertion of PV power into the grid. Nuclear is being considered in order to provide baseload carbon-free power when hydro potential is tapped, by 2030, with Generation III technology and an adapted management of public acceptance, in particular, for plants in inland regions.

In **India**, as in China, growing electricity demand justifies leveraging the widest possible range of technologies. Hydropower offers very significant potential, although projects will have to take into account public acceptance, the sharing of water resources and the needs of communities.

There is also real scope for India to develop wind and solar power. Most of its wind resources are concentrated within five states in the Southern and Western regions of the country. India is currently adding 2,000 MW of wind capacity a year and the pace could pick up if the power grid is expanded at the same time.

As for solar power, if the Indian government's target of adding 100 GW of capacity by 2022 is to be met, project development will have to accelerate and the issues of financing and the cost of electricity generated be addressed, as providing energy access to as many people as possible remains one of the government's key objectives.

With regard to nuclear power, India has developed the industrial fabric and skills to meet its objective of lifting installed capacity to 28 GW in 2022 from 5.8 GW today.

SUSTAINABLE HYDRO: ENHANCING PUBLIC ACCEPTANCE THROUGH STAKEHOLDER ENGAGEMENT

An aerial view of the fish ladder at the Itaipu hydropower plant. Local fish, known as lambari, swim up the ladder's steps (Eletrobras).

MITIGATE GHG EMISSIONS FROM FOSSIL FUEL POWER GENERATION THROUGH INCREASED EFFICIENCY AND FUEL SWITCHING

While avoiding lock-in regarding emissions remains an important concern, in 2025, coal will still be playing a leading role in electricity generation, notably in Asia.

The development of new capacity will nonetheless be bringing more efficient units into the system (such as new supercritical pulverised coal plants), helping to improve average efficiency for existing coal capacity and thus limiting emissions. CCS-readiness is another potential solution, in some countries, to avoid emission lock-in.

In **China**, some inefficient coal plants have already been decommissioned and supercritical coal plants are becoming the standard. The creation of an emissions market in the country could accelerate the substitution of other fuels for coal and the promotion of the most efficient technologies.

New gas import infrastructure and the exploitation of domestic unconventional gas resources could allow CCGT plants to replace coal plants along the coast near urban centres. High gas prices could limit this substitution trend in the absence of a significant CO_2 price. However, gas penetration could still move forward via thermal uses, substituting for coal-based heating.

In the **United States**, low gas prices due to an abundance of natural gas from major shale gas deposits have resulted in more combined-cycle gas power generation being approved by state financial regulators. Large volumes of coal-fired generation are also being retired due to environmental regulations on mercury emissions. By 2030, 160 GW of coal-, gas- and oil-fired capacity will reach the end of its useful life and will be replaced. The choice of replacements will be important as total US power sector CO_2 emissions have already been reduced 15% below 2005 levels according to the June 2015 Energy Review report from the US Energy Information Administration.[vii] Although the US Environmental Protection Agency (EPA) has proposed CO_2 emissions regulations for new and existing power plants, a majority of states have raised serious concerns about legality, grid reliability, technology capability, costs, implementation schedule and other issues which will impact their ability to work with electricity providers to comply with the final regulations. The policy framework is currently the subject of consultations, discussions and court challenges.

In **Europe**, low CO_2 and coal prices have made coal more competitive than gas in the short term. The challenge is the replacement of the existing coal plant fleet as it reaches the end of its lifespan by 2030. A moderate and reasonable increase in CO_2 prices in the short run could facilitate the restarting of some CCGT plants, and would make CCGTs more competitive than coal for new build.

In **Japan**, following the Great East Japan Earthquake in 2011 and the resulting nuclear plants shut down, the electricity sector's dependence on fossil-fired power has temporarily increased significantly, leading to a spike in both CO_2 emissions and electricity costs. In order to bridge the supply-demand gap and decrease electricity costs, some new fossil-fired plants are being planned in some regions, using best-available technologies such as ultra-supercritical coal plants or IGCC. Considering the current situation of the energy industry, the government of Japan revised its energy policy and announced an appropriate energy mix for 2030 in order to ensure safety, energy security, economic efficiency and environmentalism (S+3E).

In **Brazil**, thermal power helps cover electricity demand during drought periods. CCGTs are the backbone of the thermal generation fleet. By 2030, the lion's share of the hydroelectricity potential will likely have been tapped, so rising demand and more severe weather conditions could justify the development of new thermal power capacity, the volume of which will depend on the development of other renewables, interconnections and nuclear.

In **India**, coal plays a central role in the electricity generation mix and currently covers 90% of demand. Plant efficiency currently averages 33.1%. Improving the efficiency of existing plants and developing supercritical ones are key challenges in India's 13th five-year plan.

4

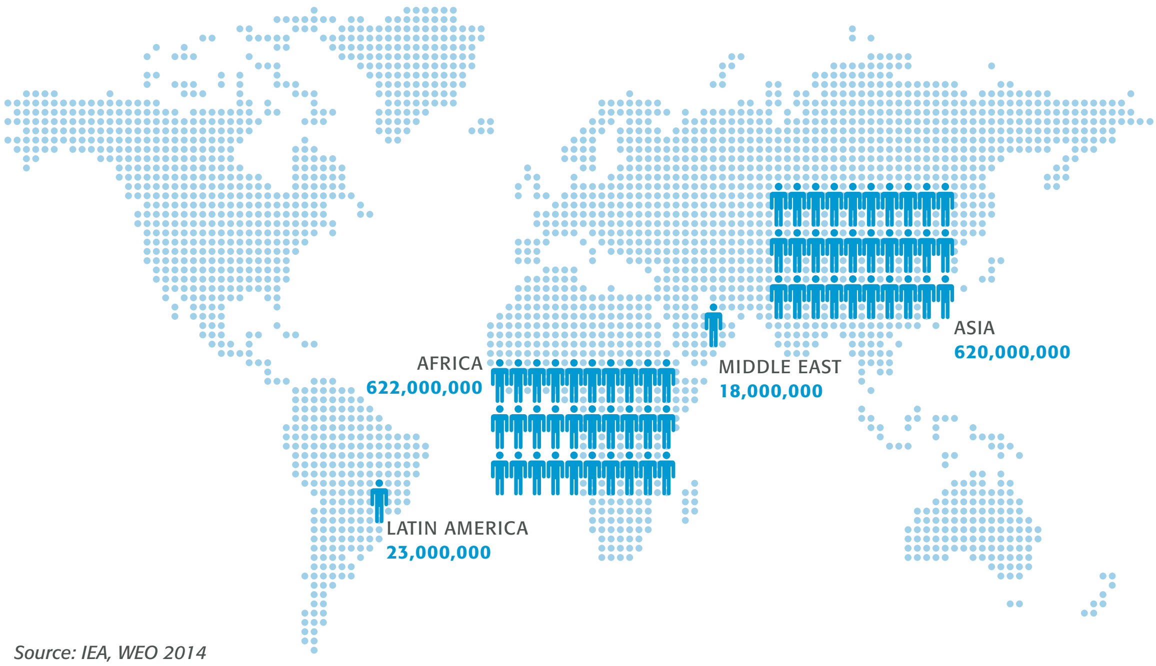
FOSTERING INCLUSIVE, SUSTAINABLE DEVELOPMENT

To successfully decarbonise the energy sector there are three fundamental issues to be integrated in decision-making from the start in order to match the needs and expectations of citizens and communities: (i) access to energy, (ii) adaptation to the effects of climate change and (iii) the water-energy-food nexus. On these three issues, real progress will be made through an approach that takes into account local situations as well as the careful articulation of the various aspects involved (social, economic, industrial, skills and capacities, etc.), backed by a commitment to plan for the long term.

WIDEN ACCESS TO ELECTRICITY

In 2014, close to 1.2 billion people still did not have access to electricity, mostly in rural areas in Asia and in sub-Saharan Africa. This figure rises to more than 2 billion people when you add citizens across the world without access to the reliable electricity networks needed to

PEOPLE LIVING WITHOUT ELECTRICITY WORLDWIDE – 2012



Source: IEA, WEO 2014

use it productively. Energy poverty is not only a lack of access to energy, but also entails the intensive use of fuels that can cause respiratory diseases and other health problems. GSEP members are committed to the goals of the Sustainable Energy For All initiative.

Access to modern energy, especially electricity, is essential to sustainable development, and it is difficult to imagine one without the other.

While an essential step, delivering energy and building infrastructure to enable access cannot alone guarantee growth and development. Access and development should be approached holistically via local, national or regional development plans that combine governance, technical, managerial and entrepreneurial training for locals, the development of economic activity (irrigation, use of electric motors by local artisans, etc.), and the channelling of aid.

In order to build such comprehensive development strategies, skills in electricity planning are essential to making technology choices that are best adapted to local situations. There are three typical patterns of expanding access:

- Network expansion areas (for instance, peri-urban zones on the periphery of existing networks).
- Mini-grids (small towns far from the grid with a certain degree of economic activity such as irrigated agriculture, cottage industries, etc.).
- Isolated off-grid regions (remote rural or very sparsely populated areas).

Good technology choices and support levels are different for each of these three situations. GSEP's experience with electrification in various parts of the world indicates that the key variable for electricity cost is consumption density. The cost per MWh delivered via grids within a large system (OECD countries for instance) is in the order of $100; in smaller electricity systems, it is usually closer to $200; for mini-grids with a combination of diesel and PV it is around $300 to $400; for very sparsely populated areas with PV systems used in conjunction with batteries it is above $500.

The Nepal Energy for Education project featured the installation of stand-alone PV systems at two schools, along with the distribution of small solar home systems to residents of the remote off-grid village of Matela (GSEP).

ACCESS TO MODERN ELECTRICITY IS ESSENTIAL TO SUSTAINABLE DEVELOPMENT AND OFF-GRID SYSTEMS CAN PROVIDE SOLUTIONS TO REMOTE ISOLATED REGIONS

Such a cost scale clearly shows that the poorest populations are likely to need the highest levels of support (even if their per capita consumption is far lower). Designing the proper support schemes is an important dimension for sustainability. Excessively high subsidies for end-uses could, for instance, be detrimental to facility maintenance. Aid focused on investments might be effective if combined with policies ensuring that locals acquire technical and maintenance, managerial and entrepreneurial skills, with programmes geared to developing local end-uses (irrigation for agriculture, supply of electric motors for cottage industries, etc.).

What this means for strategic development plans is that the best-fit technological choices (primarily the least expensive ways to meet local needs) should be carefully considered, as should international aid to subsidise investments in producing and delivering electricity, capacity building (technicians, salespeople and entrepreneurs), and an institutional system that integrates these different fields over the long term.

PREPARE THROUGH ADAPTATION AND RESILIENCE

According to the IPCC, even if the global temperature rise is kept under 2°C by 2100, electricity systems will have to adapt to new climatic conditions, while a rise beyond 2°C would call for even greater adaptation. The most significant threats are from rising sea levels, floods, storms and water shortages. Rising temperatures will also reduce the efficiency of thermal generation, and heat waves will significantly increase peak demand.[viii]

Electricity utilities have always taken into account weather hazards. Based on time series data and statistical inference, generation facilities and networks have been designed to resist most weather condition scenarios. However, the prospect of climate change introduces radical uncertainties in the type and the scale of extreme weather events:

- While the general effects of climate change are global, specific events – and the greater frequency and intensity of extreme weather events – will be local in impact and specific to each technology and asset class.
- The impacts may be unpredictable and may vary during the lifetime of assets, potentially raising serious challenges to their operation.

Utilities are already witnesses to the impacts of climate change. For instance, droughts and melting glaciers are forcing utilities to modify the intake and the management of hydro facilities. Understanding that current practices – which try to anticipate and resist disruption – are vulnerable to unforeseen factors caused by climate change, utilities are stressing the importance of "resilience". Resilience is based on two principles:

- The ability to anticipate, absorb, accommodate, and recover from the effects of an extreme event.
- Enhanced management capabilities in dealing with uncertainty and setting up emergency response.

Factoring in the adaptation and resilience challenges from the beginning of a project and in the design of solutions through comprehensive long-term strategies is a key factor to keeping costs in check as opposed to ex-post modifications.

MANAGE THE WATER-ELECTRICITY-FOOD NEXUS

With economic development and a rising global population, a more holistic approach to the resources on which our economies depend is vital for our future. In the first place, it must be stressed that water and electricity are interdependent: water resources are required to generate electricity, and electricity is necessary for the transport and treatment of water. In addition, growing demand for food – which is also profoundly dependent on water and energy – increasingly calls for us to consider water, electricity and food as three parts of the same system.

WATER FOR ELECTRICITY

The energy sector as a whole relies on water for the extraction, transport and processing of fossil fuels, as do power generation technologies. It is therefore vulnerable to physical constraints on water availability and to regulations that might limit access to it.

In 2012, global water withdrawals in the energy sector were estimated at 583 billion cubic meters (bcm), or some 15% of the world's total water withdrawals. Of that, water consumption – the volume withdrawn but not returned to its source – was 66 bcm, or less than 2% of global water consumption.[ix]

With relatively small volumes of water withdrawal, except in regions where water is particularly scarce, the power sector is more concerned by the deterioration of water quality than its lack; for example, warmer water may not be usable as a cooling method in power generation. The monitoring of water quality (and in particular its temperature) is growing in importance as a criterion for the physical, economic and environmental viability of energy projects.

Solutions exist, adapted to each local context, with considerable gains in terms of cost, efficiency and effectiveness when put in place at the conception phase of a project.

ELECTRICITY FOR WATER

Electricity is needed to power the pumps that abstract, transport, distribute and collect water. The amount needed depends on the distance to (or depth of) the water source.

Water treatment processes, which convert water of various types into water fit for a specific use, also require electricity.

Desalination, a process that removes salt from water, is the most energy-intensive and expensive option for treating water and is used where alternatives are very limited, such as in the Middle East and Australia.

In areas where fresh water is scarce and drinking water is brought in from a long distance, the energy footprint for drinking water is extremely high. The energy consumed for pumping groundwater is typically between 140 kWh and 600 kWh for one thousand cubic meters, depending on pumping depth.

WATER, ELECTRICITY AND FOOD

To feed the world population in 2050, the world will need to produce 60% more food, while ensuring a sustainable approach to ecosystems and to water and energy systems.

Today, agriculture accounts for 70% of total global freshwater withdrawals, making it the largest user of water. Water is used for food production, forestry and fishery, and along the entire agro-food supply chain, as well as being used to produce or transport energy in different forms. Meanwhile, food production and its supply chain accounts for about 30% of total energy consumed globally.

Without a considered approach to harmonising the needs of food, water and energy, these three systems will be drawn into competition for resources. This will have to be taken into account at global level.

5

POLICIES TO DRIVE MITIGATION AND INNOVATION

Rising to the challenge of climate change and transforming our electricity systems calls for commitment. Now is the time to establish a dynamic that will carry us to COP21 and beyond, and that will mobilise governments, industry and civil society. The companies that comprise GSEP are ready to contribute, bringing their practical experience of the sector, their expertise in low-carbon technologies and their capacity for R&D.

Governments will play a leading role in setting the world on the right track, by creating and implementing policies to spark innovation and control emissions. Their ability to organise strategic action and leadership can forge strong coalitions and build momentum. At the international level, cooperation between states and regional blocs is crucial to creating a virtuous circle in which action to tackle climate change is pursued over the long term.

It is through this process and dynamic of cooperation and dialogue that a stable, long-term policy framework should emerge. Such a framework, integrating the core components described below, is vital to our industry, which plans its investment decisions for the long term.

FOSTER INNOVATION

Innovation in our energy systems is not only desirable, it is eminently achievable. Greater efforts in R&D and developing more partnerships between corporations and governments will bring a greater range of effective solutions to the climate change challenge.

Power companies can make a major contribution to this dynamic, through our research capacity, our technological expertise and our knowledge of how the energy system as a whole works. One key input will be working with all stakeholders to develop detailed roadmaps for each technology to help build effective regulatory frameworks and foster R&D. Innovation on governance as well as on ways to foster inclusive dialogue and stakeholder engagement is also an essential dimension of innovation.

What would the shared technology roadmaps entail?

One key aspect is identifying the maturity of each technology with a qualitative measure of how far it is from being economically competitive and ready for distribution on the market. For technologies at the R&D stage two broad categories are important:

- Relatively immature technologies (test phase) just out of fundamental research which are tested on reduced-scale prototype facilities. Investments are moderate, in the order of about €1-10 million a year. Costs per MWh tend to be very uncertain and far from competitive (typically more than five times the market benchmark)
- Maturing technologies (premarket phase) are those that are close to being competitive, with costs somewhere between two to five times the average market price, suggesting that industrial deployment could be competitive in the near future. Technology uncertainty has been reduced and only a small number of alternatives still compete at this stage of development. This is when industrial demonstrators, or facilities the size of those that would be developed on the market if the technologies were mature, are built. Investments are more significant in this

Massangis PV farm in France, equipped with 700,000 thin-film CdTe PV panels of 56 MW (EDF).

SOLAR: FOR PV TO DEVELOP IN REGIONS WITH LOWER SOLAR IRRADIATION, THE TARGET IS R&D ON BREAKTHROUGH TECHNOLOGIES

case (from €100 million to €1 billion to build industrial demonstrators or to descend the learning curve of certain technologies). For example, clean coal technologies with carbon capture fall into this second category.

In addition, it is important to identify the key technology improvement targets (What?), the timeline (When?), and the various entities involved – firms, public entities, research centres, etc. – and their respective responsibilities (Who?).

Effective policy design to foster R&D incorporates such roadmaps. These roadmaps are also adapted to the type of technology involved, whether "centralised" (large unit size and unit investment) or "decentralised":

- "Centralised technologies" involve large individual unit sizes (above 100 MW, and a capital cost per unit of €100 million or more), with a small number of manufacturers. On the demand side, there is a relatively limited number of industrial players, namely major electricity companies. Market conditions are thus typically characterised by fairly low transaction costs but by high levels of technology complexity, extensive coordination between stakeholders and the issue of integrating large facilities into the environment. Examples of such centralised markets include clean coal and nuclear.
- "Decentralised technologies" involve small individual unit sizes (about 1 MW) and low investment per unit (less than €1 million). There are numerous manufacturers, and installation and maintenance are handled by a wide range of operators, which are often local. There are also many buyers, including, in some cases, consumers (e.g. heat pumps or photovoltaic panels). Here, transaction costs are higher. In addition, incentives are often split, for example in energy efficient buildings when the inhabitants are not the owners.

Governments also have a key role to play in encouraging international collaborative R&D, particularly for key technologies like CCS, nuclear, renewables and storage.[1]

1. In the field of nuclear power the GenIV International Forum (GIF) and ITER are examples of international collaborative research. The Carbon sequestration Leadership Forum (CSLF) is example in the field of CCS. CSLF has developed a CCS roadmap which illustrates how governments funding and supportive public policies can play facilitating roles.

EXAMPLES OF POLICIES FACTORING IN MATURITY ANALYSIS OF TECHNOLOGIES AND THEIR UNIT/INVESTMENT SIZES

TECHNOLOGIES	MATURITY	
	TEST PHASE	PREMARKET PHASE
CENTRALISED	• Framework programme, • Public-private partnerships (particularly with equipment suppliers)	• Public-private partnerships with subsidies or repayable advances, tenders, tax credits • Preparation of necessary regulatory conditions (legal, security and long-term visibility)
DECENTRALISED	• Framework programme • Identification of "centres of excellence"	• Feed-in tariffs with control of volumes, tax credits • Standards/labels • Structuring of offers and decrease of transaction costs

PRIORITISE COST-EFFECTIVENESS AND SECURITY OF SUPPLY

THE VALUE OF INTEGRATED SYSTEM PLANNING AND OPERATION

As practitioners responsible for planning, operation and development of effective power systems from generation to grids and supply, our experience highlights the importance of a "power system" approach in order to maintain a continuously reliable, affordable and secure service to customers. Operators constantly manage the amount of electricity that is placed on power systems at any given time. While many technologies can generate electricity in a controlled and scheduled manner (i.e. thermal plants, renewables like hydro or biomass, etc.), important renewable resources, like wind and solar, are intermittent and available only when the wind is blowing or the sun is shining. While they provide the grid with useful low-carbon energy, they can have limited capacity value (i.e. the ability to produce energy on-demand and when needed, such as time of system peak-load). Sophisticated power models, integrating advanced technology innovations are needed to design, monitor and manage the increasing penetration of intermittent energy technologies on the grid.

Within GSEP, great efforts are being made to design and operate transmission and distribution projects so that they always deliver electricity that meets power quality, performance, affordability, and reliability standards. The laws of physics demand that a "power system" approach be used to integrate these technology innovations successfully. Generation facilities that are not working at design production levels can change the magnitude and direction of power flows on the grid, as well as the reactive power supplied to the network required to maintain stable voltage. Intermittent generation requires baseload generation as back up. Stable voltage profile and reactive power are vital to maintain, so there must always be electric energy flowing into the grid from baseload generation and/or from bulk storage systems or, moving forward, flexible demand. The practitioners of the power sector must ensure the reliable and secure planning and operation of the power systems by assessing changes in the mix of intermittent and baseload generation in combination with planned and unplanned disruption to the electricity grid.

BUILDING EFFECTIVE ENERGY POLICIES

The evidence demonstrates that only cost-effective policies can win the long-term commitment of businesses and communities. Energy policies that result in non-affordable energy prices are generally challenged and abandoned. The resulting "stop and go" in policy implementation is damaging for the energy sector, for the climate, and for communities.

The cost-effectiveness and affordability of climate and energy policies are therefore essential conditions for the long-term stability of institutional frameworks:

- Limiting the financial resources needed to curb GHG emissions to a reasonable level is not a given; well-conceived, well-designed, and well-implemented energy and climate policies are necessary.
- In order to engage businesses and communities, keeping the cost of transforming power systems under control is vital. Mitigation policies can be sustained in the long run as long as stakeholders and the public are convinced that least-cost options are being pursued.

In the long term, reducing climate risk is essential to sustainable economic development.[x] Even in the medium term, there is no reason for climate policy and growth to be in conflict: many of the policy and institutional reforms that will spur growth and improve the lives of global citizens over the next 15 years will also contribute to reducing climate risk. Correcting market and government failures in urbanisation, land use and energy systems are potential "win-win" reforms that will help forge a path to sustainable development, improve economic efficiency and foster the commitment of businesses and communities to climate mitigation.

While no "ideal solution" to the design of an energy and climate policy framework exists, the experience of the GSEP companies indicates that there are several guidelines that can ensure that policies will be affordable, effective and sustainable:

- Clear evaluation of technology maturity is essential. Deploying insufficiently mature technologies on a large scale has led to economic inefficiencies, high prices and reduced public support. A long-term strategy calls for the deployment of mature, proven, and cost-effective technologies. However, non-mature technologies may hold the key to deep decarbonisation in the long run; a greater collective effort in research and development will enhance the potential for promising technologies to reach mass deployment
- Technology competitiveness should be assessed on a transnational, national, regional or even local basis. The cost of technologies may differ significantly from one country to the next based on differences in primary energy endowment, geography, labour costs, and access to capital, tax system, grid characteristics, etc.
- Infrastructure and integration challenges should be taken into account. A significant portion of final electricity delivery cost is incurred at the system level, creating (positive or negative) externalities that should be taken into account when designing policy. Here again, the local characteristics of existing systems matter. Introducing new forms of energy production and consumption should consider the energy infrastructure, and how each part of the system is integrated into the whole, in order to boost effectiveness and minimise costs. In particular, technology competitiveness assessments should take into account cross-subsidy issues.
- Innovation and R&D should be pursued with a spirit of openness towards the multiple possibilities before us. "Picking the winner" syndrome can give us valuable experience (as has been the case for some renewables), but results in other technologies being ignored or insufficiently tested and developed. The goal of public policy should be to widen the field of possibilities and develop a range of options in the medium run. Thus sufficient resources should be allocated to R&D and demonstrators, and a level of technology neutrality should be ensured.

SOLAR PV: TODAY CLOSE TO COMPETITIVENESS IN SUNNY REGIONS WHERE PEAK DEMAND IS CORRELATED WITH THE SUN

Longyangxia Hybrid Photovoltaic Power Plant Project in Qinghai province, in China: the largest single-unit grid-connected photovoltaic power station worldwide (530MW) features the complementary use of solar energy and hydro in hybrid systems (SGCC).

MOBILISE FINANCE

Action to reduce climate risk will involve a major mobilisation and channelling of financial resources. There is no question that the resources are available; the issue is how to trigger them most effectively while maintaining the benefits of electricity: clean, safe, affordable, secure, continuously reliable energy for social and economic development. In the power sector, there are two core questions today:

- How can low-carbon power best be financed?
- What contribution can a CO_2 value bring, whether it is implicit (through legislation or regulation) or explicit (through market-based instruments)?

We already have considerable information from the policies that many countries and regions have introduced to foster a solid investment climate for low-carbon technologies. Policy-makers have had two main goals in mind:

- Supporting immature technologies on their path to competitiveness
- Encouraging investors by ameliorating the risks they are called to bear, by reducing market risks in deregulated power markets and political risks in regulated ones.

Financial support has taken various forms, including feed-in tariffs (FiTs), output-based subsidies, tax credits and quota systems.

How have these financial instruments performed? Administratively-driven support mechanisms can give investors biased incentives. In particular, FiTs, when applied to immature technologies, may not adapt in step with the evolution of the costs of technologies, resulting in overly generous financial incentives and sparking excessive development of new capacities. More generally, FiTs can contribute to the amplification of market imbalances by adding new capacity in oversupplied markets and failing to attract investment in undersupplied markets.

All this speaks for limiting the scope of use of FiTs to technologies close to maturity and/or combining FiTs with other instruments (auctions, tendering processes) to regulate quantities, based on cost and the state of the supply-demand equilibrium.

Although it is extremely important that investors and financial regulators see that sufficient investment is made and can be recovered in order to capitalise electricity generation and delivery projects, tax credits are an interesting tool allowing:

- A broadening of the sources of finance (i.e. tax payers and not just electricity consumers)
- Control of the level of the subsidies by governments.

In addition, several governments from developed countries intend to restrict financial support to new coal power without CCS in developing countries. A careful assessment is needed to see whether this will not have the unintended consequence of the construction of low-performance coal technologies (subcritical and/or supercritical) instead of ultra-supercritical and/or IGCC.

In competitive electricity markets, low-carbon power plants (renewables and nuclear) are expected to be "price takers" in line with market demand, resulting in revenue streams that will be uncorrelated with the costs they incur. Combined with lower wholesale market prices, market revenues alone might thus prove too volatile and too low to provide adequate return on what are capital-intensive investments.

In such contexts, tailored risk-sharing schemes, such as long-term power purchase agreements, well-designed capacity remuneration mechanisms, contracts for differences, and single buyer models with competitive schemes, could stimulate investment in long-lasting capital-intensive assets.

One vital component of climate policy is a carbon value. CO_2 emission reduction legislation and regulations are preferred in some countries. In other countries, various institutional forms (such as emissions trading systems or carbon taxes) have been adopted by policy-makers, while the assignation of a carbon value in policy appraisal and evaluation can be envisaged in both types of countries. Several points need to be underlined:

- In a given country or region, a calculation of the shadow value of carbon implied by each policy measures is a powerful tool to reduce the cost of mitigation policies significantly.
- The planning of the carbon value is key. It should be set at a reasonable level at first, evolving smoothly over time, in order to support the long-term development of low-carbon technology. The value should be high enough to foster the deployment of the appropriate technologies and low enough to ensure cost-efficiency and credibility. Clear and transparent mechanisms to monitor a smooth and credible evolution of the carbon value are essential.
- Attention should be paid to the market design when carbon cap-and-trade systems are introduced. According to the International Carbon Action Partnership (ICAP), there are 17 emissions trading systems in force across four continents, covering 35 countries, 12 states or provinces and 7 cities. Together, those jurisdictions produce about 40% of global gross domestic product.[2] For emissions markets to perform effectively and yield maximum benefits, the International Emissions Trading Association (IETA) recommends that they be embedded in local policies where compliance occurs, that they be harmonised in developing countries with international support structures and that national and subnational markets be linked together for additive economic value, where it makes economic sense.[3] The EU Emissions Trading System is a key tool which has been introduced to meet European CO_2 targets cost-effectively. It provides a unique test case from which one can draw lessons for the design of future systems: favour long-term visibility in setting targets, ensure bankability as a requirement, and avoid free allowances to new projects and exemptions of large emitting sectors from the system while addressing "carbon leakage" issues appropriately.

For a carbon value to work effectively, the long-term commitment of governments is essential. In that respect, international climate negotiations are a key factor for ensuring sustainable and credible policy frameworks.

2. ICAP's 2015 Status Report on Emissions Trading Worldwide at www.icapcarbonaction.com contains practitioner insights in the design and operation of each of the emissions trading systems.

3. IETA's 2014 Greenhouse Markets Report and Case Study Guide at www.ieta.org provide detailed analyses of the performance of global climate markets, finance developments and key design elements.

END NOTES

i. International Energy Agency (IEA), World Energy Outlook, 2014

ii. International Panel on Climate Change (IPCC), Fifth Assessment Report (AR5), Working Group III, Mitigation of Climate Change, 2014

iii. IEA, CO_2 Emissions From Fuel Combustion Highlights, Edition 2014

iv. IPCC, AR5, Working Group III, Mitigation of Climate Change, 2014

v. Installed capacity and generation figures for renewables are drawn from REN21 and IRENA data.

vi. IEA, Energy Technology Perspectives, 2014

vii. http://www.eia.gov/environment/data.cfm#summary

viii. IPCC, AR5, Working Group II, Impacts, Adaptation, and Vulnerability, 2014

ix. IEA, World Energy Outlook, 2012

x. See, for instance, Better Growth, Better Climate, the New Climate Economy Report, September 2014

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GLOBAL SUSTAINABLE ELECTRICITY PARTNERSHIP

The Global Sustainable Electricity Partnership (GSEP), a not-for-profit comprising the leading companies in the global electricity sector, promotes sustainable energy development through electricity sector projects and human capacity-building activities in developing nations worldwide. Our projects and activities are financed mainly by our member companies, who also contribute in-kind resources for their execution.

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