International Council of Academies of Engineering and Technological Sciences

This report juxtaposes the contributing academies' views on an all-electric society comparing the countries' approaches to generate, distribute and store electricity.

CAETS Energy Committee Report 2018

Clean Energy Technologies– Challenges and Solutions

CAETS Energy Committee

Contents

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Executive Summary

One of the United Nations most important “sustainable development goals” is the use of clean and affordable sources of energy for all nations. A transition from our over-reliance on fossil fuels to more sustainable energy sources is one important way to achieve this goal. One strategy is to substitute electricity as the energy carrier of choice to replace fossil fuels wherever possible.

In order to achieve this goal, we need to replace energy predominantly generated from fossil fuel sources with electricity produced in an efficient and sustainable way. However, the availability of energy resources, existing infrastructure, and the technological possibilities for change are unique for each country.

Considering these factors, the strategies used by each country to tackle the challenges of reconfiguring their infrastructure towards a predominantly electrical energy system will be unique. Some of these factors include the following:

- How can electricity be used to replace fossil fuels?
- How is electricity generated, distributed, and stored now?
- What alternative options are available to be considered for the future?
- How will increased electrification affect vehicles and transportation in general?

In order to gain some understanding of these factors the representatives of the eleven academies that serve on the CAETS Energy Committee (Australia, Canada, China, Czech Republic, France, Germany, Japan, South Korea, South Africa, Switzerland and the United Kingdom) contributed information on the status quo and strategies of their respective countries by completing a questionnaire developed by the Committee with support from the Institute for Advanced Sustainability Studies (IASS) in Potsdam. This information is summarized in the tables below which show the following:

- Seven of the eleven countries intend to increase the share of (renewable) electricity.
- Seven of the eleven countries have developed strategies to promote an increase in the number of electric vehicles.
- In all eleven countries electric vehicle sales have been below expectations but are increasing rapidly.

The purpose of this report is to provide policy makers with an overview of the approaches taken by selected CAETS member countries to reduce greenhouse gas emissions.

Comparison of country strategies

Electrification of the energy system

Australia	The Australian Government has not stated an aspiration to attempt a transition to an all-electric society. The Academy notes that deep decarbonisation of the economy will certainly involve a significant degree of electrification and fuel switching, but expects that other energy sources such as biofuels and hydrogen will play an important part of the future energy mix for certain transport modes and industrial processes.
Canada	Canada will most likely move to significantly greater use of electricity for transportation and domestic heating, although fossil fuels will still be needed for large commercial vehicles as well as for air transportation and the significant marine transportation infrastructure on both the West and East coasts of the country. Energy policy varies widely from province to province.
China	Electrification will be an important driving force for the green transition of China's energy system. Although China pushed forward the electrification tremendously especially in the transport sector, it Is far from heading towards an all-electric society. A mix of different technologies are promoted on a large scale and will play an important role for the future energy system.
France	The objective of carbon neutrality in 2050 should be passed into law before the end of 2019, but there is no long-term plan to transition to an all-electric society. A ten-year energy plan should be decided this summer by the Government; on the electricity side, the main orientations are to close all coal power plants by 2022, reduce nuclear share from present 72% to 50% in 2035 and expand the share of renewables. Biofuels and hydrogen should play an important role in the future energy mix for certain transport modes, and industrial processes in the longer-term future.
Germany	Electrification, along with digitization, will continue to be a major trend and driver in the German energy transition. Germany has set ambitious goals to increase the share of renewables in electricity consumption (30% of the overall energy consumption by 2030 and 60% by 2050). This will only be possible by using the expanding wind and solar electricity production in the heat and transport sector. However, Germany is not on the way to an all-electric society – chemical energy carriers will remain important for certain transport options and industry processes.
South Africa	South Africa has had a very successful renewable energy procurement programme, which has had four rounds of bidding. It contains clear commitments for sustainable energy production at an affordable price range. There is no strategy to go all-electric.
South Korea	Electrification of the Korean energy system, along with renewable energy sources and EVs, will continue to be a major trend and driver in the Korean energy transition. As planned, renewable electricity will be more than 20% of total power supply by 2030, and 1 million EVs will be operating in Korea. Although complete electrification will not be achieved by 2030, it seems that Korean energy system will be much more electrified than now. The Government also announced 'Hydrogen Economy Roadmap' towards 2040, which aims at producing 6.2 million Hydrogen FC cars by 2040.
Switzerland	With its Energy Strategy 2050 Switzerland is moving towards a higher share of (renewable) electricity (from 25% to 50%) and yearly energy related CO_2-emissions of 1-1,5 ton/capita (a reduction of 70-80% as compared to today), while abandoning nuclear power which today covers 40% of the nation's consumption.

USA	Production and consumption of liquid fuels and petroleum products will remain widespread across the U.S. economy, with the largest use in transportation. Although electrification of transport will continue, market penetration of electrified vehicles has been slow in the U.S. and is projected to increase modestly over the next 30 years

Generating Electricity

	Nuclear energy	Coal	CCS
Australia	Prohibited. The Academy recommends considering it as an option.	63% share, increasingly displaced with gas, hydro, wind and solar power.	Significant geological potential. Some pilot projects are in development or under construction.
Canada	15% share of total electricity generation	10% share of total electricity generation	Several demonstration plants have been built to capture CO_2 from a coal-fired powerplant as well as from an oil-sands upgrader and a gas-processing plant.
China	2% share (2017), up to 110 additional reactors are planned until 2030	58% share, planning to reduce the share; largest coal consumer.	China worked on CCS demonstration for coal-fired power plants including post-, pre- and oxy-combustion technologies. Huaneng GreenGen Project has solved the technical difficulties of integrated gasification combined cycle with pre-combustion capture taking the leading position in the world.
France	Nuclear electricity to be reduced from 72% to 50% by 2035. Decision on new plant construction by 2021.	Presently 2% share in the electricity mix, to be closed by 2022 if the grid security allows.	A few pilots were financed, one including the full chain (capture, transportation and storage).
Germany	5% share (2017), phasing out until 2022	23% share in 2017	Law from 2011, decision of federal states. Prototype operated until 2014 due to aversion of citizens and missing support of the government
South Africa		Two major coal-fired plants have recently been built, but there are plans to retire about 20 GW of old stations by 2025.	

South Korea	26.8% share (2017), to be reduced and phased out within the next 60 years based on the current government's policy	43.0% share in 2017. Coal power generation will decrease due to air pollution issues in Korea; Tax system will be modified to promote the renewables but to deter the nuclear and the coal.	Most of the R&Ds related with CCS was handled by the Government in the last 20 years developing various (both wet and dry) technologies to capture CO_2; but recently the R&D scope is changing more towards 'Utilization.'
Switzerland	40% share (2017) to be abandoned without defined end of service date.		
USA	20% share (2017), forecast to have modest declines due to higher costs	30% share (2017), forecast to have modest declines due to higher costs	Since the late 1990s, the US has invested billions of dollars in developing CCS technologies, and several demonstration projects have been supported through the Department of Energy. The viability is seen controversial.

Distribution approaches

	Grids	Smart Grids	Grid challenges
Australia	Isolated, relatively sparse and extending electricity supply network; mostly alternating current (AC) transmission infrastructure, some high voltage direct current (HVDC) technology, incl. 290 km submarine	Platforms driven by private companies are in development status	Weak interconnections between states. Many areas of high renewable energy potential are isolated or do not have network capacity for additional generation.
Canada	Many long-distance grids bringing power from remote hydro-power facilities to large urban areas. Connections to the U.S.A. on the West and East coasts.		Lack of grid synchronization across the country makes it difficult to share power from West to East.
China			
France	Large increase in grid interconnections with all neighbouring countries	Platforms driven by private companies are in development status	Double the capacity of interconnections with neighbouring countries.
Germany			High share of renewables; expansion of grid infrastructures
South Africa			

South Korea	Isolated; two HVDC lines (over 100 km submarine) connecting the country's largest Jeju island with the peninsula	A smart grid testbed project has been implemented on Jeju island led by the consortium of private and public companies. In Gasa Island, world's first independent microgrid was constructed using a Korean-built Energy Management System (EMS).	Saturation of high voltage grids in the nation; modernization of grid infrastructure to accommodate higher share of renewables
Switzerland			
USA			

Storing Options

	Hydrogen storage	**Pumped Hydro Stations**
Australia	Trials and demonstration projects	A small number of existing stations, including Tumut-3 (1,800 MW), Shoalhaven (240 MW), and Wivenhoe Dam (500 MW) Significant plans for expansion. See Snowy Hydro 2.0, and the Battery of the Nation initiative in particular.
Canada		Storage is dominated by large conventional hydro reservoirs.
China		
France	Trials and demonstration projects	Studies to possibly increase by 2 GW the present 8 GW capacity of pumped hydroelectric energy storage (PHES)
Germany		6.36 GW in 2017
South Africa		
South Korea	Hydrogen Economy Roadmap was announced by the Government which includes hydrogen storage as an option	4.7 GW in 2017
Switzerland		
USA		

Electric vehicles

Australia	Slow uptake at present. See this article1 and article2 for more details. Biofuels and hydrogen may also play a part of the future transport energy mix for certain transport modes
Canada	There is a considerable interest from the public to go for hybrid-electric vehicles in the short term and all-electric vehicles in the long-term. Canada has due to large installed hydroelectric capacity some of the lowest electricity prices in the world. As electric cars become more efficient, and are designed to have a longer range, they will be increasingly used by consumers, primarily in large urban centres with widespread charging facilities. However, long cold winters limit the opportunities.
China	China has taken several steps toward vehicles decarbonisation through accelerating the deployment of electric cars. China aims to fully commercialize the electric vehicles market after 2025 through continuing policy supports, e.g., targeting deployment of 5 million EVs by 2020 and generous purchase incentives. To achieve this goal, car producers have to sell 8-12% electric cars – or reduce their production. There is also a strongly increasing number of electric public busses.
France	Market penetration of electrified vehicles is slow, the bulk of them being hybrids and plug-hybrids
Germany	In the transport sector, battery electric cars are expected to play a key role. Until 2020, the German government aims for 1 million electric cars in Germany. Since 2016, there is a one-off premium for buyers of new electric vehicles. Nevertheless, combustibles and (synthetic) fuels will remain indispensable even in the long term, because easily storable energy carriers are required. There are also plans for overhead wire trucks.
South Africa	Electric drive vehicles are low on the agenda at present. Much of the internal heavy transport is by diesel, and given the distances involved, electric drive is not attractive.
South Korea	According to the '2030 Proliferation Strategy of New Energy Industry' announced in 2015, national projects have been carried out with the goal of 1 million electric vehicles by 2030. In June of 2018, Korean government also announced a plan for expanding hydrogen vehicles (15,000 vehicles by 2022 including 1,000 buses) and constructing 310 hydrogen charging stations by 2022. Newly announced 'Hydrogen Economy Roadmap' targets the domestic production of 6.2 million hydrogen FC vehicles by 2040.
Switzerland	CO_2 emissions regulations similar to EU for transportation and electrification of cars, ambitious targets for the building sector facilitated by a CO_2 tax for heating oil and subsidies for thermal insulation measures, and Industry by options to avoid CO_2 taxes by technical improvement that help reduce emissions. Target for cars: CO_2 target in 2015 was 130 g/km; target 2020 is 95 g/km
USA	Although electrification of transport will continue, market penetration of electrified vehicles (defined as hybrid electric, plug-in hybrid, and battery electric vehicles) has been slow in the U.S.

Introduction

Using clean energy technologies is a decisive challenge for the future of all societies by following the UN Sustainable Development Goal 7 (Ensure access to affordable, reliable, sustainable and modern energy for all) and 2015 Paris Summit goals. However, the worldwide energy demand increases constantly. Available resources, existing infrastructures, geo-political situations and technological possibilities result in each country's individual technological and social situation.

For the promising potential to tackle the challenges, in this report, the CAETS Energy Committee places a focus on electrification, the long-term shift from fossil fuels to electricity. Electrification will play a constantly growing role for the future energy systems. By substituting the direct energy supply by electric vehicles, heat pumps or other technologies, societies can focus on clean power plants and increasing efficiency. Besides the generation of electricity, the distribution of electricity is also of great importance. The electrification demands therefore stable, modern or even intelligent grids. Economies have to deal with storage solutions for temporary power overproductions. The Committee is fully aware of the importance of energy usage, efficiency and recycling or even demand management. Anyhow, addressing all these topics would go beyond the scope of this report.

The committee member academies contribute their countries' approaches for clean energy technologies in a comparable questionnaire (Annex II). It aims to combine the academies' views and the government's strategies including references to publications. The report thus does not aim to evaluate, but to compare the performance of participating countries in fulfilling their respective goals. This comparison shall provide an overview for policymakers and everyone who is interested in designing the energy future of societies.

The CAETS Energy Committee thanks…

- All contributing academies.
- Especially its members Frank Behrendt (acatech), Robert Evans (CAE Canada), Chinho Park (NAEK), Peng Suping (CAE China), and Wei Yi-Ming (CAE China) for shaping this report's idea at the Berlin meeting.
- TU Berlin for hosting the Berlin meeting on April 11-13, 2018.
- Institute for Advanced Sustainability Studies (IASS) in Potsdam for contributing to the questionnaire.
- The acatech publication team.

And, finally, in memoriam the committee would like to especially acknowledge the important contributions made by recently deceased members Baldev Raj (INEA) and Philip (Taffy) Lloyd (SAAE).

Australia Contribution: ATSE

Australian Academy of Technology and Engineering
Dominic Banfield, Bruce Godfrey, Matt Wenham

1. Going towards an all-electric society?

The Australian Government has not stated an aspiration to attempt a transition to an all-electric society. However, Australia's Chief Scientist and ATSE's Past-President, Dr Alan Finkel AO FAA FTSE, has previously heralded the concept of an "*electric planet*"[1]. The Academy notes that deep decarbonisation of the economy will certainly involve a significant degree of electrification and fuel switching but expects that other energy sources such as biofuels and hydrogen will play an important part of the future energy mix for certain transport modes (aircraft, heavy logistics vehicles, for e.g. mining, marine) and industrial processes (e.g. iron and steel, cement and chemicals).

2. Generating electricity

2.1. Generating electricity from sustainable resources

2.1.1. Status quo: current national energy mix

Electricity generation is the largest single source of Australia's greenhouse gas emissions, responsible for more than a third of total emissions in 2017. The carbon dioxide equivalent emissions intensity of electricity generation in the National Electricity Market (857.8 g/kWh)[2] is more than double the OECD average (404 g/kWh)[3]. This difference can mostly be attributed to the increasing displacement of coal with gas, higher penetrations of renewable energy and the use of nuclear energy in many OECD countries. Figure 1 shows Australia's 2016 electricity generation by fuel type.

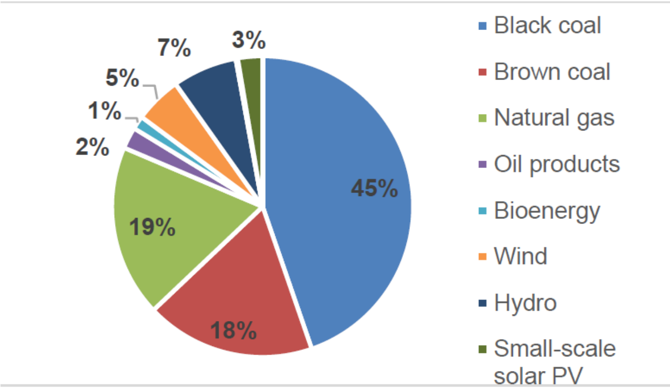

Figure 1 – *Australian electricity generation by fuel type (2016).* Note that *Large-scale solar PV* and *Geothermal* are not visible in this chart as they accounted for only 0.2 per cent and 0.00008 per cent of generation in 2016, respectively[4].

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[1] See *https://www.atse.org.au/Documents/Events/clunies-ross/2013-alan-finkel-speech.pdf* and *http://www.abc.net.au/radionational/programs/bigideas/a-vision-for-the-electric-plant/8001888*

[2] Average for 2017 calculated on 20 November 2017 using data from: AEMO (2017) *Carbon Dioxide Equivalent Intensity Index Summary Results File – Current Year,* available at https://www.aemo.com.au/Datasource/Archives/Archive1634.

[3] 2015 data from IEA (2017) *Energy and CO2 emissions in the OECD,* available at *https://www.iea.org/media/statistics/Energy_and_CO2_Emissions_in_the_OECD.pdf*

[4] Data sourced from Australian Government (2017). *Australian Energy Update 2017*, Table O1. https://www.energy.gov.au/publications/australian-energy-update-2017

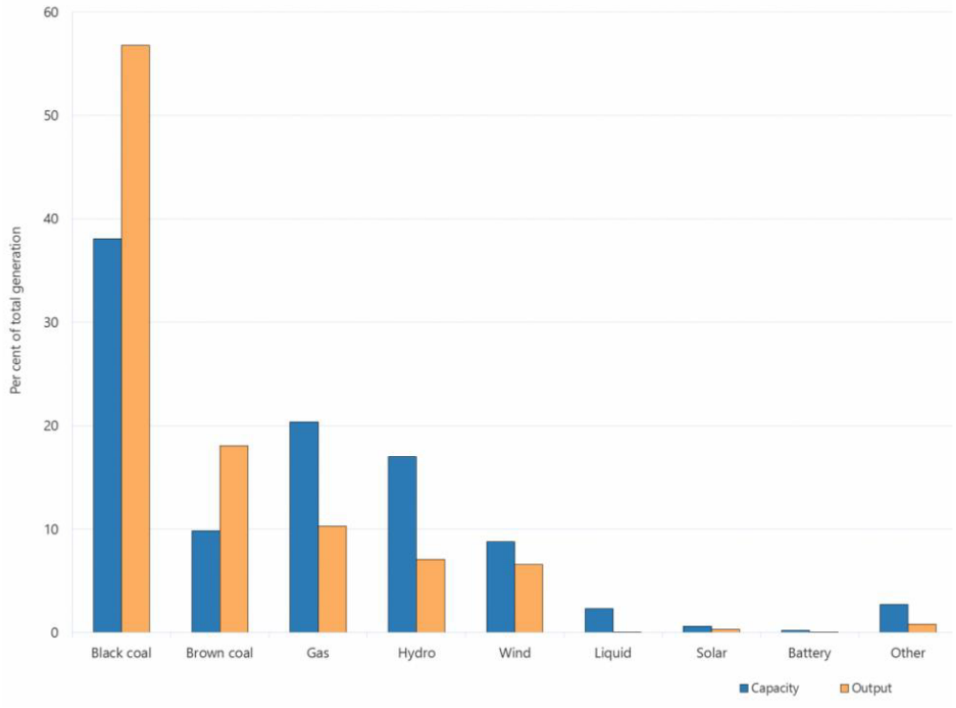

Figure 2 – National Energy Market (NEM) Generation capacity and output by fuel source[5]

2.1.2. Energy mix –future goals and national strategy

The Australian Government has ratified the Paris Agreement and has set a target to reduce emissions to 26–28% below 2005 levels by 2030. The target for the electricity sector is proportional. The Academy has noted that this target is significantly lower than the 45-65% target that Australia's Climate Change Authority has recommended as a responsible trajectory for Australia to avoid exceeding its share of the carbon budget implied by the goals of the Paris Agreement. The Academy has recommended that the Australian Government produce a roadmap to net-zero emissions across all sectors by 2050[6]. The Australian Government has not yet set long-term emission reduction targets. However, some state and territory governments have set targets for net-zero emissions by 2050.

Australia implemented a carbon pricing scheme in 2012 (and planned to transition to an emissions trading scheme in 2014-15) but this was repealed in 2014[7]. A Renewable Energy Target (RET) supports decarbonisation of the electricity sector. The original RET of 41,000 GWh by 2020 was reduced in June 2015 to 33,000 GWh. There is now enough new renewable energy project capacity under construction or already built to meet the RET.[8] The current Australian Government has ruled out extending the RET,

[5] Australian Energy Regulator (2018), Retrieved from https://www.aer.gov.au/wholesale-markets/wholesale-statistics/generation-capacity-and-output-by-fuel-source on 5 June 2018.

[6] ATSE (2017). Australia's Response to Climate Change. Available at https://www.atse.org.au/content/publications/policy/australias-response-to-climate-change.aspx

[7] See http://www.cleanenergyregulator.gov.au/Infohub/CPM/About-the-mechanism

[8] See http://www.cleanenergyregulator.gov.au/RET for more information about the RET.

and has also ruled out implementing a carbon pricing scheme, a carbon trading scheme, an emissions intensity scheme, or a Clean Energy Target[9] to replace it.

Other major government programs that support the clean energy transition include:

- The Clean Energy Finance Corporation (CEFC), which has committed more than $4.3 billion for projects worth over $11 billion (as at 30 June 2017).
- The Australian Renewable Energy Agency (ARENA), which has commitments of more than $1 billion matched by more than $2.5 billion in co-funding (as at 30 June 2017).
- The National Energy Productivity Plan, which aims to improve Australia's energy productivity by 40% between 2015 and 2030.
- The Government has also committed up to $110 million for a new concentrated solar thermal (CST) power plant in Port Augusta, South Australia.

2.1.3. Latest technologies facilitating the strategy

The Academy has produced policy statements discussing the potential role of different technologies and how their development could be supported. However, overall the Academy argues that a technology-neutral, outcomes-focused approach to policy for the sector is appropriate to facilitate an efficient transition and enable innovative solutions. Some key examples of sustainable technology development and deployment, and relevant ATSE policy statements are briefly described below.

Hydropower energy

Hydropower contributed 5.7% of electricity generated in 2017[10]. Historically it has contributed significantly more than other forms of renewable generation, but it is now being challenged by wind energy. Opportunities for the development of pumped hydro systems are currently receiving a lot of attention. This is discussed further in the answers to questions about storing electricity, below.

Wind energy

Wind energy accounting for about 5.7% of total energy generation in 2017. A total of 4,816 MW of capacity has been installed across Australia and there were a further 15 new wind farms under construction or financially committed at the beginning of 2018[11].

Solar Photovoltaics

Australia currently has the highest per-capita deployment of residential solar PV in the world with approximately 1.8 million installations, providing over 6 GW of generation capacity[12].

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[9] As recommended by the Independent Review into the Future Security of the National Electricity Market (Finkel et al., 2017). https://www.energy.gov.au/publications/independent-review-future-security-national-electricity-market-blueprint-future.

[10] Clean Energy Council (2018). 2018 *Clean Energy Australia Report.*

[11] Clean Energy Council (2018). 2018 *Clean Energy Australia Report.*

[12] https://www.energycouncil.com.au/media/11188/australian-energy-council-solar-report_-january-2018.pdf

Furthermore, ARENA ran a targeted competitive funding round for large scale solar in 2016, which helped 12 new solar projects reach financial close and enabled the large-scale solar industry to grow from zero to 20 plants within only five years[13].

In 2015, the Academy published a policy statement on *Enhancing Australia's Solar Photovoltaic Advantage*.

Concentrated Solar Thermal (CST)

Australia has only limited deployments of CST, with two relatively small plants currently operating in Queensland and New South Wales. A 150 MW CST plant in South Australia is expected to begin construction in 2018.

Marine Energy

Tidal and wave energy has significant potential, but is not yet a developed resource in Australia. Research activities and demonstration projects are underway to support further development of new marine energy technologies, such as Carnegie Clean Energy Technology's CETO 6 demonstration off the coast of Western Australia, and a 200 kW peak demonstration unit proposed for installation at King Island by Wave Swell Energy.

Nuclear Energy

Nuclear energy technology is prohibited in Australia. The Academy has recommended that nuclear energy be considered as an option to support deep decarbonisation of Australia's electricity sector[14] but notes that nuclear energy faces significant economic, social and political challenges in Australia. See also ATSE's 2014 Action Statement on Nuclear Energy.

2.1.4. Phasing-out technologies

Australia currently has no policy to phase out any existing generation technologies. To ensure efficient and flexible policy that can support innovation, the Academy supports technology-neutral policy design. A well-designed emissions policy focusing on outcomes should efficiently drive decarbonisation of the sector without discriminating between specific technologies.

[13] https://arena.gov.au/news/arenas-perfect-score-large-scale-solar-12-12/

[14] https://www.atse.org.au/atse/content/publications/policy/nuclear-energy-is-an-option.aspx

2.2. Carbon Capture and Storage (CCS): binding carbon dioxide (CO_2) emissions when dealing with carbon

2.2.1. Status quo and relevance for the country

Australia has significant CO_2 geological storage potential. In 2017, Australia had one large scale CCS facility constructed on Barrow Island for the Gorgon LNG project[15], which is expected to be commissioned in 2019. Major CCS Projects are under evaluation in Victoria (CarbonNet) and Queensland (CTSCo). The CO2CRC Otway demonstration project has been successfully storing small quantities of CO_2 since 2006 and will commence a major new phase of R&D in 2019.

2.2.2. Challenges, future plans/strategies

The Academy published an Action Statement, *Deep reductions in emissions using CCS*, in 2017. The statement argues that "as long as fossil fuels are used for energy and industrial processes, carbon capture and storage is an essential technology to limit emissions and keep the global rise in temperature to well below 2 °C."

The Australian Government has indicated support for carbon capture and storage (CCS) to capture emissions from power plants and industrial sites. It has introduced a Bill to the Parliament to remove the CEFC's prohibition from investing in CCS technology. Initiatives such as the CarbonNet Project and the CO2CRC are also supporting the development and demonstration of CCS in Australia.

The single biggest impediment to the uptake of CCS is the lack of long term clean-energy policy in Australia and elsewhere. The Academy notes that obtaining a social license for CCS may be challenging as some consider CCS to be an expensive and inefficient investment that will prolong the life of fossil fuel assets and undermine efforts to decarbonise the electricity system. However, CCS is essential if natural gas is to be used as a transition fuel as many projections and governments propose.

2.2.3. Latest technologies facilitating the strategy

A Japan-Australia pilot-scale brown coal to hydrogen project (HESC) is under development in Victoria, with CCS seen as a pivotal technology.

Investigations are underway into the use of CO_2 to produce useful products. CO_2 in enhanced oil recovery (EOR) is the major use of CO_2 at present and the technology is receiving increased attention in Australia

[15] When fully operational the Gorgon CCS project is intended to bury between 3.4 million and 4 million tonnes a year of carbon dioxide, injecting it into a saline aquifer more than two kilometres underneath Barrow Island. Chevron says it will cut greenhouse gas emissions from Gorgon by about 40%.

3. Distributing electricity – Grids

3.1. Status quo – current national situation

The Australian electricity supply network has significantly different characteristics to those in most other developed countries, being isolated, relatively sparse and extending over great distances. It features four main electricity grids and many remote 'island' grids. Figure 3 shows the transmission lines that form the backbone of Australia's electricity networks.

The main grid, which covers the east and south east of Australia, is referred to as the National Electricity Market (NEM). The NEM incorporates around 40,000 km of transmission lines and supplies about 200 terawatt hours of electricity each year. It features (limited) interconnection between Queensland and New South Wales, New South Wales and Victoria, and Victoria to both South Australia and Tasmania. The majority of the transmission network uses alternating current (AC) transmission infrastructure. However, there are a few examples of using high voltage direct current (HVDC) technology, the most notable being the 290 km submarine HVDC Basslink interconnection between Victoria and Tasmania.

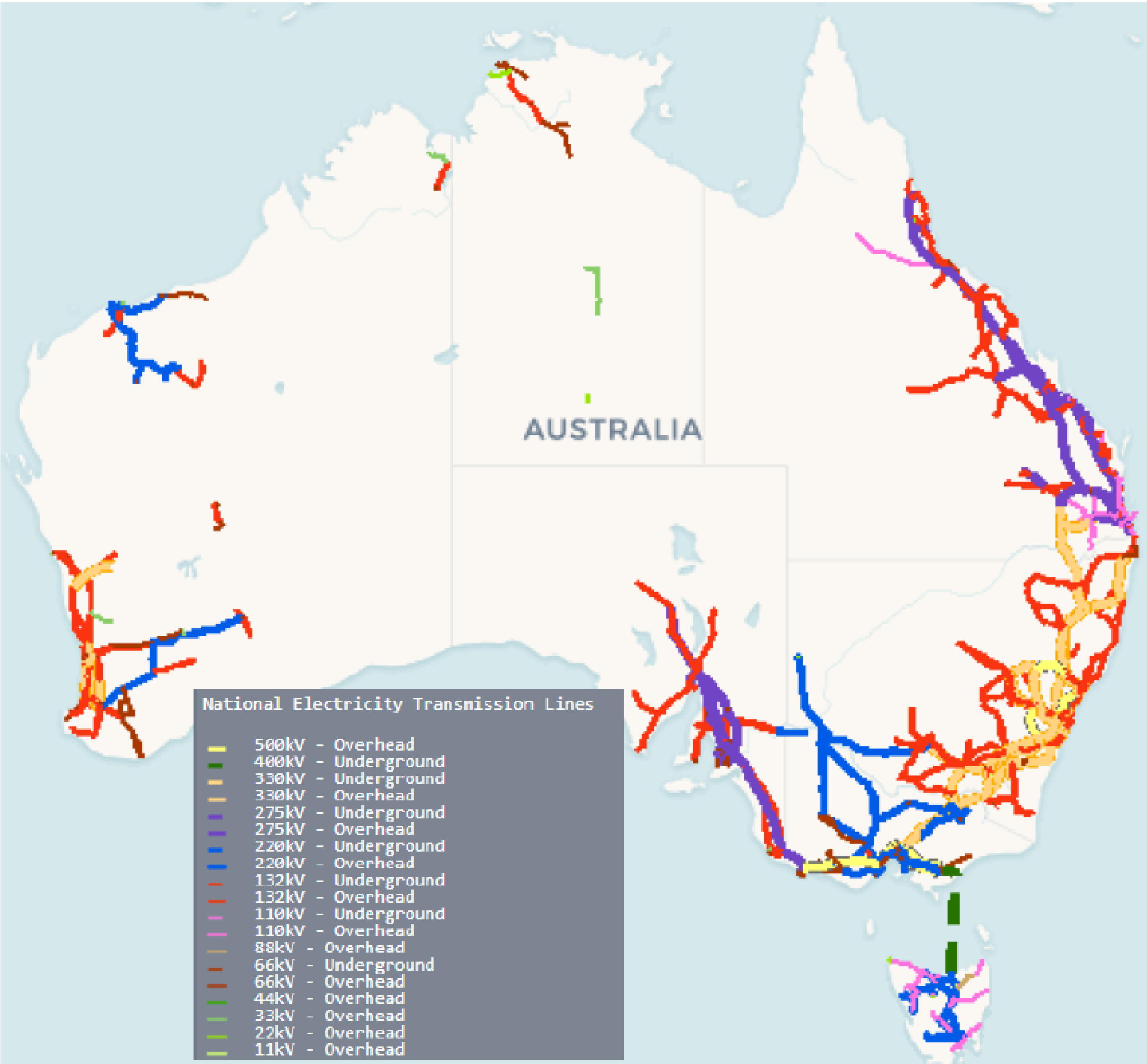

Figure 3 – National ElectricityTransmission Lines (http://nationalmap.gov.au/renewables/)

3.2. Challenges, future plans/strategies

Much of Australia's investment in renewable energy production has occurred in 'fringe of grid' locations, with lower network voltages and system strength. This poses a challenge for the operation of the grid and poses a limit to connections, which can limit investment in renewable energy generation. The operator of the NEM, the Australian Energy Market Operator (AEMO) is currently preparing an Integrated System Plan[16]. The development of this plan was one of the recommendations in the *Independent Review into the Future Security of the National Electricity Market: Blueprint for the future*[17]. The Review recommended that the plan should:

- *Identify and map prospective renewable energy zones across all NEM regions, including but not limited to wind, solar, pumped hydro, and geothermal resources.*
- *Identify transmission network routes to efficiently connect the renewable energy zones to the existing network, including routes for interconnectors that pass through these areas.*
- *Include a high-level assessment of the relative economics of different zones, taking into account the quality of the resource, approximate cost of connection, network impacts and other relevant considerations. This will enable the classification of zones according to how prospective they are and inform future decisions about the order in which to develop the transmission network.*

3.3. Latest technologies facilitating the strategy

The Academy published a policy statement, *Intelligent Electricity Networks for the Future* (2014), which stated that "Australia needs intelligent electricity networks and enabling policy frameworks to ensure that future electricity supply systems provide efficient, affordable and low-emission energy to the Australian economy."

A key challenge in modern electricity networks is to manage and optimize multidirectional flows of energy, information and payments in a distributed energy system. Companies such as Reposit Power and GreenSync are developing platforms to drive enhanced integration of distributed energy resources such as residential and commercial solar and battery systems. Other relevant initiatives include the demand response initiative run by AEMO and ARENA to help manage peak demand; the South Australian Government's virtual power plant project; and microgrid trials occurring across the country.

Opportunities for network and other non-generation technologies to help provide grid security and reliability are being investigated. The *Electricity Network* Transformation *Roadmap* developed as a partnership between Energy Networks Australia and CSIRO in 2017 states that "there are a range of technical solutions to achieve inertia and frequency management outcomes. For example, these include the use of synchronous condensers, large scale batteries, flywheel technology and emulated inertial responses from wind farms. Additionally, the distribution system is also a potential source of new ancillary services to support transmission-level system stability".

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[16] See https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan

[17] Also commonly referred to as the Finkel Review. See https://www.energy.gov.au/government-priorities/energy-markets/independent-review-future-security-national-electricity-market

4. Storing electricity

4.1. Status quo – current national situation

There is currently only a limited amount of energy storage connected to Australia's electricity grids. The Tumut-3 Power Station, which was completed in 1973 and upgraded in 2012, is Australia's largest pumped hydro station. It is part of the Snow Mountains Hydroelectricity scheme in New South Wales. There is also a 240 MW facility at Shoalhaven in New South Wales (which is slated for expansion by 2021-22[18]), and a 500 MW facility at Wivenhoe Dam in Queensland.

Research undertaken at Australian National University and led by one of ATSE's Fellows identified 22,000 potential pumped hydro sites across Australia. In 2017, the world's largest lithium-ion battery facility, the 100 MW/129 MWh Hornsdale Power Reserve (HPR), was installed in South Australia.

Australia has also seen significant growth in household storage. In 2017, 12% of new PV installations in 2017 included a battery, up from 5% in 2016. It is estimated that 28,000 battery systems had been installed across Australia by the end of 2017[19].

4.2. Challenges, future plans/strategies

ATSE released a policy statement, *Advancing Energy Storage in Australia*, in 2015. The Academy was also a key contributor to an Australian Council of Learned Academies (ACOLA) Horizon Scanning project on *The Role of Energy Storage in Australia's Future Energy Supply Mix*, which was released in 2017. Many Australian governments have announced support for energy storage research, trials, and/or projects. Major energy storage projects and initiatives include:

- Snow Hydro 2.0, a pumped hydro project that intends to increase the federally owned Snowy Mountains Scheme's generation capacity by up to 2,000 MW, and provide approximately 350 GWh of energy storage at full capacity;
- The Battery of the Nation initiative which is investigating opportunities to boost the hydropower system in Tasmania including with pumped hydro energy storage;
- Hydrogen production and storage trials in the Australian Capital Territory and South Australia;
- ARENA's Hydrogen Funding Round, which is allocating $20 million to accelerate the development of a potential renewable energy export supply chain;
- The Victorian Government's energy storage initiative, which is supporting the installation of two grid scale battery systems, one integrated with a solar farm and one supporting grid stability including power supply and frequency control services at a critical substation; and
- The Kidston Pumped Storage Hydro Project, which will be the first in the world to use abandoned gold mine pits for its reservoirs.

[18] See https://www.afr.com/business/energy/hydro-energy/origin-energy-keen-to-double-nsw-pumped-hydro-project-20180506-h0zpgr

[19] Clean Energy Council (2018). 2018 *Clean Energy Australia Report.*

4.3. Latest technologies facilitating the strategy

As outlined above, Australia is pursuing multiple technology options for energy storage with trials and demonstration projects for both hydrogen storage and grid scale batteries, as well as investment in pumped hydro systems.

The ability of energy storage systems to supply network services is clearly demonstrated by the Hornsdale Power Reserve which, as of May 2018, has already taken a 55% share of the South Australian frequency control and ancillary services (FCAS) market, and lowered prices in that market by 90%[20]. Most of the existing and planned utility scale battery systems in Australia are lithium-based chemistries, but other chemistries such as vanadium or other flow chemistries are likely to increase in adoption, particularly as prices drop due to increasing global demand for these systems.

[20] See https://reneweconomy.com.au/the-stunning-numbers-behind-success-of-tesla-big-battery-63917/

Canada Contribution: CAE

Canadian Academy of Engineering
Robert L. Evans

1. Going towards an all-electric society?

Canada is a very large country geographically, with varying sources of energy across the country. Energy policy is primarily the purview of the 10 provinces and 3 territories, although the federal government is involved in the overall coordination of energy policies through Natural Resources Canada. With large differences in primary resources across the country the geographical mix of energy supply varies widely from province to province. For example, fossil fuel production takes place primarily in Alberta and Saskatchewan, while British Columbia, Quebec and Newfoundland have large hydroelectric generating facilities. Some regions of the country will therefore be prepared to go “all-electric”, with British Columbia and Quebec being best-placed to move to a primarily renewable-electricity model primarily using hydropower. The availability of large hydroelectric capacity is particularly beneficial for those provinces, since the accompanying large hydro storage reservoirs results in dispatchable renewal energy, which is much more valuable than intermittent sources such as wind and solar power. On the other hand, those provinces with large fossil fuel resources, such as Alberta and Saskatchewan, will likely resist a complete phasing out of fossil fuels since they derive significant revenues from these resources.

Although Canada is not at the forefront of manufacturing electric vehicles, there is considerable interest from the general public in replacing the existing fleet of fossil-fuelled vehicles with hybrid-electric vehicles in the short-term and all-electric vehicles in the longer term. Electric vehicles are particularly attractive to many Canadians who benefit from some of the lowest electricity prices in the world due to the large installed hydroelectric capacity. As electric cars become more efficient, and are designed to have a longer range, they will be increasingly used by consumers, primarily in large urban centres with widespread charging facilities. With much of the country experiencing long cold winters, however, the penetration of electric cars in rural communities is likely to be more limited since driving distances are longer and significant energy is required for heating during the long winter months.

The use of electricity for domestic heating will likely also increased substantially in the coming years, again due to the relatively low cost of electricity generation in most parts of the country. Although pure electric resistance heating has been popular for some time in provinces with large hydroelectricity resources and low electricity prices, in the future there will most likely be more widespread use of heat pumps which are much more efficient and can be used in reverse to provide cooling in those parts of the country, such as Ontario and Quebec which have high summer temperatures and humidity. In summary, Canada will most likely move to significantly greater use of electricity for transportation and domestic heating, although fossil fuels will still be needed for large commercial vehicles as well as for air transportation and the significant marine transportation infrastructure on both the West and East coasts of the country.

2. Generating electricity

2.1. Generating electricity from sustainable resources

2.1.1. Status quo: current national energy mix

As seen in Figure 1, two-thirds of Canada's primary energy supply is provided by fossil fuels, while one-third is provided by non-fossil fuel sources. This is primarily due to the large installed hydroelectric capacity and nuclear generation facilities in Ontario.

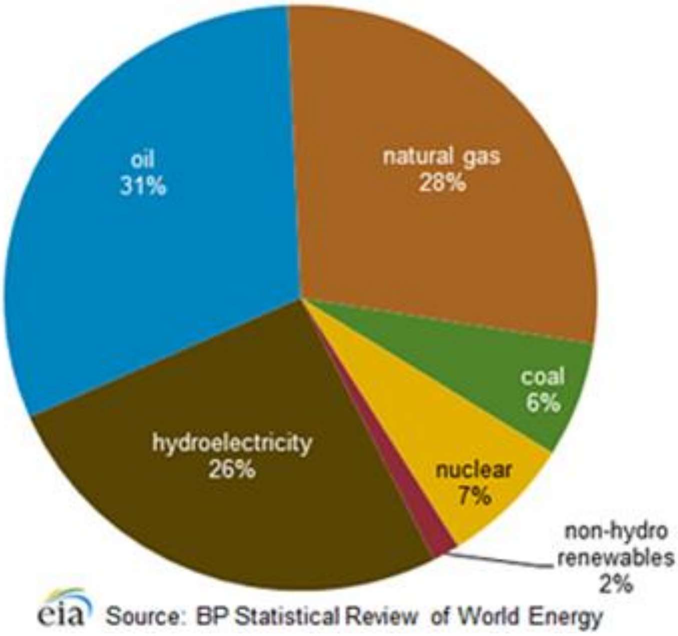

Figure 1 - Canada's Energy Consumption by Source, 2014

2.1.2. Energy mix –future goals and national strategy

Canada is fortunate to have large regions with substantial potential for more hydroelectric generation, particularly in the provinces of British Columbia, Manitoba, Quebec and Newfoundland. There will likely be a few new large hydroelectric facilities built in these provinces over the next several decades, although it is getting increasingly more difficult to get public "buy-in" to some of these very large projects which may flood large areas of land. There will likely also be significant development of new wind energy generating facilities, particularly in those provinces without potential hydroelectric facilities. The expansion of solar energy is likely to be fairly modest, as the potential is somewhat limited in a high-latitude country such as Canada.

2.1.3. Latest technologies facilitating the strategy

The use of either hybrid or fully-electric vehicles is expanding quite rapidly as they become a more mainstream product. These are particularly attractive in those parts of Canada which have very low electricity prices due to the widespread use of hydroelectric power. This, together with financial incentives for the purchase of electric vehicles in many provinces is helping to increase the penetration of fully electric and hybrid light-duty vehicles across the country. Again, however, the rather harsh winter conditions in the central parts of Canada may limit the widespread adoption of electric vehicles in these provinces.

2.1.4. Phasing-out technologies

In those provinces which have traditionally used coal to generate electricity, these facilities are gradually being phased out as they come to the end of their useful life. In most cases they will be replaced by a mix of natural gas-fired power plants and low-carbon facilities such as hydro, wind and solar power. There will likely be some pressure from those provinces without a large hydroelectric power potential to replace aging coal-fired power plants with new gas-fired ones

2.2. Carbon Capture and Storage (CCS): binding carbon dioxide (CO_2) emissions when dealing with carbon

2.2.1. Status quo and relevance for the country

Canada has been at the forefront in building and operating CCS plants for several years. The first plant was the Boundary Dam CCS facility built to capture 1 million tons of CO_2 per year from a coal-fired power plant in Estevan, Saskatchewan. The captured CO_2 is than used to provide enhanced oil recovery at a nearby oil field in Weyburn Saskatchewan. This plant has been operating since late 2014 and has been the world's first commercial scale demonstration of CCS. Another commercial scale plant has been built by Shell at their Quest oil-sands upgrading project. This plant removes 1.2 million tons of CO_2 per year from the upgrader and then stores it in a deep saline aquifer nearby. Two other CCS projects are also being developed. These include a plant in Fort Nelson, British Columbia, which will remove 2.2 million tons per year of CO_2 from a gas processing plant, and the Alberta Carbon Trunk Line project, which will collect up to 2 million tons per year of CO_2 from nearby facilities and use it for enhanced oil recovery in nearby facilities.

3. Distributing electricity – Grids

3.1. Status quo – current national situation

Electricity generation and distribution in Canada is a provincial responsibility, with each province operating its own utility. The provincial utilities also each operate their own transmission and distribution networks. However, the Western grids from British Columbia to Manitoba are synchronized, which enables power to be exchanged between the Western utilities. For example, British Columbia Hydro often imports power at night from the coal-fired plants next door in Alberta, enabling them to keep more water stored behind hydro dams. Since the British Columbia grid is connected and synchronized down the U.S. West Coast to California, British Columbia can then sell excess power generated by the stored water in its hydro facilities to California at premium rates. By using this arbitrage policy, B.C. Hydro can make several hundred million dollars each year, which then leads to reduced electricity prices for domestic customers. In a similar way, the very large hydroelectric facilities in the province of Quebec are connected with the U.S. states directly below the Canadian-U.S. border. Quebec Hydro is then also able to generate significant additional revenues by selling excess power to several U.S. utilities. This provides a very tangible demonstration of the benefit of having energy storage provided by large hydroelectric storage facilities.

3.2. Challenges, future plans/strategies

As Canada is a very large country geographically, there is not electrical connectivity across the whole country. However, the western provinces of British Columbia, Alberta, Saskatchewan and Manitoba do operate synchronized transmission systems with some ability to exchange power between these provinces. However, the western grid is not in phase with the Eastern grid network, which connects the province of Ontario with the neighboring provinces up to the East coast. There has been discussion about connecting the Western grids with the Eastern grids, but this would likely require a very large AC-DC-AC link at the Manitoba-Ontario border. B.C. Hydro is now building a new 900 MW_e hydro facility in Northern British Columbia, which will enable it to continue to supply renewable energy to meet all of the province's requirements for several years to come.

4. Storing electricity

4.1. Status quo – current national situation

Electricity storage in Canada is dominated by the many large hydroelectric facilities across the country. This enables the country to benefit from the ability to share electricity with nearby jurisdictions, both in Canada and in the United States, to the benefit of both. The storage of renewable electricity in this way provides Canada with a largely renewable electricity generation system.

4.2. Challenges, future plans/strategies

Canada will continue to expand the extensive hydroelectric storage facilities that already exist in several provinces. It is likely that new hydro storage facilities will also be built by a number of the provincial utilities. The additional storage provided by these facilities will help to expand the availability of electricity for transportation and other uses across the country.

China Contribution: CAE

Chinese Academy of Engineering
Peng Suping, Wei Yi-Ming

1. Going towards an all-electric society?

China has made strenuous efforts to address climate change as an important strategic task. An Intended Nationally Determined Contribution (INDC), including the target to lower carbon dioxide emissions per unit of GDP by 60–65% from the 2005 level and to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030, has been ratified by Chinese government[21]. As the largest coal consumer and the largest emitter of greenhouse gases, China is determined to phase out fossil-fuel based energy from its leading role and have green electricity generation as the primary energy source to achieve a clean and low-carbon energy-consuming mode in the future. Hence, electricity will play an important role in China's prospective energy system.

The power sector will be crucial to helping China meet these ambitious targets. China's electricity demand has grown at an annual average rate of 10.7% during the past decade. Meanwhile, installed capacity has more than quadrupled, from 320 GW to 1,650 GW from 2000 to 2016. Electric power in China presents the structural characteristics of "thermal power is given priority and hydroelectric power is supplemented"[22]. Due to the growth of stricter energy policies, the renewables are increasingly penetrating the power systems and leading to more clean energy with an average of 100 gigawatts annually of incremental installed capacities. By 2050, nearly 2,400 GW wind power and 2,700 GW solar power will collectively become the main power source of the future green electricity system under *China 2050 High Renewable Energy Penetration Scenario*[23].

In the transport sector, China has actually taken several steps toward vehicles decarbonisation through accelerating the deployment of electric cars. China aims to fully commercialize the electric vehicles market after 2025 through continuing policy supports, e.g., targeting deployment of 5 million EVs by 2020 and generous purchase incentives. In addition to hydrogen, the advanced biomass fuels – fuel ethanol, Biological jet fuel and bio-methane – have also made important contributions to ensuring the energy security of transport sector, effectively reducing the greenhouse gas emissions, and providing a long-term sustainable alternative to fossil fuels.

Besides electricity, coal, petroleum, and gas are also the main energy, which China depends on with uneven geographical distribution. A new electric transformation has been started facing the ecological civilization construction, coping new target of climate change and improving quality and effectiveness of power industry. The pace of reform in electrification will promote the energy structure adjustment and new energy industry development. However, some challenges become even more urgent; a series of countermeasures to promote a new round of reform in a combination of energy technologies will be formulated under the background of 'new normal' in China.

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[21] Wei Y-M, Han R, Liang Q-M, et al. An integrated assessment of INDCs under Shared Socioeconomic Pathways: an implementation of C 3 IAM. Natural Hazards, 2018, 92(2): 585-618.

[22] Wei Y-M, Liao H, Tang B-J, et al. China Energy Report (2016): Energy Market Research. Science Press Beijing, China; 2016.*(in Chinese)*

[23] *China 2050 High Renewable Energy Penetration Scenario and Roadmap Study* is performed by Energy Research Institute National Development and Reform Commission of China.

Conclusion: Electrification will be an important driving force for the green transition of China's energy system. However, most probably China is not on its way to an all-electric society. We can see a mix of technologies will play their important roles in future.

2. Generating electricity

2.1. Generating electricity from sustainable resources

2.1.1. Status quo: current national energy mix

Resource endowment in China is characterized by "rich in coal but lack of oil and gas", which makes coal power always dominate in China's electricity energy mix. In 2017, China owned cumulative coal-power installed capacity of 1.02 billion kilowatts, accounting for 58% of the total amount. In addition, hydropower, gas-fired generation, grid-connected wind power, grid-connected solar energy and nuclear accounted for 19, 5, 9, 7 and 2% respectively. In terms of electricity generation, coal power ranked first with annual generation of 420 billion kWh (shown in Fig. 1.).

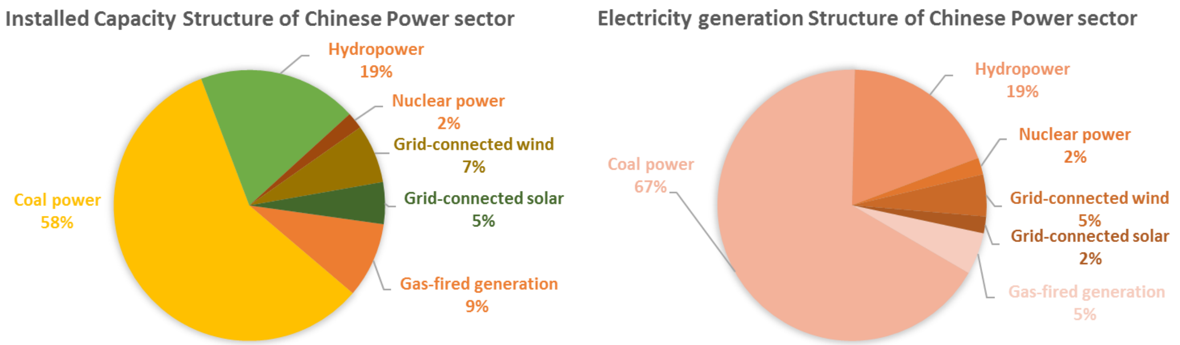

Figure 1 - Status quo of national power mix in China (2017)

Given China's vast territory and abundant resources, the power grid has been divided into six distinct regions, including Northeast, North, Center, East, Northwest and South regions. Figure 2 shows a significant difference in their power structure and demand due to geographical location. Coal is the leading fuel for generating electricity in all regions, while hydropower has been more installed in Center and South region compared to other areas. Wind and solar energy, accounting for about 29% of the regional electricity production, are mostly distributed in the Northwest. And the installed nuclear power capacities are mainly located in the coastal area of East and South.

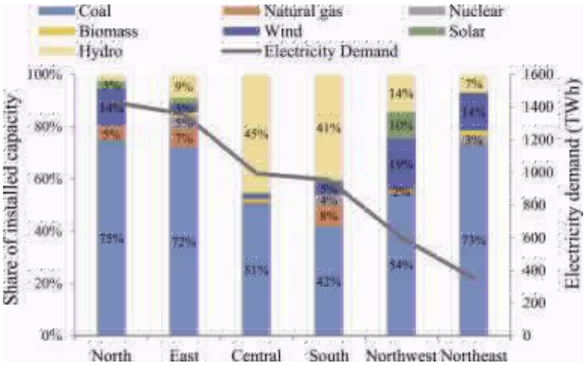

Figure 2 China's electricity generation structures and power demands of six regions in 2015[24]

2.1.2. *Energy mix –future goals and national strategy*

Chinese government has issued a series of green development policies to promote the clean transition of power sector. The policy targets are mainly embodied in energy and electricity planning, energy conservation, emission reduction and mitigation of climate change, including non-fossil generation targets, energy saving targets and low-carbon development targets. Figure 3 gives further details on key policies and their time frame.

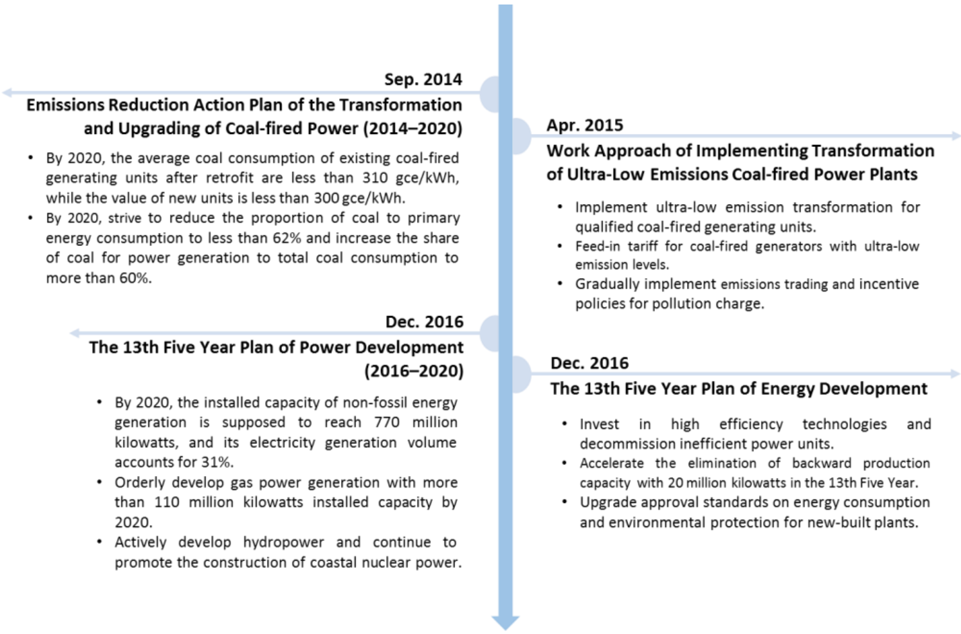

Figure 3 - Related policies on green development of China's power industry in recent five years

Furthermore, China has announced that its carbon emission will peak by 2030 in the 'U.S.-China Joint Announcement on Climate Change'. And whether the CO_2 emissions in the power industry can peak by 2030 or not strongly affects the peaking time of total carbon emissions in China. Previous studies show that only the accelerated development of clean generation technologies can make power sector reach its peak in 2030 or before[25].

[24] Image source: Tang B-J, Li Ru, Yu B-Y, An R-Y, Wei Y-M. How to peak carbon emissions in China's power sector: A regional perspective. J Energy Policy, 2009, 120: 365-381.

[25] Wei Y-M, Liu L, Liao H, et al. CO2 Emissions and Low Carbon Development in China. Science Press Beijing, China; 2017.*(in Chinese)*

2.1.3. *Latest technologies facilitating the strategy*

In terms of thermal power in China, optimizing the structure of thermal power units can help achieve green development strategy. The government always regards the adoption of efficient and energy-saving power generation technologies as a necessary solution to reduce emissions. Latest high-profile technologies mainly involve supercritical coal technology more than 300 MW, ultra-supercritical units more than 600 MW, circulating fluidized bed units, Natural Gas Combined Cycle and Integrated Gasification Combined Cycle[26]. Besides, vigorous development of non-fossil energy generation technology is also one of the main measures for the low-carbon transformation. A series of policies have been issued to promote the development of renewable generation technology such as renewable portfolio standard or mandatory market share for renewables, feed-in tariff and environmental dispatch order.

In China, imperfect market regulation and the uneven distribution of nature resources are deemed as the prime bottlenecks in development of China's renewable power. For example, hydropower resources are mainly distributed in the South, and wind power resources are mainly abundant in the Northwest and coastal areas. Therefore, long-distance transmission becomes a struggle for power grid and existing immature technologies also lead to a large amount of wind power off the grid[27]. Photovoltaic system, simultaneously, is not suitable for large-scale power generation at present, which is limited to small scale utilization and difficult to form scale in a short time. Most importantly, renewable power generation has the disadvantages of intermittence and randomicity, which will bring challenge to the safety and stabilization of power grid and then restrict the scale of renewable power development.

2.1.4. *Phasing-out technologies*

Aiming at the problem of excessive power supply, the 13th Five Year Plan of Power Development points out that we should strive to phase out over 20 million kilowatts of inefficient and small thermal power and actively develop non-fossil energy during 2010 to 2020. Obsolete technologies here mainly refer to conventional pulverized coal technology less than 300 MW, subcritical coal technology less than 300 MW and supercritical coal technology less than 300 MW.

2.2. Carbon Capture and Storage (CCS): binding carbon dioxide (CO_2) emissions when dealing with carbon

2.2.1. *Status quo and relevance for the country*

How to ensure energy security in the transition from traditional energy sources to clean energy is a common challenge faced by many countries. CCS technologies can realize the large-scale low-carbonization utilization of traditional fossil energy, and provide an important technology choice for the transformation. China has given active attention and vigorous support to the development of CCS technologies, and has carried out a series of work to promote the development of CCS technologies[28]. Over the past decade, CCS technologies have shown a trend of accelerated development on a global scale

[26] Chen H, Kang J-N, Liao H, Tang B-J, Wei Y-M. Costs and potentials of energy conservation in China's coal-fired power industry: A bottom-up approach considering price uncertainties. Energy Policy, 2017, 104: 23-32.

[27] Wei Y-M,Wu G,Liang Q-M, et al. China Energy Report (2012): Energy Security Research. Science Press Beijing, China; 2012.*(in Chinese)*

[28] Zhang X, Fan J-L, Wei Y-M. Technology roadmap study on carbon capture, utilization and storage in China. Energy Policy, 2013, 59: 536-550.

from a little-known technical concept to numerous industrial-scale demonstration projects; CCS technologies have gradually begun to play a role in the clean use of traditional energy sources.

2.2.2. Challenges, future plans/strategies

It must be noted that factors such high costs, high energy consumption, and unclear long-term safety have always restricted the development and promotion of CCS technologies worldwide. At present, many CCS demonstration projects are faced with challenges such as financing difficulties and decreased attention. In order to promote the rapid development of CCS technologies, the following three principles are needed to be fully considered[29]:

Firstly, the political will of cohesive development of CCS technologies should be closely integrated with their respective national conditions and development goals.

Secondly, CCS technologies should be given the same treatment with other clean energy technologies to promote its innovation, development and demonstration.

Thirdly, there is a need for an increased focus on the exchange of technical achievements and R&D experience.

2.2.3. Latest technologies facilitating the strategy

Recently, China has boosted efforts on CCS demonstration for coal-fired power plants including post-, pre- and oxy-combustion technologies. It is worth mentioning that the Huaneng GreenGen Project has solved the technical difficulties of integrated gasification combined cycle with pre-combustion capture taking the leading position in the world.

3. Distributing electricity – Grids

3.1. Status quo – current national situation

The State Grid in China consists of five regional power grids and cross-regional AC/DC transmission systems. Among them, the North China Power Grid and Central China Power Grid are connected by the synchronous UHV AC technology, while the others are connected by asynchronous DC systems. Recently, with the rapid growth of power need and development of power industry, the 500 kV power transmission system has been main power system network in China, while the voltage level of the main grid in the Northwest has been 750 kV.

3.2. Challenges, future plans/strategies

To establish the "smart grid + clean energy" which completes the "Belt and Road Initiative" and promotes the development of global energy connectivity and cleanliness, the Global Energy Interconnection Development and Cooperation Organization proposes that it is expected to achieve domestic interconnection by 2025 and realize energy interconnection within each continent by 2035. Hence, it determines the necessity of building the long-distance, large-capacity, and high voltage transmission system and needs continuous innovation of UHV transmission technologies.

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[29] Wei Y-M, Liao H, Tang B-J, et al. China Energy Report (2008): CO_2 Emissions Research. Science Press Beijing, China; 2008.*(in Chinese)*

3.3. Latest technologies facilitating the strategy

The acute imbalance between supply and demand of safe stable energy determines UHV technology has been playing an increasing role in power system in China. By the end of 2017, China has already built eight 1,000 kV UHV AC projects and eleven ± 800 kV UHV DC projects.

The UHV project with one AC line and three DC lines is continuing to push forward, and GIL (Gas Insulated Transmission Lines) will be used to cross through the Yangtse River. What's more, the government continue to make great R&D investment in a higher voltage AC transmission technology of ± 1,100 kV.

The future challenge is how to make transmission lines afford greater capacities and longer transmission distances as well as suited for extreme weather conditions to ensure the operational safety of power grid.

4. Storing electricity

4.1. Status quo – current national situation

Energy storage technology is crucial to promote large-scale development of renewable energy utilization, chip peak demand off and fill valley up, and ensure economic performance of power grid. Since 2014, China has given more attention to the energy storage industry and includes energy storage technology as a preferred low-carbon technology for tackling climate change. By 2017, the total capacity of energy storage was 28.9 GW among which pumped storage station occupied the highest application proportion of nearly 99%. LiB and PbAB are the two most installed technologies considering electrochemical energy storage.

When it comes to the application areas of newly-added energy storage projects, it is not difficult to find that energy storage devices are mainly installed in consumer side with a share of 59% and centralized grid-connected renewable energy generation accounting for 25%. The phenomenon is caused by the great promotion of policies on demand side response and power consumption structure optimization.

4.2. Challenges, future plans/strategies

Currently, energy storage industry in China is gradually commercialized from demonstration project stage. But high costs of storage devices are far over the current electrovalence which hinder the development of storage technologies to a large extent. Besides, some core technologies are still behind the world advanced level, e.g., the high load compressor technology of CAES, the advanced battery technologies, bearings and high strength composite material of FWES and so on. In addition, there is also a lack of perfect incentive policies such as the subsidy mechanism and preferential policy.

To break through the above bottlenecks, we need strengthen research of core technologies and achieve scale economic early through an increase in market maturity and a reduction in the cost. Meanwhile, reasonable tax subsidy and feed-in tariff mechanisms are urgent to be perfected by the national and regional government.

With the vigorously support of government, it is predicted that energy storage capacity of China will exceed 100 GW by 2020. Among them, 70 GW is PSS and 30 GW is other energy storage technology including CAES, various chemical energy storage systems, etc.

4.3. Latest technologies facilitating the strategy

Considering the non-pumped storage, lithium-ion battery has the highest annual reduction rate of cost up to 10% which promotes its development and demonstration, making it the mainstream technology of energy storage battery in the next 5 years. Besides, the unit volume of sodium-sulfur battery has higher effective power and can release more power in a short time. Due to its high temperature at runtime, improving operational reliability has become another development direction of this technology in addition to reducing costs. Additionally, the flow battery is characterized by larger capacity, higher reliability and longer lifetime, which can be used for high-capacity charge and discharge. It is presumed to be the preferential choice for large-scale energy storage application in the future.

From the perspective of technology itself, the breakthrough of key energy-storage elements will affect the overall development of energy storage industry. Accordingly, it is crucial to devote more efforts to prolonging the service life, improving the energy density, shortening the charge time and greatly reducing the cost under the premise of safety and reliability.

Czech Republic Contribution: EA CR

Engineering Academy of the Czech Republic,
Stanislav Mišák

1. Going towards an all-electric society?

The Czech Republic has prepared long-term energy vision that ensures reliable, secure and environmentally-friendly supplies of energy to meet the needs of the population and economy of the Czech Republic, at competitive and acceptable prices under standard conditions. It must also secure uninterrupted energy supplies in crisis situations to the extent necessary to ensure the functioning of the main components of the state and the survival of the population. This vision is summed up in the three top strategic energy objectives, which are security – competitiveness – sustainability.

The strategy is based on the specific natural, economic and social conditions of the Czech Republic in the context of development in Europe and formulates basic strategic objectives in compliance with the European Union's long-term energy strategy focused on decarbonisation, high security of supply and competitive energy prices.

Fulfillment of these objectives is managed by the following individual action plans: Smart Grids; Clean Mobility; Energy Efficiency; Energy from Renewable Sources; Biomass; and Development of Nuclear Energy in the Czech Republic.

2. Generating electricity[30]

2.1. Generating electricity from sustainable resources

2.1.1. Status quo: current national energy

Current situation and state of the domestic energy sector mix

In recent years the Czech Republic has made noticeable progress in the field of energy, improved its energy policy and climate protection policy, as well as its progress in ensuring oil and gas security, its steps forward in the liberalization of the electricity market and the contribution it has made towards the development of the electricity market in the whole of the Central European region. However, at the same time Czech Republic is obliged to implement policies relating primarily to energy efficiency. The Czech transmission system is closely connected up with all neighboring states. The sum total available transmission capacity in relation to the Czech Republic's maximum load is more than 35% for exports and 30% for imports, and there is increasing transit in the north-south direction, equivalent to up to 30% of maximum load.

The Czech Republic has also made progress in reducing the impact the energy sector and industrial production have on the environment. It is, however, important to bear in mind that CO_2 emissions are not a key indicator for the environment of the Czech Republic and the health of its inhabitants. Reduc-

[30] State energy policy of the Czech Republic. Czech Ministry of Industry and Trade, Dept. 32400, Prague, Dec. 2014. Updated version approved on 18. May, 2015.

ing CO_2 emissions is primarily a political commitment of the EU and therefore also of the Czech Republic and has no direct impact on the health of the population of the Czech Republic. Critical factors here are local emissions of airborne dust, which absorb harmful chemicals and enter the body in concentrated form. Other factors are primarily SO_2 and NO_x emissions. These emissions are a significant burden on public health result mainly from (local) inefficient combustion of solid fuels, including parts of biomass, and from transport.

Almost 50% of the consumption of primary energy sources in the Czech Republic is covered from domestic sources. The import energy dependence indicator of the Czech Republic (including nuclear fuel) is therefore roughly 50%, one of the lowest in the whole of the EU.

The Czech Republic is fully self-sufficient in its production of **electricity and heat**. The structure of its electricity sources is stable. The most significant change in the last decade has been the construction of the Temelín nuclear power plant. As a result of support for renewable energy sources in the past there has been an increase in the proportion of renewable resources other than hydro power plants, yet so far, despite high subsidies, this has not succeeded in replacing a more significant proportion of fossil fuels. The proportion of **heat production** from domestic fuels is around 60% and more than 80% in heat supply systems. The Czech Republic has done well in introducing combined heat and power, while in the case of large and medium sources the proportion of cogeneration is almost 70% of total gross heat production.

The remaining coal stocks should be used in the most effective and environmentally-friendly manner possible

Nuclear sources now supply over 33% of all electricity produced. Another important source of energy in the Czech Republic is **natural gas**, used for the generation of electricity or for district and individual heating.

Gas storage facilities are connected up with systems in neighboring countries which proved beneficial. When natural gas supplies from the Russian Federation through Ukraine were restricted and interrupted there was no need to impose any restrictions on supplies to end customers.

The potential of energy from renewable resources is limited by the natural conditions of the Czech Republic (climate, geology and soil) and the environmental protection requirements (soil, water, landscape character, flora and fauna).

During the period in question there is a rising trend in the total proportion of renewable energy sources. This trend partly reflects efforts to make the maximum possible use of this domestic energy source assuming its economic return, and also the effort to minimize the impact on the state budget and the populace. Development in this field will be primarily due to the gradual increase in competitiveness as compared with conventional sources of energy.

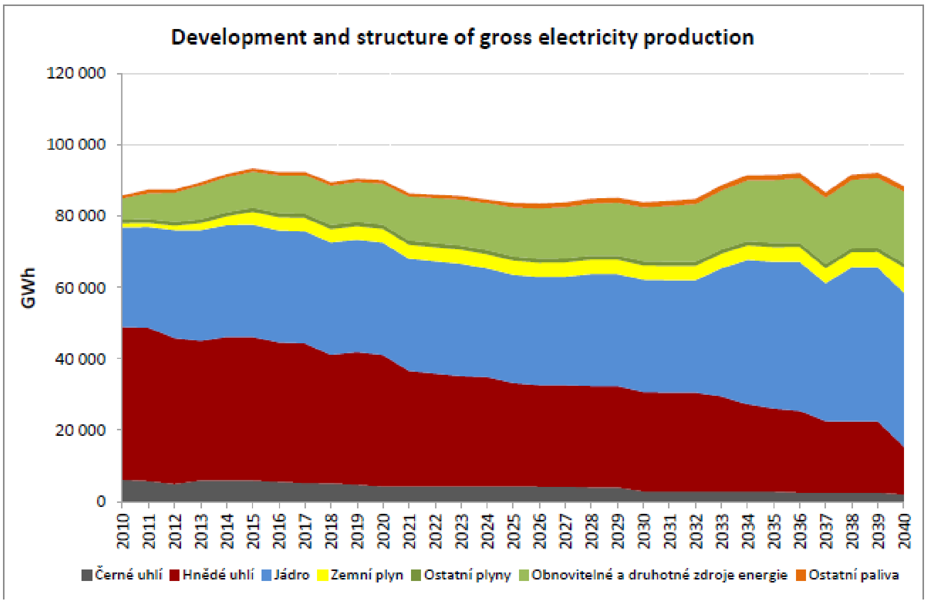


Figure 1 - Description downwards: Other fuels | RE |Other gases | Natural gas | Nuclear| Brown coal| Black coal

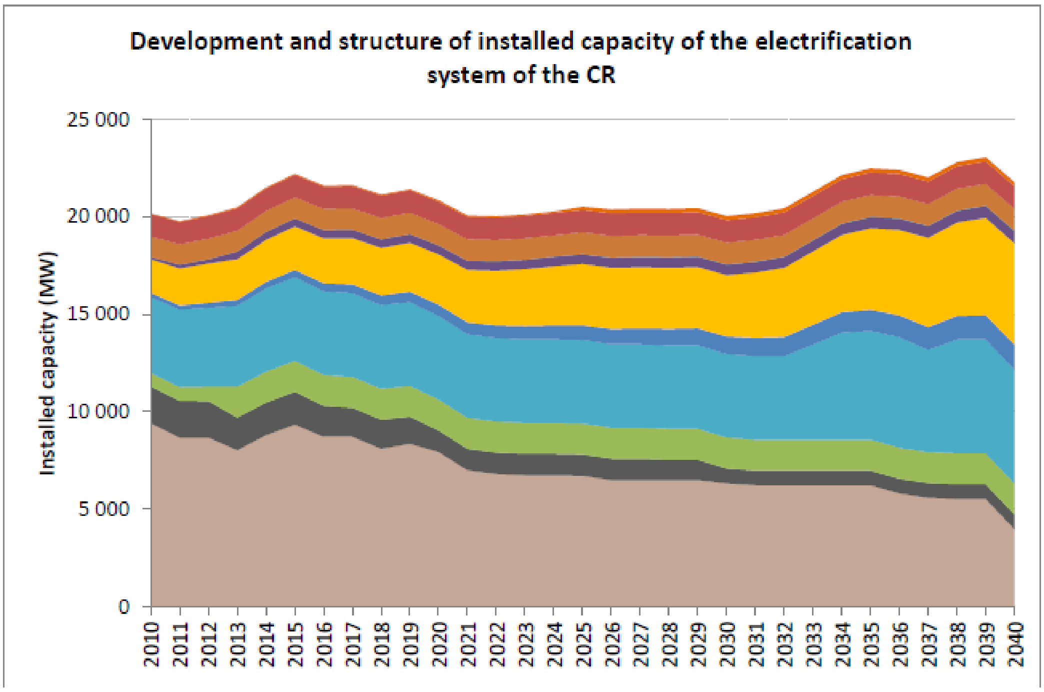


Figure 2 - Description downwards: Waste incinerators|Hydro|Wind|Photovoltaic|Biogas|Nuclear|Natural gas|Black coal **|** Brown coal

This means that due to the new capacities of RES the available capacity of sources will not increase any further.

2.1.2. Energy mix, future goals and national strategy

The future development of electricity production is anticipated as follows:

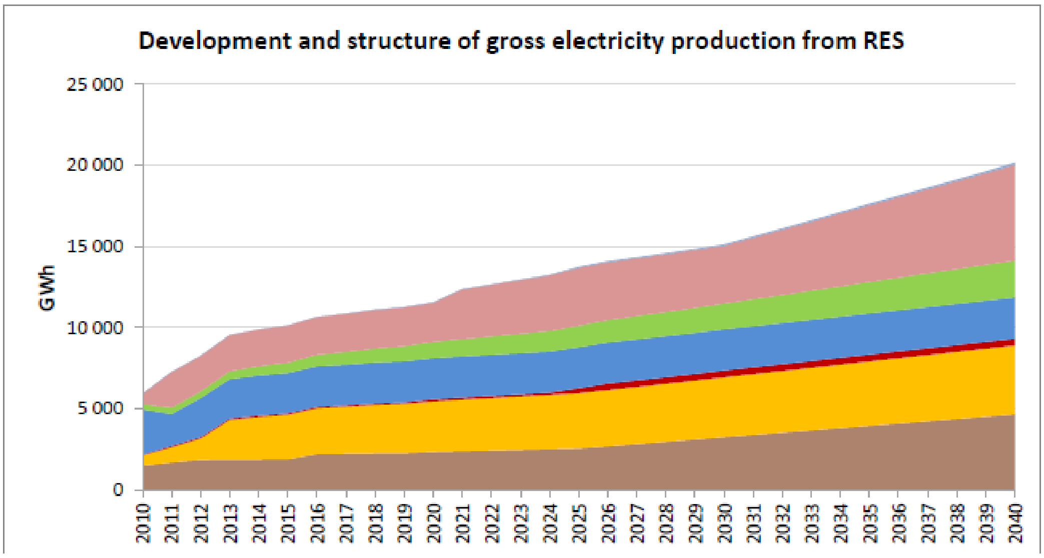


Figure 3 - Description downwards: Photovoltaic| Wind| Water| Biodegradable waste| Biogas| Biomass

Total electricity production from renewable and secondary sources of energy will continue to rise between 2010 and 2040. This is motivated by an effort to make the maximum possible use of this domestic energy source, although on the assumption that it is competitive. Besides hydro energy, the potential for which has now been practically exhausted after more than a century of developing hydro power stations in this country, there is clear potential for the further development of biogas stations and PPS. Electricity generation from biomass and waste will continue to develop until domestic potential has been exhausted.

3. Distributing electricity – Grids[31]

3.1. Status quo – current national situation

Electric grids of the Czech Republic – current situation

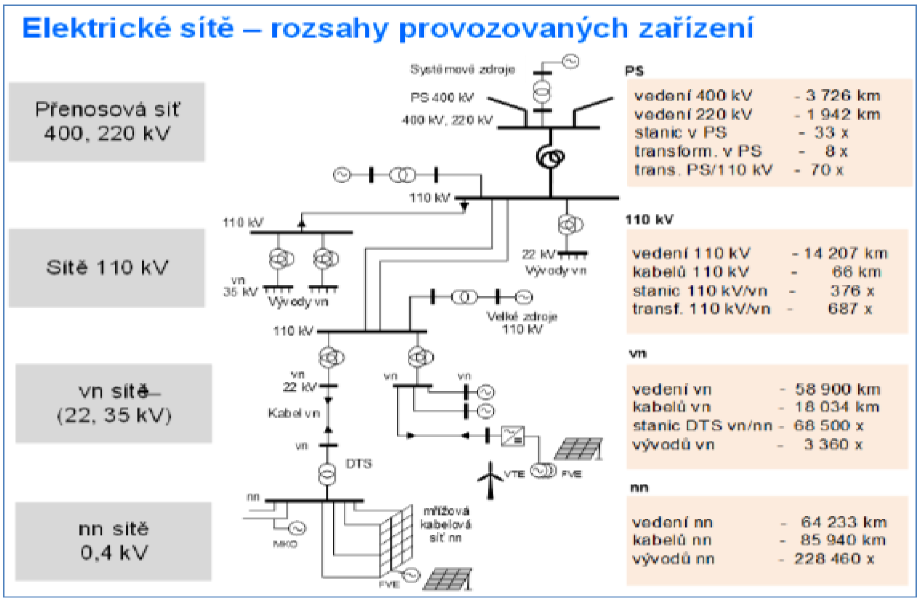


Figure 4 *- Description downwards: Transmission grid 400, 220 kV| 110 kV| Distribution grid 22, 35 kV|0,4 kV*

Time discrepancy between consumption of electricity and its production is currently kept by production regulation and in a smaller scale also by its accumulation so that a necessary technical balance of the grid can be maintained.

3.2. Challenges, future plans/strategies

Increase of electricity production from renewable sources (RES) leads to necessary over-estimation of the grid balance keeping methods concerning regulation of both production and the new way of consumption as well as to step-by-step controlled exclusion of the power plants with the high level of emissions.

This goal can be achieved by:

- Direct control of consumption by regulation of the voltage in the grid
- Direct accumulation of electric energy, controlling device is loading of batteries and its releasing to the grid in the period of its high price
- Accumulation using pumped hydro storage power plants, CAES (compressed air energy storage)

[31] Technologický foresight a průmyslové vlivy v oblasti energetiky v České republice. Issued on 31. Oct. 2017. Report TPUE 2017

- Switching-on the new consumers:
  - Heating plants (e.g. controlled temporary transfer of heating plants form cogeneration to accumulation of the heat with un-used available electricity as well as the similar way of the new micro-grid cogeneration sources.
  - Transport systems (e.g. loading of the vehicle batteries and/or installation of the new hydrogen producing systems) that can profit from the cheap electricity available.

3.3. Latest technologies facilitating the strategy

Development of the decentralized energy sources will support the growth of the sources in the distribution networks, mainly in the low-voltage ones. Expected development showing the growth in the period 2016 -2040 can be seen from the following diagram:

Expected development of power sources for different grids from 2016 through 2040

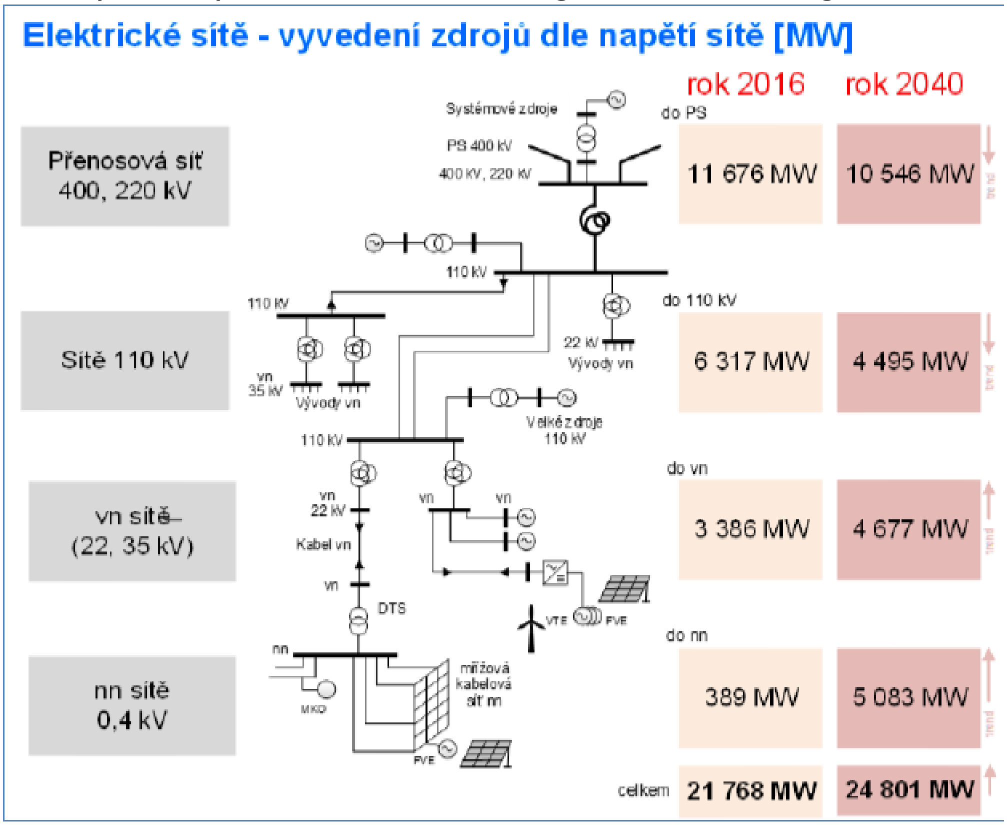


Figure 5 - Description downwards: Transmission grid 400, 220 kV| 110 kV| Distribution grid 22, 35 kV|0,4 kV

EWIS Study (European Wind Integration Study – http://www.wind-integration.e/) has analyzed the development of wind sources for power generation up to 2015 and worked out a realistic market model of European networks up to that year. The EWIS report has recommended a series of measures to mitigate identified problems. Some technical solutions (e.g. installation of phase shifting transformers

PST) that protect the system they are responsible for can be implemented, but at the same time such solutions force power flows to enter the neighboring systems[32].

4. Storing electricity

4.1. Status quo: current national situation

Since the year 1930 the pumped-storage hydroelectricity plants (PSH) have been in operation in the Czech Republic. With development of the nuclear power generation they were used mostly for balance of the consumption diagram. The biggest Czech PSH has capacity of 650 MW and the 76,5% round-trip energy efficiency. To support the nuclear power development program in the future the 20 suitable building sites for the new PSH have been localized in the country offering up to 1200 MW capacity and accumulation up to 20,000 GWh. The PSH Dalešice (450 MW) that was built to support the Dukovany nuclear power plant enable also to compensate the reactive power at the 400 kV transmission system level. The total installed capacity of the country's PSHs in 2017 was 1,171 MW with 1.173593 MWh delivery to the grid.

4.2. Challenges, future plans/strategies

The novelization concept of the Energy Law, ready for approval, newly defines a support of the RES in accordance with the country's obligations towards the EU. Based on this concept the action measures for accumulation of electricity and integration of electric vehicles into the distribution grids are being prepared. There are some demonstration projects of CAES technology, PSH in abandoned underground coal mines. Lithium-ion batteries for electric vehicles are produced and also battery storage capacities for the grid have been installed (E.ON-SIE-STORAGE, 1.6 MW , 10 MWh).

4.3. Latest technologies facilitating the strategy

Besides lithium-ion batteries with increasing power and capacity also the NaS batteries with higher density of energy (250 kWh/m^3) and flow redox vanadium storage for electric vehicles can be used. Research of the superconducting magnetic energy storage (SMES) is promising fast-time reaction, high efficiency and a lower lost. Verification testing of batteries manufactured according to the World Patent HE3DA (of the Czech inventor Procházka) is in progress as well. The HE3DA nanotechnology utilizes the high charge and discharge of nanomaterials, resulting in superior safety and many new properties of Li-accumulating modules (non-flamable solution).

[32] Transmission network in the Czech Republic and Central Europe in 2013/2015. ČEPS, a.s. Prague

France Contribution: NATF

National Academy of Technologies of France
Bernard Tardieu

1. Going towards an all-electric society?

The goal, which will be part of energy transition law revised mid - 2019, is to achieve carbon neutrality by 2050. Two vectors will be developed: electricity and biomass. Carbon neutrality means that the entire energy sector must be decarbonized by this time horizon. An objective that can only be achieved, according to Governmental agencies (such as ADEME) if final energy consumption is halved. This long-term objective is not officially endorsed by the Government, but the Government assumes a steady decrease of energy demand in the forthcoming years.

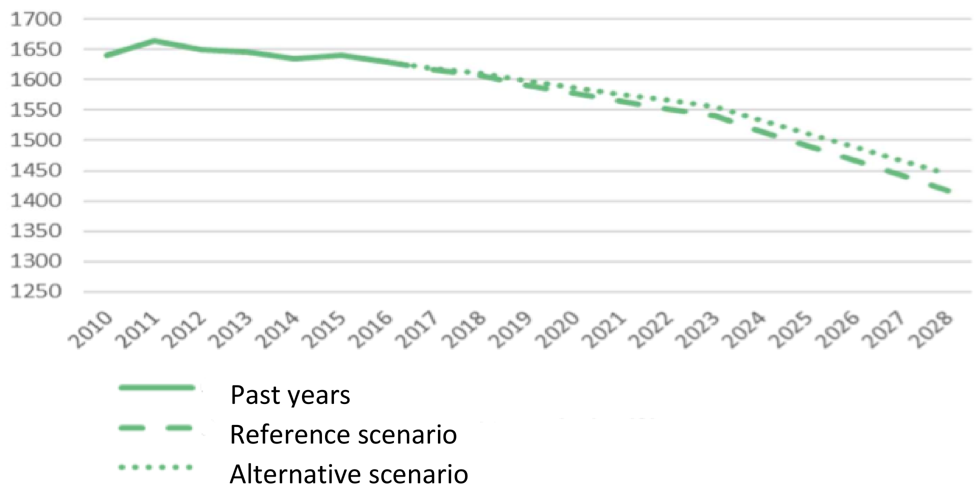


Figure 1 - Final energy demand 2010 - 2016 (TWh)

The French Government is presently following through the result of a nationwide people consultation on the energy multi-year programing to define policy for the next 10 years. The result of this consultation led in January 2019 to the issuance of a draft plan[33] by the government which is subject to review by various energy stakeholders (consultative bodies, the public as well as neighboring countries) Therefore the future policy is not yet firmed.

The French Government has not expressed an aspiration for an all-electric society; according to his proposed plans, electricity demand should remain stable. But due to the planned decrease of the total energy demand, the share of electricity in the final energy consumption should increase from 27% today to 31% by 2038 overcoming the petrol products and becoming the first energy source in France's overall energy system. Further deep decarbonisation of the economy should certainly involve a significant degree of electrification and fuel switching: Electricity demand will increase for transportation. Electricity usage for domestic heating will likely also increase in the coming years with the push forward by the government for the use of heat pumps, and for hydrogen production using surplus electricity

[33] National strategy for the energy transition – Multi-year planning of energy – Minister of Energy and Solidarity – January 2019 - in French

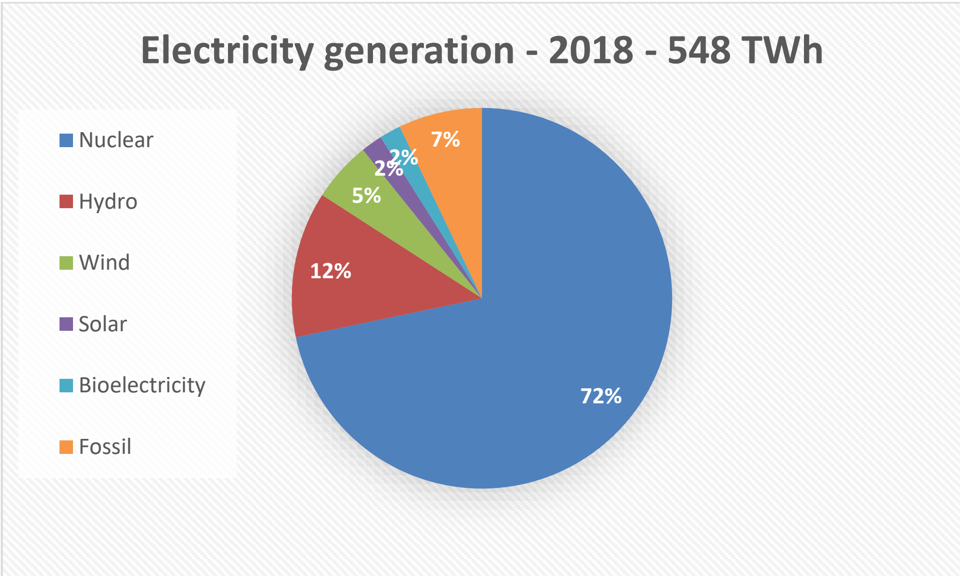
from non-dispatchable renewable electricity. Our Academy considers that there is a contradiction between the stated forecast of a stable electricity demand, and the goal of carbon neutrality in 2050.

The figures and presentation below are based on the plan presented by the Government.

2. Generating electricity

2.1. Generating electricity from sustainable resources

2.1.1. Status quo: current national energy mix



Electricity generation is the smallest single source of France's greenhouse gas emissions, thanks to its large nuclear based production. Today coal is a very small part of electricity production as well as (non-hydro) renewable sources

2.1.2. Energy mix –future goals and national strategy

Electricity

On the one hand, an increasing electrification of uses, on the other hand, efforts to reduce consumption.

Although electricity production is forecast to become first source of energy, domestic consumption should be reduced to 438 TWh in 2028 from 481 TWh in 2017, thanks to improved efficiency.

The very large part of nuclear has led the past Governments and Parliament to plan a reduction of its share in the electricity production, and to pursue the goal of largely increasing the renewable part (mainly solar PV, and wind) on one side and increasing use of electricity in the transportation sector (electrical cars) and in the home and building heating through the use of heat pumps .

Hydrogen as a vector

may play an important role because it can take on many functions within the energy system but the present policy toward development of a hydrogen society has yet to be formulated after experimental schemes are developed

The goal stated by the former Government to reduce the share of nuclear to 50% of electricity generation in 2025 has been shifted to 2035 by the present Government, and it should come into law this year. So far, there is no plan for a complete phase-out of nuclear in a longer term. On the opposite, a decision to build a new series of large size nuclear reactors in the next decade is due to be debated in 2021.

The planned electrical evolution of the electrical mix is as shown in the next figure.

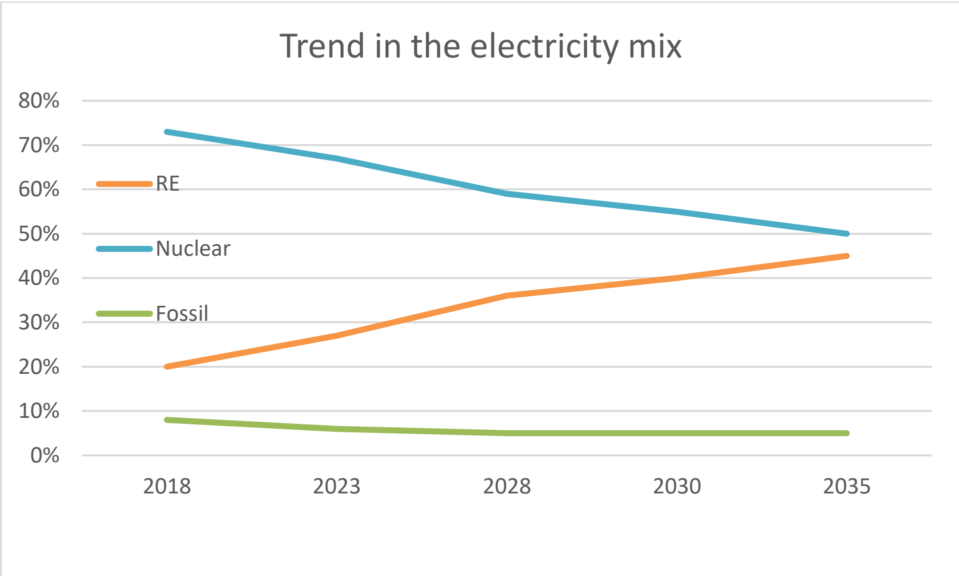
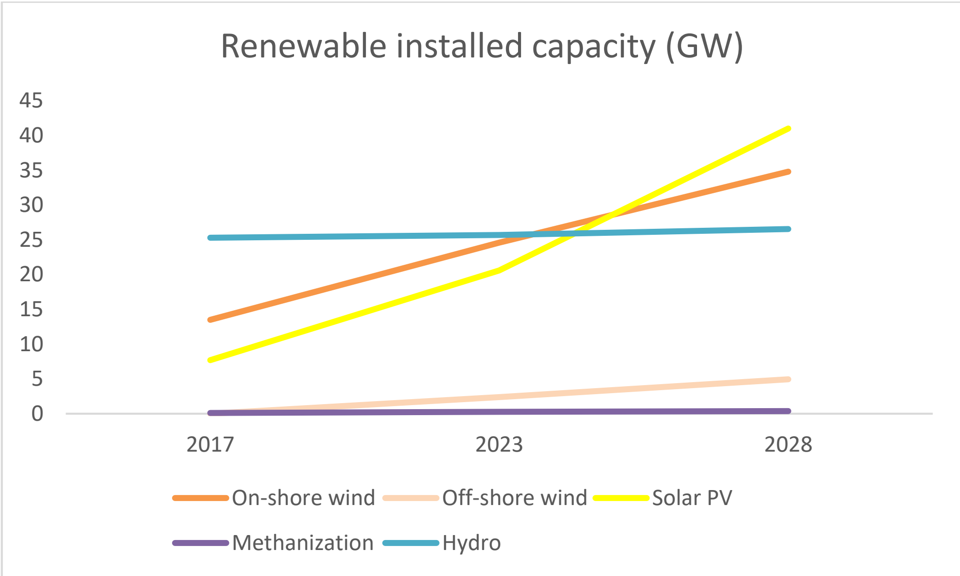


Figure 2 - Trend in the electricity mix

With respect to renewable energy, the Government plans to increase installed capacity by nearly 60% by 2028, with very different paths depending on the technologies. The progress will be based mostly on photovoltaics, onshore wind, and gradually offshore wind, "the most competitive sectors" and therefore the least demanding in terms of public support. In solar energy, preference will be given to large ground-based power plants "because it is the most competitive sector". However, roof-top installations will not be left out and the government plans to make it compulsory to solarize large roofs without specifying when.

Target 2028: between 35,6 and 44,5 GW, i.e. five to six times the installed capacity

2.1.3. Latest technologies facilitating the strategy



Hydropower energy

Hydro is already very developed in France and potential sites for additional plants are scarce.

In 2017 hydropower installed capacity is 25,3 GW including 8GW of pumped storage, with annual generation of 61TWh. The planned forecast is a few% increase to 25,7 GW in 2023 and between 26,4 and 26,7 GW in 2028.

Wind energy

On shore wind

In 2017, wind power installed capacity was 15 GW. The planned forecast is a large increase to 24.6 GW in 2023 and between 34.0 and 35.6 GW in 2028.The present number of wind turbines (8,000) should rise to 14,500 in 2028.

This plan is facing social difficulties as more and more people are locally fighting against installation of wind turbines. The government has issued new rules in order to simplify and speed up the licensing of new wind farms, but these rules are being fought across the French judiciary system.

Off shore wind

Although power purchase agreements (PPA) for first wind farms were awarded a long time ago, none has yet been installed due to difficulties in obtaining permits, due to local opposition. Those PPA have been recently re-negotiated to take into account large reductions in cost of such technology abroad; and today only 2.4 GW is forecast to be commissioned in 2023 and between 4.7 and 5.2 GW in 2028

Solar Photovoltaics

In 2017, solar PV installed capacity was 7,7 GW. The planned forecast is a very large increase to 20.6 GW in 2023 and between 35.6 and 44.5 GW in 2028.

Concentrated Solar Thermal (CST)

In 2017, there was no CST in France except for a demonstration facility. The Government plans to issue calls for tender to support this technology, but with an R&D approach.

Marine Energy

A large Hydro dam has been installed seventy years ago at the mouth of La Rance river, with a 400 MW installed capacity. The Government plans to issue calls for tenders for immersed hydrokinetic technology with the following targets:

MW	2016	Installed capacity 2023	Contracted capacity 2023
	340	440	440 to 2,240

Figure 4 - Marine energy

However, a recent project (1MW) immersed off Paimpol/Brehat (North Britanny) failed, and is now decommissioned. And the industry is unwilling to continue developments on the basis of power purchase agreements as sole support. Therefore, the high forecasts considered by the Government are very unlikely to be achieved.

Nuclear Energy

The last previous energy plan (2016) planned a reduction to 50% of the nuclear share in the electricity mix by 2025.

Since it was recognized by the French government and Transmission system operator that 2025 was not achievable, the present plan shifts this target to 2035. It is forecast:

- to close the first two reactors by 2020 (Fessenheim – 1,900 MW) provided the first EPR reactor is on line by this date.
- The next twelve reactors will be closed at their fifth ten-yearly visit. Of these twelve units, two would be closed early in 2025 and 2026 to avoid a feared "cliff" effect both socially and in terms of security of supply. Finally, two other reactors could be shut down in 2027-2028 but under multiple conditions: guaranteed security of supply, but also a reduction in coal-fired capacity and massive development of renewable energies in neighboring countries leading to a drop-in electricity prices on European markets "likely to reduce the profitability of extending existing reactors". The French electricity regulator (CRE[34]) is assessing these targets and will report back to the government by December 2022. EDF has to decide in the course of 2019 which will be the first twelve reactors to decommission. There will be 900 MW units at Tricastin, Bugey, Gravelines, Dampierre, Blayais, Cruas, Chinon and Saint-Laurent, with the concept of avoiding the complete closure of any site.
- The tacit implication of this decision is the extension of the 18 other reactors of the same generation (CP1), which will be between 50 and 56 years old in 2035. By mid-2021, the government and the industry will examine the costs and financing models of new nuclear

[34] Commission de Régulation de l'Energie (CRE)

power (EPR) to determine which technologies (nuclear or renewable with storage) are the most competitive.

2.1.4. Phasing-out technologies

Coal power plants are forecast to be phased out by 2022.Consultations are being held with the various stakeholders (owners of the plants, worker's unions...) on this plan, including the conversion of some of these coal plants to biomass (wood).

2.2. Carbon Capture and Storage (CCS): binding carbon dioxide (CO_2) emissions when dealing with carbon

2.2.1. Status quo and relevance for the country Having already achieved a high level

With an electricity mix which is highly decarbonised, and heavy industries declining or being localised to developing countries, France has a limited motivation for CCS and CCU. However, a few demonstration projects have been launched or at least considered.

- *Lacq pilot*
  In 2010, it was the first European CCS project combining pure oxygen generation, combustion, CO_2 capture, transportation and injection. 52,000 t of CO_2 were injected up to 2013; no releases were demonstrated until 2016. The project was successfully terminated at this time.

- *Amines project*
  In 2013 and 2014, 1,900 t of CO_2 were captured at the Le Havre Coal-fired power station, meeting the objectives of the projects, using the «Advanced Amine Process» and the UCARSOLTM FCG 3000 solvent developed par Alstom et DOW Chemical.

- *France Nord project*
  This project was aimed to identify salted aquifers in the Northern part of France. It ws completed in 2014.
- *UCLOS*
  This project aimed to capture CO_2 from a blast furnace at Florange was terminated in 2012 when the furnace had to be phased out.

2.2.2. Challenges, future plans/strategies

There are no active plans underway.

2.2.3. Latest technologies facilitating the strategy

Dito

3. Distributing electricity – Grids

3.1. Status quo – current national situation

Since the unbundling process mandated by the European law in 2009, the power supply companies and the grid operators (RTE for HV grid, and Enedis for MV and LV) are separated from each other and are independent companies. They are independently managed subsidiaries of EDF. RTE is part of the ENTSO-E (European Network of Transmission System Operators for Electricity) consortium and therefore connected and synchronized with all direct neighbors.

High Voltage grid

RTE network shown below with nearly 105,961 km of lines, is the largest in Europe (3 times German's one). 46.3% of very high voltage lines (400 and 225 kV) carry electricity over long distances and up to 50 cross-border links with neighboring countries

The security of electricity supply has increased in the last years. As shown in Table 11 – Unplanned SAIDI System Average Interruption Duration Index (HV) of the "CEER Benchmarking Report 6.1 on the Continuity of Electricity and Gas Supply" published in July 2018 without exceptional events (minutes per customer) France's HV grid, by far the largest grid in Europe, has only 2.4 minutes of unplanned events par year.

Figure 3 - French HT grid - Source: RTE

Low and Medium Voltage grid

Enedis operates the public electricity distribution network for 95% of continental France. In France, the MV and LV grids belong to local authorities and municipalities. Their operation and maintenance are assigned to Enedis within the framework of a public service delegation. Through this delegation, Enedis fulfils the public service duties related to electricity distribution.

Enedis MV and LV grid, with 1.4 million km of lines, has 377,000 generators connected to its grid. In the context of the opening of markets to competition, the transmission and connection to the public electricity distribution network are public service tasks. As such, the tariff paid by network users, i.e. Enedis customers, is regulated by public authorities.

One of the important tasks that Enedis has been pursuing for the last three years is the deployment of smart meters, which automatically transfer collected data to a central unit and to suppliers and service operators.

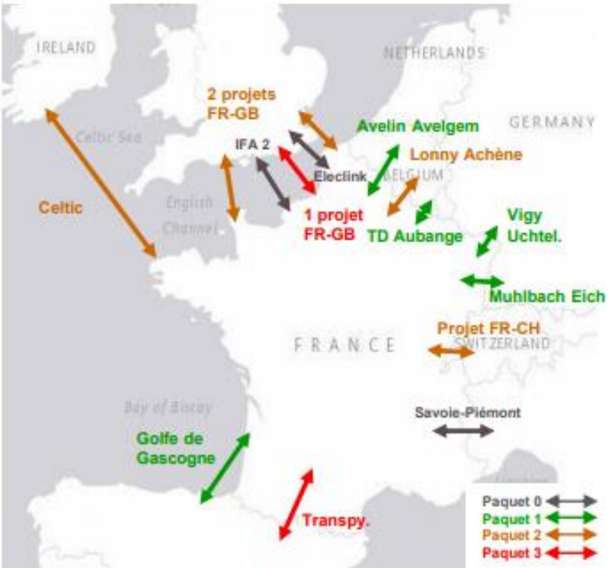
3.2. Challenges, future plans/strategies

RTE

On the HV side of the grid, RTE plans and challenges is mainly to increase the number of interconnections with neighboring countries. Being in charge of the security of supply, RTE starts experimenting a capacity market.

Interconnections: an ambitious and necessary development. Long-term scenarios for electricity mixes require new interconnections to ensure a successful European energy transition, increase security of supply, and pool capacities, especially with respect to non-dispatchable supplies.

The plan is to approximately double the exchange capacities with neighboring countries from 12.5 to 27 GW on the import side and from 17 to 33 GW on the export side (Germany Italy, Ireland, UK, Spain, and Switzerland)..Such doubling is forecast to be reached between 2025 and 2035.



When more than 50 GW of RE (Wind +PV) are installed, i.e. on or around 2025-2028, more structuring upgrades of the network may be necessary. Network adaptations must be part of a collective and accepted narrative of the energy transition to promote the best compromise. In order to assess the issues associated with the acceptability of new infrastructures, different strategies for the development of regional networks have been studied with strong impacts on costs: overhead vs. underground links.

Enedis

On the MV and LV side the deployment of a smart meter (Linky) has sometimes met social acceptance issues, insignificant in%age terms, but strongly relayed by social networks and the media Therefore completing this deployment, which is half-way, is still a challenge to allow a smart grid structure in the future.

Upgrades of the existing MV and LV network, in particular for integrating renewable energies will be needed.

4. Storing electricity

4.1. Status quo – current national situation

Electricity storage in France is dominated by hydro pump storage systems, as the figure below indicates for the year 2017. But these hydro pump storage devices have only a limited storage capacity: 5 GW, and 6 to 7 TWh per year.

4.2. Challenges, future plans/strategies

The amount of intermittent (non-dispatchable) renewable electricity in France is not forecast to be above 30% for at least 20 years. Therefore, the development of storage capacity and technologies is not as urgent in France compared to other countries such as Germany or Denmark with very high PV or wind.

However, in order not to be excluded from potential markets there is a need to develop new technologies:

- On a daily basis and below: batteries are appropriate
- At longer scales intersessional storage: thermal storage or power to X

Daily basis

Pumped water storage

It is potentially possible to increase the pumped water storage capacity in France by 2 GW; but local acceptance is not granted.

Batteries

The various lines for developing storage technologies are the following:

- investing in the market almost immediately for the non-connected French area (mainly overseas islands) to be decarbonized
- Intensify R&D for performance, manufacturing problems (impact in energy, CO2, rare earths,...),
- Manufacture batteries in France in cooperation with the EU or other European countries

Inter-seasonal storage

Initiate a hydrogen supply chain (seasonal storage, mobility)

Hydrogen

A green Hydrogen plan has been set out by the Government. Today, the main objective is to green industrial hydrogen with targets of 10% decarbonated hydrogen in 2023 and 20% to 40% in 2028. At the same time, new uses will be encouraged in mobility to reach, for example, 20 to 50,000 commercial vehicles using this energy in 2028.

Germany Contribution: acatech

The National Academy of Science and Engineering
Frank Behrendt

1. Going towards an all-electric society?

The German energy policy framework calls for cutting greenhouse gas emissions by 40% by 2020 (85-90% by 2050), phasing out nuclear energy by 2022, and safeguarding energy security and competitiveness. In October 2014, the EU leaders adopted the climate and energy framework, which sets the following targets for the year 2030:

- 40% reduction of greenhouse gas emissions (compared to 1990)
- a renewable energy share of at least 27%
- increasing the energy efficiency by at least27%

Germany enhanced these goals in two aspects:

- a reduction of greenhouse gas emissions by 55% until 2030 (in respect to 1990)
- a renewable energy share of 55 to 60% until 2035

However, the weak development of German greenhouse gas emissions reduction in recent years stands in contrast to the declared goals – even though the share of renewable energies in the power supply has continually risen. To achieve the national energy goals, coupling of the energy sectors and a systemic integration – i.e. the holistic optimization of the energy system – seem to be essential.

In the long term, electricity will become the dominant energy source in Germany's overall energy system and will be generated predominantly by wind and solar power plants. With the increasing use of electricity also in the heating and transport sectors, the future power demand is bound to rise significantly. In 2050, Germany may consume more than 1,000 TWh, i.e. almost twice as much as today. Provided that carbon emissions are to be reduced by 85%, this would require an installed capacity of up to 500 GW of wind and photovoltaic systems (about six times the existing capacity). While this seems feasible, it does come with significant technical and social challenges.

In the transport sector, battery electric cars are expected to play a key role. Nevertheless, combustibles and (synthetic) fuels will remain indispensable even in the long term, because easily storable energy carriers are required during lengthy weather periods with little wind and sun which can last up to two weeks in Germany ("cold, dark and windless periods"). Hydrogen will play a crucial role because it can take on many functions within the energy system: it can be deployed in industrial processes, used for heat supply in buildings or as fuel for transport, and converted into methane and/or liquid fuels. Gas – natural gas, biogas and synthetic gases – which has low emissions, can be deployed in many different ways and could become, in parallel to electricity, a central energy carrier in the long run.

Total installed power generation capacity could, for instance, increase from currently around 200 GW to some 600 GW (500 GW from renewable energies plus 100 GW of reserve mostly gas-fired power plants). This could be complemented by up to 100 GW of electrolysis and methanation plants and battery storage systems of equal dimensions.

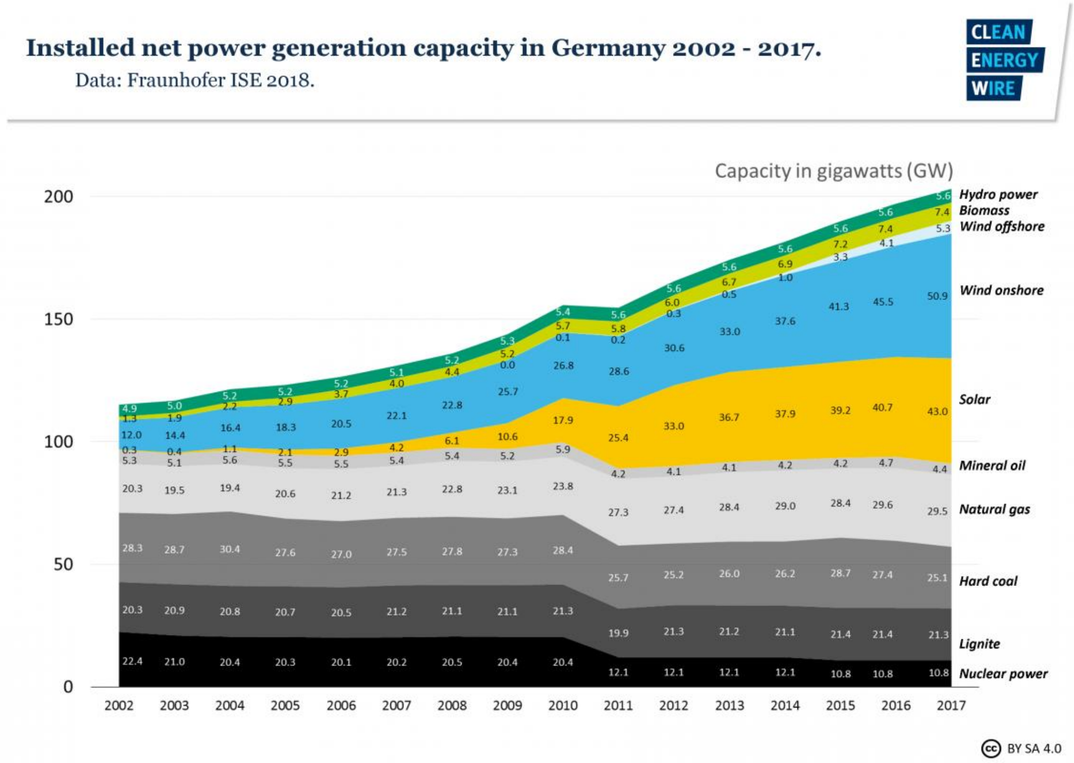
Conclusion: Electrification, along with digitization, will continue to be a major trend and driver in the German energy transition. However, it's unlikely that Germany will become an all-electric society. We will probably see a mix of technologies, and liquid energy carriers will play a crucial role in future developments.

2. Generating electricity

2.1. Generating electricity from sustainable resources

2.1.1. Status quo: current national energy mix

The share of renewable energies on the gross electricity consumption is currently 36.2% (2017) and therefore Germany already fulfilled the EU renewable share goal for 2030. As seen in the figure below the installed generation capacity of renewable energy units are constantly increasing over the last years. In 2018, there were two days in Germany in which for a few hours the whole electricity demand of the country was covered only by renewable resources. Even with this increase of renewable units in the system, the total emissions of Germany are stagnating in the last three years and it is most likely that Germany will fail the 2020 goal of 40% CO_2 reduction. This situation is due to the higher oil and gas demand in other sectors, such as transport, heating or industry. This results in a share of only 13% of renewables in the primary energy consumption.



Source: https://www.energy-charts.de/power_inst.htm

2.1.2. Energy mix –future goals and national strategy

To achieve the CO_2 reduction goals, the German government defined the following development pathways in the German Renewable Energy Act of 2017 (EEG 2017):

- the installed capacity of onshore wind should be increased by
    - 2,800 MW per year (2017 – 2019)
    - 2,900 MW per year (from 2020)
- the installed capacity of PV systems should be increased by 2,500 MW per year
- the total installed capacity of offshore wind should be 6,500 MW in 2020 and 15,000 MW in 2030
- the installed capacity of renewable units using biomass should grow
    - by 150 MW per year (2017 – 2019)
    - by 200 MW per year (2020 – 2022)

To achieve the very ambitious goal of 55% reduction of greenhouse gas emissions until 2035, a decarbonisation of the other sectors (heating, transport and industry) needs to take place. This can be done by either electrification of the sectors or by running on synthetic fuels, which again needs to be produced from electricity from renewable sources. Considering this aspect, an expansion of the installed capacity of renewable units as set in the EEG 2017 is necessary. Alternatively, the efficiencies in all sectors need to be drastically increased. Among others, Fraunhofer IWES prepared a study about the impact of the electrification of different sectors on the electricity grid in Germany. The study identifies heat pumps and electrical heaters as key technologies for the heating sector as they offer high efficiencies of the electricity conversion onto heat. Both technologies will course an increase of the electricity consumption of 132 TWh/a till 2050. Besides the heating sector the study also evaluated the impact of the mobility sector and identified electrical, hybrid and natural gas cars together with overhead electrical line trucks as appropriate technologies. With the assumption of 46% electrification of the mobility sector in 2050 the electricity demand will increase from 17 TWh/a today till 131 TWh/a in 2050. In comparison, Germany has currently a total electricity provision of around 630 TWh/a. These numbers impressively demonstrate that building more renewable units alone is not enough. Besides increasing the installed capacity limits of the above descripted development pathways, the efficiencies in the conversion technologies also need to be increased, new infrastructures need to be built, and the overall system needs to be optimized.

2.1.3. Latest technologies facilitating the strategy

GE is currently developing a new offshore wind turbine with 220 m rotor diameter, 107 m blades and a rated capacity of 12 MW. GE expects a capacity factor of 63%, which is around five points above the current industry standard for offshore wind turbines. The costs of solar modules are still falling, which facilitates the ongoing growth of the solar sector. The latest drop in the prices were cause by China bringing the promotion of PV systems to an end, which results in a higher number of modules on the world market than expected. Moreover, researchers around the world are exploring new materials for lighter solar panels, higher efficiencies or cheaper materials. One of these new crystals is Perovskite, which is a calcium titanium oxide mineral. Perovskite captures energy from different wavelength than silicon and thereby can be layered on top of a silicon cell to generate more electricity as the usable wavelength spectrum in total is widened.

Besides the development of the generation units, the integration of electricity generated by renewable sources into other sectors will also play an important role in the future energy system of Germany. As indicated above, Germany will fulfil its renewable development strategy but most likely miss its CO_2 reduction goal due to emissions in other sectors. To reduce the emissions in other sectors, the efficiencies in those sectors need to be enhanced and more renewable sources shall provide energy to cover the energy demands of those sectors. This is the reason why the power-to-x strategies are highly discussed at the moment and why the technical developments are ongoing to provide heat, hydrogen, methane or liquid fuels for the carbon intensive sectors.

Also, the integration of a high share of renewable energy into the electrical grid is technically not completely solved. Challenges like providing inertia as rotating synchronous generators and delivery of reactive power from the low voltage to the higher voltage levels to guarantee a power system stability as well as black start capability of renewables or are still under discussion and ongoing research. The integration of energy storages like batteries and long-term storages as well is an import further step. But a lot of developments have been accomplished in the last couple of years like providing frequency containment and restoration reserve or reactive power by renewable electricity generation.

2.1.4. Phasing-out technologies

Germany has a long history of anti-nuclear protests. In response to the Fukushima disaster in 2011, the German Government changed its policy to speed up phasing out nuclear energy after a first decision in 2000. With this new decision, all nuclear power plants of Germany will be shut by 2022. In June 2018 the Federal Government installed a Coal Commission. Their task is to provide options to manage an opt-out for brown coal energy reduction. This is seen as a major step to fulfil the climate targets.

2.2. Carbon Capture and Storage (CCS): binding carbon dioxide (CO_2) emissions when dealing with carbon

2.2.1. Status quo and relevance for the country

The research, development and desire for implementation of CCS-technology originally arose on the initiative of the European Union[35] in 2009 to encourage the EU countries to consider the CCS technology. In 2011, the German Government set up a new law for the capture, transport and permanent storage of carbon as demanded by EU law. This bill was adopted only after the major compromise of a veto privilege of the federal states.

The best-known example of a CCS facility in Germany is a research facility in Ketzin, which is a village in the west of Berlin. From 2008 till 2013 this facility stored around 67 000 tons of CO_2, which mostly came from the lignite plant “Schwarze Pumpe”. The lignite plant is approximately 200 km away from the CCS facility and was under the operation of the energy company Vattenfall. Because of protests of the local population and the missing back up by the local government Vattenfall stopped the project in 2014. Since that time, CCS is only addressed in theoretical research projects.

[35] https://ec.europa.eu/energy/en/topics/oil-gas-and-coal/carbon-capture-and-storage

2.2.2. Challenges, Future plans/strategies

Irrespective of whether the CCS technology will play a significant role in the future or not, the energy system of Germany remains marked by uncertainty. As descripted above, this technology was already written off because of the aversion of the citizens and thus the missing support of the government. But considering that Germany will most likely miss its reduction target of greenhouse gas emissions, it may be addressed again in future strategies. According to the Intergovernmental Panel on Climate Change (IPCC), the critical global warming increase of max 2 °C will be almost certainly crossed without (B)CCS.[36]

3. Distributing electricity

3.1. Status quo – current national situation

Since the unbundling process in 2009, the power supply companies and the grid operators are separated from each other and are independent companies. Moreover, the grid operators can be divided into two types of operators, the transmission system operator and the distribution system operator. In Europe, except for Great Britain and Germany, there is only one transmission system operator in place per country. For historical reasons, Germany has four different transmission system operators (Amprion, 50Hertz Transmission, TenneT and TransnetBW) and a transmission length of approximately 35 000 km. The transmission system operators manage the superregional grids at the highest grid level of 220 kV and 380 kV. All the other grid levels, meaning from 230/400 V to 220 kV, are managed by the distribution system operators. The total length of the distribution grid is approximately 1,679,000 km, which explains why there are around 880 distribution system operators in place. The four transmission system operators are part of the ENTSO-E (European Network of Transmission System Operators for Electricity) consortium and therefore connected and synchronised with all direct neighbours. The security of electricity supply has increased in the last years. In 2006, the average time per year without electricity for all kinds of users was 21.53 minutes, whereas in 2014, this average time without electricity was reduced to 12.28 minutes. Comparing these values to the average values of other countries in Europe (Italy with 41.32 minutes, France with 50.2 minutes or Great Britain with 53.06 minutes) it can be deduced that the German grid is operating at a high-reliability level.

3.2. Challenges, Future plans/strategies

The biggest challenge when talking about the electricity grid and a high share of renewables in the near future is the process of building new grid infrastructures in Germany. For an energy system with a high share of renewables, an expansion of the existing grid for both the distribution and transmission of electricity is necessary. At the moment, the transmission grid is highly equipped with measurement and control technologies, but for the distribution system, this level of measurement and control is still missing. Moreover, it is necessary to equip the distribution level with a higher share of step-switchable transformers to avoid voltage problems in the low voltage level if, e.g., several PV systems are connected to this level. To enable a better transmission in Germany but also in Europe the expansion of the transmission system is necessary. These interconnected transmission lines supply other parts of Germany or Europe with electricity in times of bad weather conditions. One big project of the two transmission system operators TransnetBW and TenneT is the SuedLink project, which aims to connect

[36] https://www.globalccsinstitute.com/news/institute-updates/role-ccs-explained-latest-ipcc-report

the north and the south of Germany via a high-voltage direct current line. Planned are two lines, each with a transmission capacity of 2 GW. This project should enable the following aspects:

- The compensation of volatile feed-in from the north of Germany with little industry but a lot of wind turbines and the south/west of Germany with the heavy industry, only a small amount of wind turbines but a greater number of installed PV systems
- Compensation of the missing generation units after the phase out of the nuclear power stations. All the nuclear power stations currently operating in Germany are located in the west and south of the country together with the heavy industry.
- A connection to the European storage systems

In addition to the necessary changes in the infrastructure, also a methodology change in the operation of these grids is necessary. The major task of a transmission system operator is to provide ancillary services, such as:

- frequency control
- voltage control
- system restoration
- system control

In the past, the ancillary services were mainly provided by conventional power plants. Providing all ancillary services by renewable units is currently highly addressed in the research. Renewable units already proved the capability of providing reactive power for the voltage control and therefore helped providing this ancillary service, but further research is necessary to run the total voltage control only on renewable energy units. There are wind parks in Germany which can provide balancing power. However, there is still a long way to go until the complete balancing power can be provided by renewable units in combination with storage devices. Moreover, in the future renewable units need to be able to help during a black start situation. Alongside the renewables, flexible loads can also provide some of the ancillary services mentioned above. In the past, flexible loads which was mainly provided by the heavy industry showed the capability of providing balancing power. The transmission grid operator 50 Hertz is currently working on a flexible load platform which should provide flexible loads to reduce the costs of the feed-in management of renewables. Feed-in management is part of the ancillary service system control. In summary, it can be said that flexibilities can help in the provision of some ancillary services as the position paper of the Academies' project "Energy Systems of the Future" showed, but there are other ancillary services which can only be provided by generation units. That is the reason why further research activities in the field "ancillary services provided by renewables" are necessary in the future.

4. Storing electricity

4.1. Status quo – current national situation

Electricity storage in Germany is dominated by hydro pump storage systems, as the figure below indicates for the year 2017. In times of high renewable energy generation without the appropriate demand, electricity is stored in these facilities, with a total capacity of 6.36 GW, by pumping water to a higher level. But these hydro pump storage devices have only a limit storage capacity. They can only provide the 6.36 GW for 6 h if all hydro storage stations of Germany are fully filled. If currently planned projects are considered Germany ends up with a total capacity of hydro storage systems of 8 GW, but the demand in peak times can be up to 80 GW. Besides hydro storage systems, stationary battery storage devices could help in the future to smooth out discrepancies between renewable generation and load. These battery storage devices can be mainly divided into two types, which are home batteries (280 MW in 2017) and large battery storage devices for providing ancillary services for the transmission system operator (178 MW in 2017). Currently, the best business case for large batteries, if they are not directly used in the industry, is the provision of ancillary services and not the net general storage of electricity. Small battery systems are mainly used in combination with PV systems to store and restore self-generated electricity and therefore enhancing the share in self-consumption.

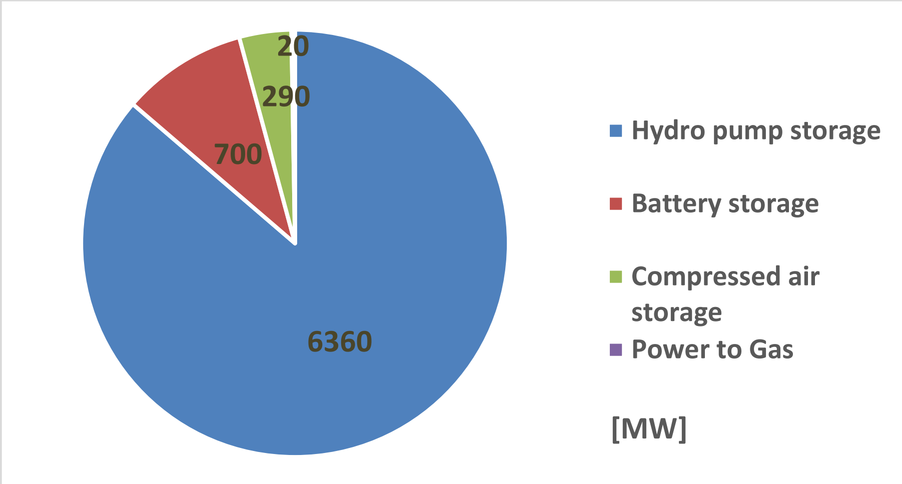


Figure 1 - Electricity storage systems (data from Bundesverband Energiespeicher)

4.2. Challenges, Future plans/strategies

In the near future, Germany will continue to use hydro pump storage systems for pure electricity storage and batteries for ancillary services. If the prices for batteries will continue to fall, these systems will be also used for pure electricity storage.

With a growing share of renewables, the importance of power-to-gas will also rise. But both hydrogen or synthetic fuels will be first used in other sectors (e.g. transport sector) rather than the electricity sector due to transformation losses if used to produce electricity again. The reconversion of these carries into electricity, meaning a power-to-gas-to-power process, will be necessary in the far future when there is a very high share of renewable energies. Because of the current low efficiency of the power-to-gas-to-power process, further research is necessary.

Japan Contribution: EAJ

Engineering Academy of Japan
Masakazu Sugiyama

1. Going towards an all-electric society?

Japanese government issued 5th Strategic Energy Plan in July 2018[37]. It is comprised of realization of the long-term energy supply and demand outlook in 2030 (July 2015 Ministry of Economy, Trade and Industry decision; hereinafter referred to as the "energy mix in 2030"[38]) and the design of scenarios focused on 2050. In this document, it is stated that "Japan, which has experienced the accident at TEPCO's Fukushima Daiichi Nuclear Power Station, is giving the top priority to safety regarding nuclear power when realizing the 2030 energy mix and making its energy choices for 2050 and is reducing its dependency on nuclear power as much as possible as it aims to expand renewable energy."

The share of electricity in an entire energy demand was 25% in 2013. In the outlook of energy mix in 2030, the fraction of electricity increases only slightly to 28%.

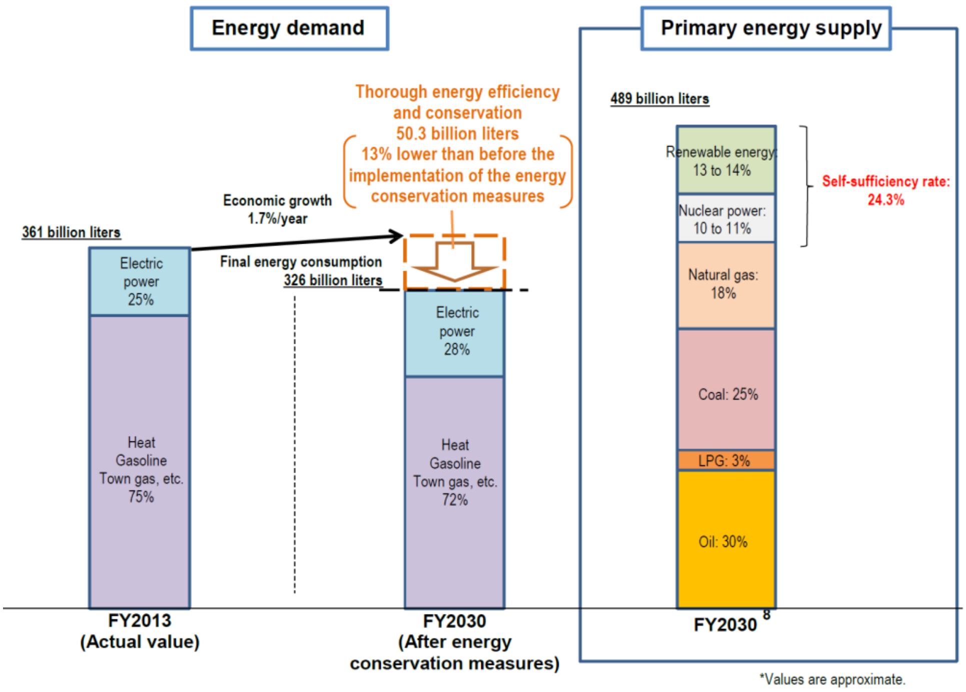


Figure 1 - The outlook of energy demand and the fraction of electric power. The breakdown of primary energy supply in 2030 is also shown[38]

Electrification is not expected to expand substantially in the 2030 energy outlook, partially because centralized electricity grid system is already well developed in Japan. Instead of simply substituting existing heat supply with electric heating, local cogeneration system between electricity and heat is

[37] Strategic Energy Plan, Energy Strategy Office, Policy Planning and Coordination Division, Commissioner's Secretariat, Agency for Natural Resources and Energy, Japan (2018).

[38] Long-term Energy Supply and Demand Outlook (Ministry of Economy, Trade and Industry, Japan) July 2015

regarded as a method of boosting energy efficiency, including distributed electricity power generation by fuel cells and the use of waste heat.

2. Generating Electricity

Table 1 - Fractional electric power generation

	2010	2016	2030 outlook[37]
Nuclear	26%	2%	22 – 20%
Coal	27%	32%	26%
Renewable	10% (almost all hydro)	15%	22 – 24% (incl. 8.8 – 9.2% hy-dro)

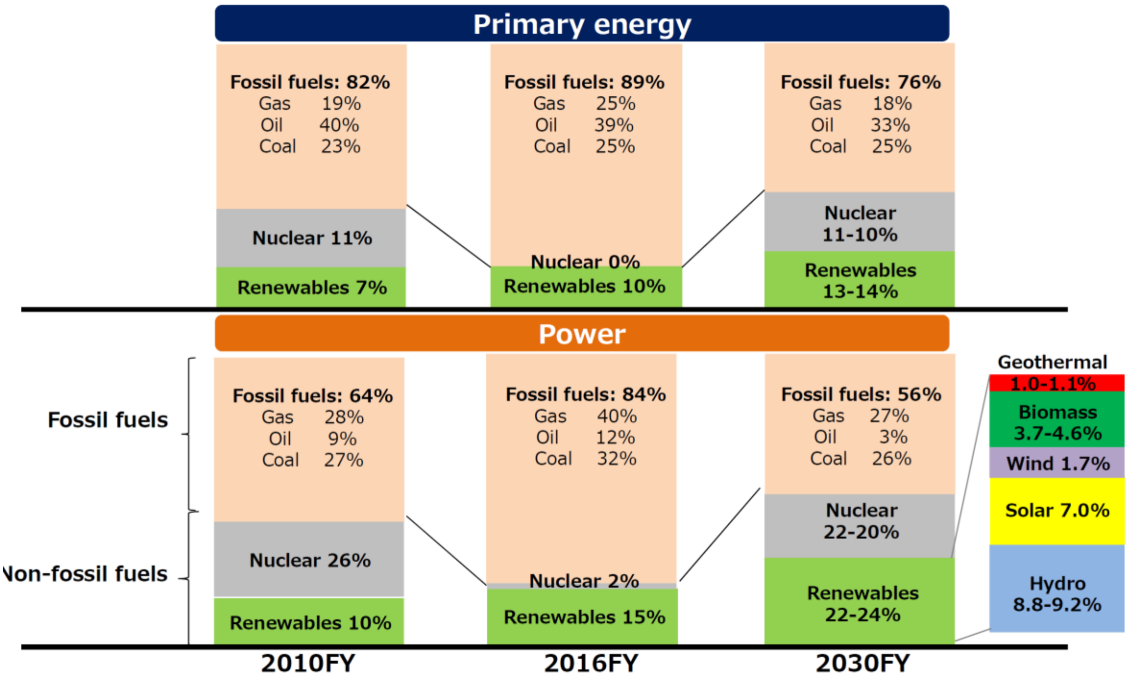


Figure 2 - Fractional energy sources in both primary energy supply and electric power generation

Energy mix in electric power supply is targeted as summarized in Fig. 2[38]. After the disaster of nuclear power generation plants in 2011, all the nuclear power generation plants were terminated in operation tentatively. Then, more severe safety standard was imposed to the nuclear power plants for their future operation. As a result, out of 60 nuclear power plants that existed so far in Japan, 9 plants are currently in operation and 6 have passed the review of the national nuclear agency and got the permission for changing reactor installation, as shown in Fig. 3. Summing them up, 15 reactors can be in operation in 2030. However, the total capacity of them is insufficient to satisfy the fraction of nuclear, 22 - 20%, in the 2030 energy mix. On the other hand, 24 plants have been decided to decommission. In view of such situation of nuclear power generation plants, the only way for enhancing the self-sufficiency of energy in Japan is the expanded installation of renewable power generation.

According to the report by Ministry of Environment (MOE)[39], Japan, expected supply potential of all renewable power generation sources including hydro power generation is 81.7 billion liter-oil in 2030. This is larger than the expected renewable electricity supply (68.5 billion liter-oil) in the 2030 energy mix, suggesting that the scenario is achievable in terms of the abundance of renewable energy resources provided that the intermittency of renewable electricity is manageable by electricity grid. On the other hand, the MOE report[39] expects the amount of total renewable power supply as large as 164 billion liter-oil in 2050, which is nearly the half of the expected energy demand in 2030, 326 billion liter-oil. In order to implement such a large amount of renewable electricity in the energy mix of Japan in 2050, further electrification is mandatory.

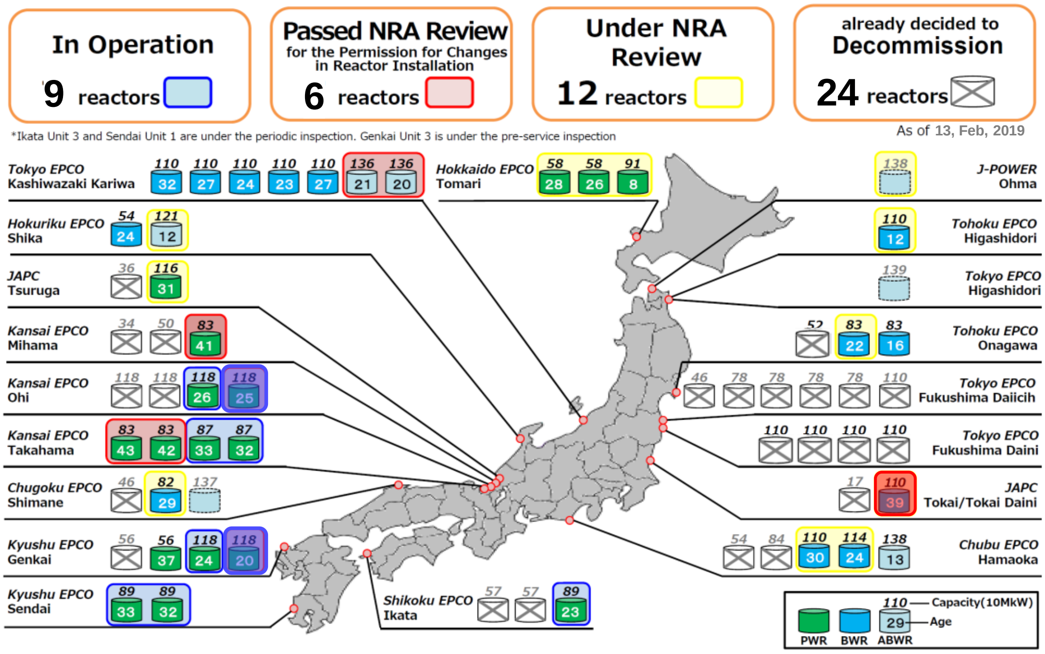


Figure 3 - The status of nuclear power plants in Japan

3. Distributing Electricity - Grids

Japan is equipped with electricity grid system with precise control of voltage and frequency (±0.2 Hz, except for ±0.2 Hz in Hokkaido). National grid system is divided into 10 segments operated by independent and private electric power companies. Interconnection among the 10 segments is not broad, especially between the east (50 Hz) and west (60 Hz) sides. This frequency difference stemmed from the development history of power grids. In between Tokyo and Chubu grids, frequency conversion is necessary, and the capacity of electricity transmission is limited to 1.2 GW. Another narrow interconnection exists between Hokkaido and Tohoku grids because of the strait dividing Honshu and Hokkaido islands; a DC transmission line is used to avoid power transmission loss in the submarine cable.

Electricity supply in Japan is very stabilized with almost no significant blackout. However, segmented power grid system imposes a constraint for the increase in the installation of intermittent renewable power generation sources such as solar and wind. For example, recent installation of photovoltaic power generators is concentrated in Kyusyu and Hokkaido grids while large electricity demand exists

[39] Report on the installation potential of distributed energy such as renewable energy in 2050, Ministry of Environment, Japan (2014), in Japanese

in Tokyo, Chubu and Kansai grids where solar power capacity is still small. Similarly, a large amount of wind power resource exists in the northern part of Tohoku grid which is apart from the site of large electricity demand. Therefore, there is a strong demand for the expansion in the capacity of inter-grid transmission lines, but there is a debate on who to pay for such new installation of broadband transmission lines.

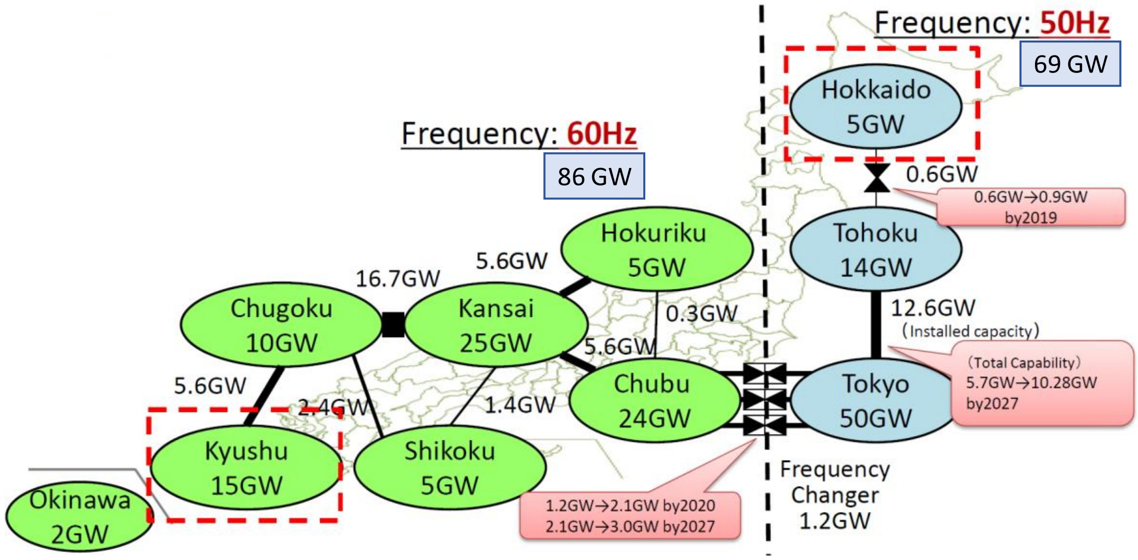


Figure 4 - Power grid system in Japan. The values indicate the maximum electricity demand in 2016[40]

Aiming at better management of intermittent renewable power generation without relying on the future expansion of inter-grid transmission capacity, there is an initiative for the installation of local grid management system combining solar/wind power generation, a large capacity of electricity storage such as batteries, and demand-response for individual consumers. However, the cost for such a system is still beyond the affordable range of private investment and the installation is limited to depopulated rural area.

4. Storing Electricity

In Kyushu grid, the capacity of photovoltaic power generation is 8.07 GW as of the end of August, 2018. This exceeds the half of the maximum electricity demand. In a sunny holiday when electricity demand is limited and photovoltaic power generation is abundant, adjustable power generation sources such as coal, oil and LNG were unable to manage the gap between the limited demand around the noon (with very small need for air conditioning) and large photovoltaic power output. In such situation, pumped hydro functioned as a large-capacity electricity storage as depicted in Fig. 5.

[40] “Electricity System and Market in Japan,” Electricity and Gas Market Surveillance Commission, Japan (2018)

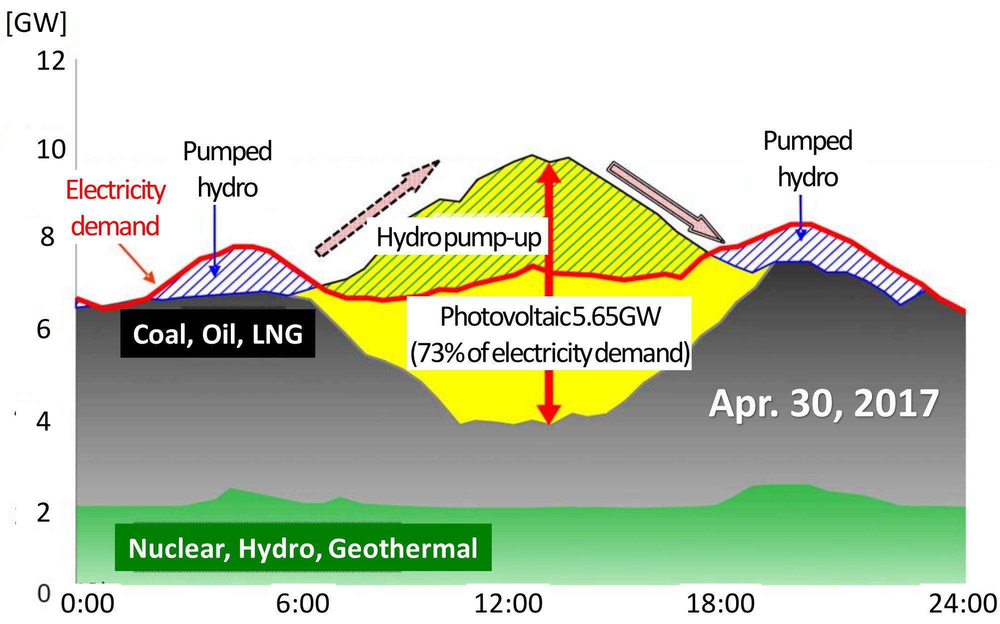


Figure 5 - Electricity demand and supply in a sunny holiday in Kyusyu, Japan[41]

Later, the situation got more severe for renewable power generation. Two additional nuclear power generators started operation and the base electricity supply was increased ca. 4 GW. The management of power grid such as an example in Fig. 5 has become more difficult. As a result, Kyusyu electric power company started to request the suppression of photovoltaic power output. Figure 6 depicts the balance of electricity demand and supply potential on a sunny Sunday when electricity demand is relatively small and there was relatively small electricity demand with limited air conditioning. Suppression in photovoltaic amounted to ca. 14% of the total photovoltaic capacity. Frequent suppression in photovoltaic power output tends to discourage further installation of photovoltaic.

Currently, there is no apparent initiative to install a large capacity of battery to electricity power grid which can offset electricity from daytime to nighttime because of gigantic capacity and cost of the battery.

As an alternative method of strengthening power grid to allow expanding capacity of intermittent renewable power generation, substitution of fossil fuel with hydrogen is an important option in Japanese policy. In 2017, the government decided the basic hydrogen strategy in Japan[42]. In this policy, hydrogen is targeted as a fuel for electric power generation as well as the fuel for vehicles. Targeted as 2050, approximately 20% of electricity generation is expected to be powered by hydrogen. The source of hydrogen is targeted at oversea countries because of the limitation of renewable resources in Japan such as solar irradiance and available land area. Intercontinental transportation of hydrogen is thus regarded as one of the most important R&D targets. In order to decarbonize hydrogen, which is currently produced from fossil resources, the combination of CCS/U (carbon capture and storage/utilization) in the production site of hydrogen (outside of Japan) is considered. Hydrogen produced from

[41] Agency for Natural Resources and Energy, Japan

[42] Basic Hydrogen Strategy in Japan, Ministry of Economy, Trade and Industry, Japan (Dec. 26, 2017)

renewable electricity and water electrolysis in both domestic and oversea sites is expected as the ultimate source of sustainable energy, but most people regard such renewable hydrogen difficult to be cost effective to substitute existing fossil fuel.

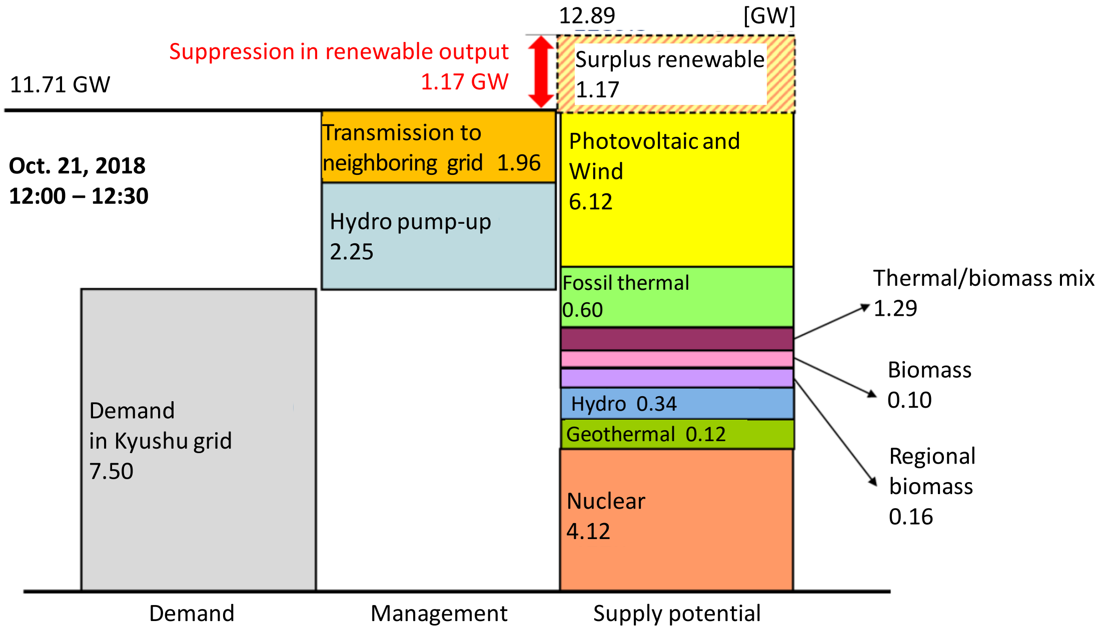


Figure 6 - An example of the electricity balance in a sunny weekend in Kyushu, Japan, when the suppression of photovoltaic was requested by the power grid company[43]

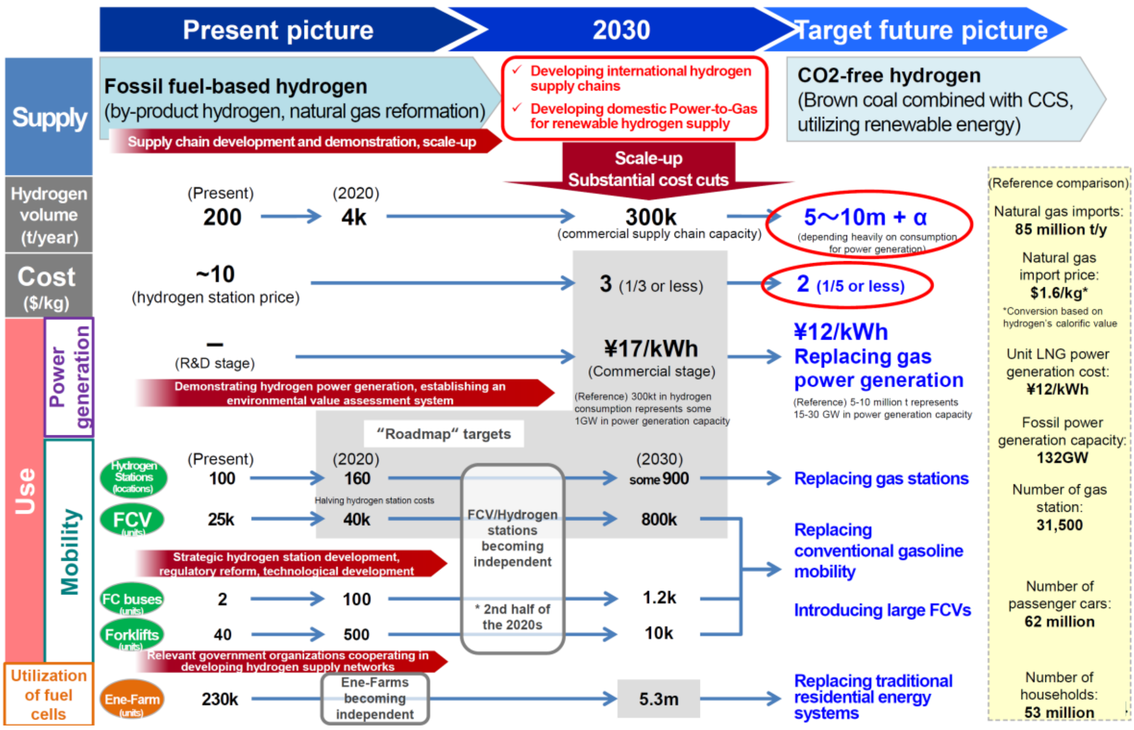


Figure 7 - The timeline of the basic hydrogen strategy of Japan[42]

[43] "Verification of the suppression of renewable electricity output in Kyushu," Organization for Cross-regional Coordination of Transmission Operators, Japan (Nov. 21, 2018), in Japanese

Electric vehicles[44]

Electric vehicles (EVs) are very suitable to urban area in Japan where the average driving distance between charging can be relatively small and a large density of charging stations can be installed. The number of EV sales in Japan was 54000 in 2017, corresponding to a share of 1.0% in an entire sale of vehicles. Among the EV sales, 1/3 is pure electric vehicles and 2/3 is plug-in hybrid. Japanese government set a target number of EV ownership, 1 million in 2020, and an EV share of 20 - 30% of the entire annual car sales in 2030. The price of pure electric vehicles is higher than conventional internal-engine vehicles with a similar spec by nominally 1 million yen (ca. 10k dollars). Japanese government provides several subsidies for the purchase of pure electric vehicles. In 2017, the subsidy amounted to 550k yen for a Nissan Leaf, the most popular electric vehicle in Japan.

[44] EV·PVH roadmap in Japan (Ministry of Economy, Trade and Industry, Japan) March 2016

South Africa Contribution: SAAE

South African Academy of Engineering
Philip Lloyd

1. Going towards an all-electric society?

We have had a very successful renewable energy procurement programme, which has had four rounds of bidding. Its present commitments are:

	Capacity, MW	*No. of projects*
Onshore wind	*3357*	*34*
Solar PV	*2292*	*45*
Solar CSP	*600*	*7*
Landfill gas	*18*	*1*
Biomass	*42*	*2*
Small hydro	*19*	*3*
	6327	*92*

Contract prices have fallen with each of four rounds of bidding. Some of the more recent solar CSP have included thermal storage, and receive more for power delivered during peak demands.

Energy policy envisages plateauing emissions about 2025, with a decline towards zero by 2050. Two major coal-fired plants have recently been built – approximately 4,800 MW each, but there are plans to retire about 20 GW of old stations by 2025. CCGT using imported LNG is to take its place.

Electric drive vehicles are low on the agenda at present. Much of the internal heavy transport is by diesel, and given the distances involved, electric drive is not attractive. The rail system is largely electrified, but it suffers from low maintenance and consequent erratic service, and is far from realizing its potential.

2. Generating electricity

2.1. Generating electricity from sustainable resources

2.1.1. Status quo: current national energy mix

See list in table above

2.1.2. Energy mix –future goals and national strategy

Our Government would like to plateau emissions around 2025 and see declining emissions thereafter

2.1.3. Latest technologies facilitating the strategy

All renewable technologies are in play. We have an excellent solar resource, and are tapping this via both PV and CSP, the latter both linear mirrors and solar towers. The wind resource is good, and we are employing the latest onshore technology – offshore, conditions are too extreme to be attractive.

2.1.4. Phasing-out technologies

Much of the conventional coal-fired generation is to be phased out.

2.2. Carbon Capture and Storage (CCS): binding carbon dioxide (CO_2) emissions when dealing with carbon

2.2.1. Status quo and relevance for the country

Does your country/academy work with CCS? Yes

2.2.2. Challenges, future plans/strategies

We lack pore space. The sub-continent is old and consolidated. We are exploring two potential sites for CCS, but have doubts about the integrity of seals.

2.2.3. Latest technologies facilitating the strategy

See above

3. Distributing electricity – Grids

3.1. Status quo – current national situation

Most transmission is high voltage AC; there is a high voltage dc line 1000 km from Cahora Bassa. Local distribution is shared between the state utility, Eskom, and municipalities. Energy security depends on fuel supply; at present it is shaky because of underinvestment in coal mines. It is intended to move towards CCGT, but this will require import facilities as well as new generation facilities.

3.2. Challenges, future plans/strategies

Probably the most important is UHV DC; we intend to import at least 20GW from Inga Falls on the Congo.

4. Storing electricity

4.1. Status quo – current national situation

We have about 3.6 GW of pumped storage, the only proven, cost effective storage technology.

4.2. Challenges, future plans/strategies

None

4.3. Latest technologies facilitating the strategy

Hindrance is general lack of water and geography to extend pumped storage.

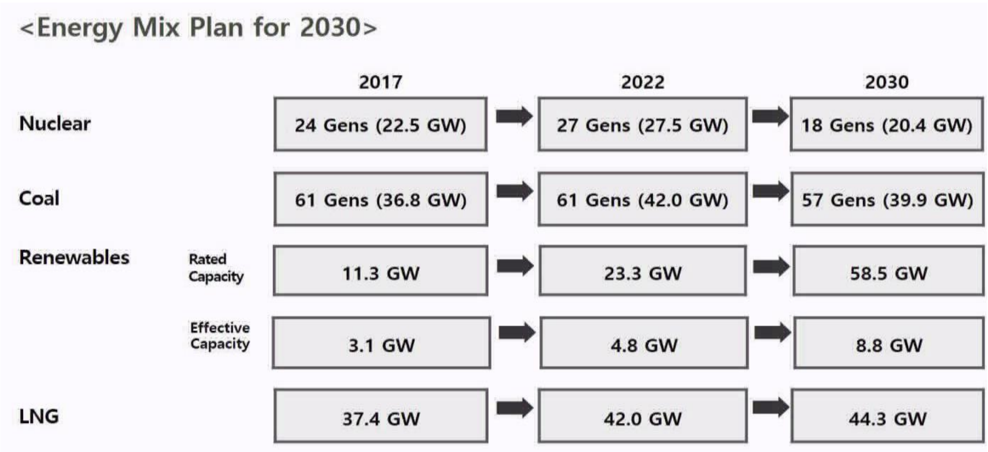
South Korea Contribution: NAEK

The National Academy of Engineering of Korea
Seung-il Moon and Chinho Park

1. Going towards an all-electric society?

Korea has recently suffered from serious environmental pollutions due to fine dust, radioactive contamination, and greenhouse effect. For this reason, Korean government is strongly promoting clean energy as well as all electrification. For electrification, Korean government is making efforts to 1) change the energy mix focused on renewable energy sources such as PV and wind, and to 2) promote electric vehicle (EV) and hydrogen vehicle (HV) dissemination.

For renewable energy-driven power supply, Korean government established the Korea's Energy Transition Roadmap which outlines a basic direction of the government's new energy policy in October 2017. On the basis of this roadmap, The 8th Basic Plan of Long-term Electricity Supply and Demand was prepared. In this plan, while ensuring economic feasibility, the safe and clean energy mix is further emphasized. Future energy mix plan of Korea is shown below: It shows that the nuclear and coal energy will decrease, and renewable and gas energy will increase.



<Energy Mix Plan for 2030>

		2017	2022	2030
Nuclear		24 Gens (22.5 GW)	27 Gens (27.5 GW)	18 Gens (20.4 GW)
Coal		61 Gens (36.8 GW)	61 Gens (42.0 GW)	57 Gens (39.9 GW)
Renewables	Rated Capacity	11.3 GW	23.3 GW	58.5 GW
	Effective Capacity	3.1 GW	4.8 GW	8.8 GW
LNG		37.4 GW	42.0 GW	44.3 GW

Figure 1 - Energy Mix Plan in The 8th Basic Plan of Long-term Electricity Supply and Demand

In order to reduce the environmental pollution caused by internal combustion engine vehicles, there is a growing interest in electric and hydrogen vehicles. To commercialize electric vehicles, Korean government has set various goals and strategies for electric vehicle technology development, supply, production, and infrastructure construction at the national level. According to the '2030 Proliferation Strategy of New Energy Industry' announced in 2015, national projects have been carried out with the goal of 1 million electric vehicles by 2030. The main contents are as follows:

- Targeting 100% EV in Jeju Island by taking advantage of short driving range and more than 10 million visitors every year
- Promoting the supply of public transportation and rental cars for expanding EV market (17.9 trillion KRW market - 30,000 new hires by 2030). Expanding EV markets can reduce 1.2 million tons of greenhouse gas.
- Establishing EV-related policies to create EV-friendly ecosystem.

- In June of 2018, Korean government also announced a plan for expanding hydrogen vehicles (15,000 vehicles by 2022 including 1,000 buses) and constructing 310 hydrogen charging stations by 2022.

Conclusion: Electrification, along with renewable energy sources and EVs, will continue to be a major trend and driver in the Korean energy transition. As planned, renewable electricity will be over 20% of total power supply by 2030, and 1 million EVs will be operating in Korea. Although complete electrification will not be achieved by 2030, it seems that Korean energy system will be much more electrified than now. The Government also announced 'Hydrogen Economy Roadmap' towards 2040, which aims at producing 6.2 million Hydrogen FC cars by 2040.

2. Generating electricity

2.1. Generating electricity from sustainable resources

2.1.1. Status quo: current national energy mix

Table 1 - Installed Electricity Generating Capacity and Gross Generation (as of 2017F)

		Capacity (MW)	Generation (GWh)
Hydro		6,489 (5.56%)	6,995 (1.26%)
Thermal	**Oil**	4,155 (3.55%)	8,648 (1.56%)
	LNG	37,838 (32.37%)	123,232 (22.27%)
	Coal (Bituminous)	36,109 (30.89%)	235,860 (42.62%)
	Coal (Anthracite)	600 (0.51%)	2,378 (0.43%)
Nuclear		22,529 (19.27%)	148,427 (26.82%)
New & Renewable		9,187 (7.86%)	27,928 (5.05%)
Total		116,908 (100%)	553,467 (100%)

Table 1 shows the Korea's installed electricity generation capacities and annual gross power generation amount by energy sources as of 2017F (ref. Kepco in brief 2017). In Korea, New & Renewable Energy (NRE) power and hydro power are defined as sustainable resources, in which renewable energy includes PV, wind, marine, bio and waste, and new energy includes fuel cell and IGCC (integrated gasification combined cycle). As of 2016F, electricity generation by NRE and hydro was 40, 655.8 GWh which is about 7.24% of total electricity generation of 561,825.75 GWh. It should be noted that there is a mismatch in values with the ones in Table 1 due to the self-use NRE power. The (NRE+hydro) power is consisted of 12.6% PV, 4.1% wind, 1.2% marine energy, 15.3% bio energy, 56.0% waste energy, 2.8% fuel cell, 0.9% IGCC, and 7.0% hydro. In Korea, the portion of waste and bio energy among the sustainable energies is the majority, and some waste energies are not the renewable energy by international standards. Table 2 lists a few relevant statistics of Korea.

Table 2 - Country Information of Korea

Retail Electricity Prices for an household (range)	KRW 93.3~280.6
Retail Electricity Prices for a commercial company (range)	KRW 53.7~196.6
Retail Electricity Prices for an industrial company (range)	KRW 53.7~196.6
Population at the end of 2017	51,778 million
Country size (km^2) at the end of 2017	100,363.7
Name and market share of major electric utilities	KEPCO only

2.1.2. Energy mix –future goals and national strategy

To promote further development of renewable energy, the Ministry of Trade, Industry and Energy (MOTIE) of the Republic of Korea released a draft of its "Renewable Energy 3020" implementation plan. It declared that renewable energy electricity share will increase from 7% to 20% of total generation by 2030, adding 48.7 GW new RE generating capacity (currently 15.1 GW as of 2017). Total RE power generation capacity will reach 63.8 GW by 2030.

To achieve this goal, the MOTIE intends to expand PV systems for personal use in rural and small business area by 19.9 GW, which would represent 40% of new capacity. The remaining 28.8 GW will be supplied by large-scale PV projects and wind projects (16.2 GW). Specific Renewable Energy 3020 targets are shown in Fig. 2.

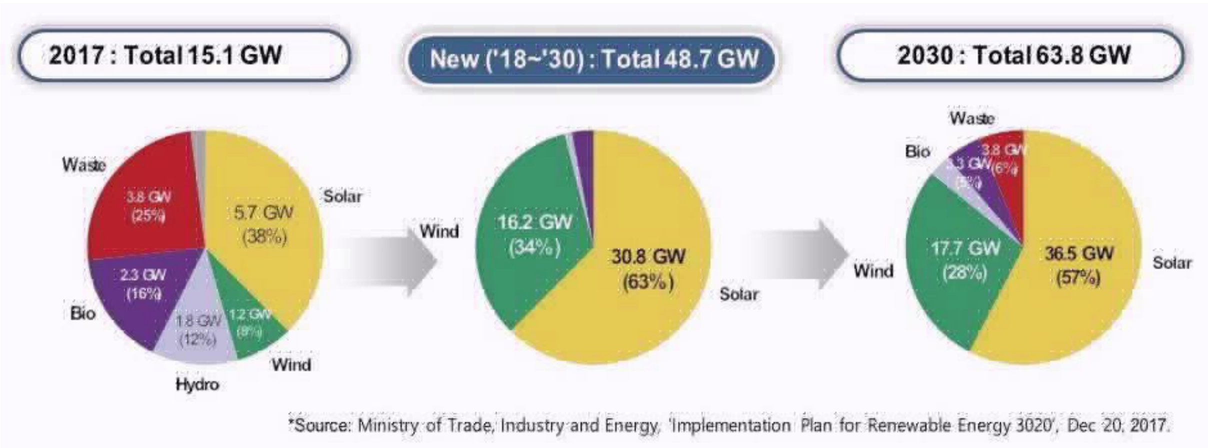


Figure 2 - Renewable Energy 3020 Plan

In order to facilitate RE dissemination, the MOTIE is planning to introduce a feed-in tariff system tailored to South Korea. This system will make it mandatory for the six public power producing companies to purchase energy produced by PV systems with a capacity of less than 100 kW owned by farmers and with a capacity of less than 30 kW owned by private business operators. The energy will be purchased at a fixed price for the next twenty years. The government also announced that it will encourage public power generators to work on large-scale projects by increasing the mandatory renewable energy supply rate from its current level of 5% to 28% in 2028 under the existing Renewable Portfolio Standard (RPS) scheme.

In addition to this, various regulations that had limited the expansion of solar energy for personal use will be relaxed. The government is planning to adjust the rules so that KEPCO can provide cash reimbursement for leftover electricity generated by personal solar panels.

Furthermore, previous policy for a program that had only allowed the installation of solar panels on buildings constructed prior to the end of 2015 is changed. And even inside agricultural promotion zones, where solar panel installation is banned, 20-year solar panel projects will be allowed. To prevent rampant development by outsiders, a “planned site system” is being adopted by local governments.

The Ministry predicts that facility investment will cost about 100 trillion KRW ($93 billion) altogether, including 51 trillion KRW ($47.4 billion) from the public sector and 41 trillion KRW ($38.1 billion) from the private sector. The Ministry estimates that the price of electricity will only rise by 1.3% through 2022 and by 10.9% through 2030 compared to 2017, even if the cost of investing in renewable energy facilities is taken into consideration.

2.1.3. Latest technologies facilitating the strategy

As explained in the previous paragraph, PV and wind will be two major sustainable electricity sources by 2030 in Korea. Due to the limitation of the sites in Korea, many different types of installation will be promoted. In PV sector, Building Integrated PV (BIPV), Agri-PV, On-water PV, Marine PV, Road Integrated PV, Car-roof PV will be developed and deployed. In the wind sector, off-shore wind and floating wind will be mainly developed and deployed. Small scale wind for building applications will also be investigated. To overcome the intermittency of variable renewable energy (VRE) sources, various types of RE-hybrid systems including PV-ESS are expected to be developed.

2.1.4. Phasing-out technologies

Korean government announced a long-term (over 60 years) phase-out of nuclear power plants due to issues in nuclear wastes, recent earthquakes near nuclear power plants area. Also due to the air pollution and fine dust issues, new coal power plants will not be constructed, and old coal power plants will be closed earlier than the designed life. To facilitate the clean energy expansion in South Korea, tax system will be modified to promote the RE electricity but to discourage the nuclear and the coal.

2.2. Carbon Capture and Storage (CCS): binding carbon dioxide (CO_2) emissions when dealing with carbon

2.2.1. Status quo and relevance for the country

In Korea, most of the R&Ds related with CCS was handled by the Government in the last 20 years developing various (both wet and dry) technologies to capture CO_2. Pilot-scale (10 MW) CCS plant (wet type) was constructed by POSCO in 2013 but still not commercialized due to its high cost. Additionally, the issue of CO_2 storage is not solved (there is no reliable site for storage) until now, thus the CCS research is changing its direction more towards ‘Utilization.’

2.2.2. Challenges, future plans/strategies

There is no specific strategy or roadmap made in Korea for CCS technology deployment aiming for 2035. As mentioned above CCS research is changing its direction more towards utilization.

2.2.3. Latest technologies facilitating the strategy

Both wet and dry processes to capture CO_2 more efficiently will be developed in Korea, but the utilization R&D is expected to grow in the near future.

3. Distributing electricity – Grids

3.1. Status quo – current national situation

Korean electricity systems are all interconnected by a single national grid which is consisted of AC 765 kV (1,019 c-km), 345 kV (9,746 c-km), 154 kV (22,831 c-km), and 66 kV or lower (128 c-km) lines together with DC 180 kV (231 c-km) transmission lines as of 2017F. Distribution route length is 483,467 c-km as of 2017F. Korea's transmission and distribution loss factor is 3.57% which is one of the best electricity quality in the world, having a yearly average blackout time for a household of 8.59 min. Korea's electricity is precisely controlled in voltage (110±6 V, 220±13 V, 380±38 V) and frequency (60±0.2 Hz), too. Electricity is generated and sold by Kepco (the only company in Korea handling generation, transmission and distribution of the electricity) to 22,858,000 customers from residential, commercial/public and industrial sectors.

Although two HVDC lines (submarine) are connecting the Korea's largest island, Jeju, with the main peninsula, Korea is completely isolated in electricity from neighboring countries (China, Japan, and North Korea). Therefore, the security and reliability of electricity supply has been the upmost policy priority in Korea in the last 70 years.

3.2. Challenges, future plans/strategies

1. Microgrid (MG)

The smart grid has been one of the main Korean green growth strategies since its inception in 2008. There have been several initiatives, including the creation of new institutions such as the Korea Smart Grid Institute (KSGI), a new industry association, the Korea Smart Grid Association (KSGA), and the formulation of an industrial roadmap, the Korean Smart Grid Roadmap 2030.

Korean government has focused on modular microgrids with the development of an urban-based modular concept and island-based microgrids. In December 2008, the government allocated investment funds of 76.6 billion KRW (approximately $66 million) to the construction of a smart grid test-bed on Jeju Island – at the time the largest smart grid test bed in the world – with investment from the private sector totalling 172.7 billion KRW ($149 million).

Gasa Island Microgrid is one of the microgrid test beds. Gasa Island in South Jeolla province, is the world's first independent microgrid using a Korean-built Energy Management System (EMS). The Korea Electric Power Corporation (KEPCO) purchased all necessary devices including wind turbines, PV modules, batteries, computer systems and other components, while the EMS was developed in-house as shown in Fig. 3 below.

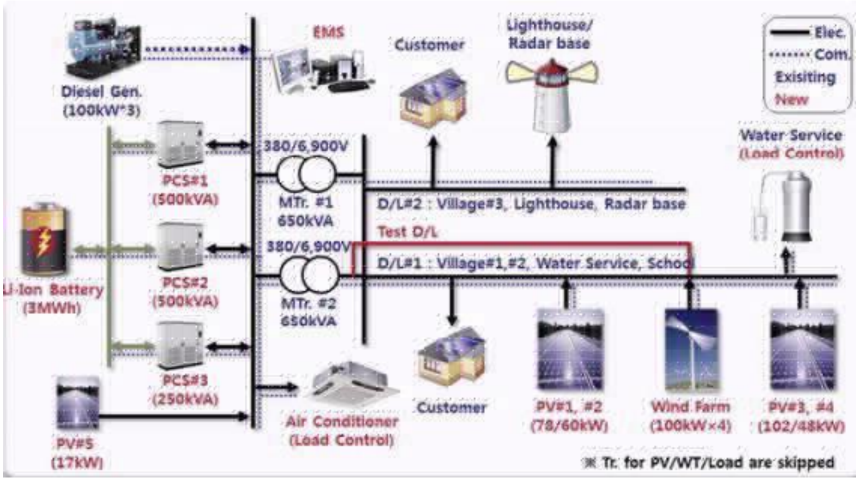


Figure 3 - Gasa Island Microgrid Plan

Since the beginning of operation, the microgrid has typically replaced around 80% of the diesel-engine power output in the island. After the microgrid was installed, the cost of generated electricity in Gasa fell by around 40%. Power quality on the island has also been improved very significantly. Only 57% of the total time comes in the range of frequency within 0.2 of 60 Hz as compared to 100% with the microgrid. By being able to run the diesel generator set at its highest efficiency, rather than using it to regulate frequency, this has improved its fuel efficiency by over 14%. The Gasa Island project was launched as a prototype for as many as 86 other island-based projects planned by KEPCO. KEPCO is planning to roll out the microgrid on the Ulleong Island with 10,000 residents (and five other island locations) by late 2017 or early 2018. One of the main goals in the next development phase of these microgrid projects is to increase the renewable make-up of energy sources on islands such as Ulleung to 100% by 2021.

2. High Voltage, Direct Current (HVDC)

At present, South Korea has ac transmission and distribution system. However, as the scale of the power grid and the importance of renewable energy are emphasized, research on dc system is actively attracting attention. Nowadays, high voltage direct current (HVDC) is the main topic of research in transmission field. Although the cost of facility is higher, low power losses make the grid more efficient for long-distance transmission and thus total cost for transmission can be lower. In South Korea, sub-marine HVDC cables are installed from Jeju Island to Jindo and Haenam. Also, Jeju smart grid test bed, which is for researching smart power grid, smart place, smart transportation, smart renewable energy, and smart power service, is coordinated with HVDC. HVDC project linking Godeok and Dangjin is also in progress. These projects are to prepare for East Asia super grid. The super grid is a huge plan to connect several countries' grids which are South Korea, North Korea, Russia, China, Japan, and etc. By building a power grid that crosses the border, it can draw electricity from one country to others. It could contribute to lowering the costs and stimulating the use of renewable energy. The East Asia Super Grid plan is schematically shown in Fig. 4.

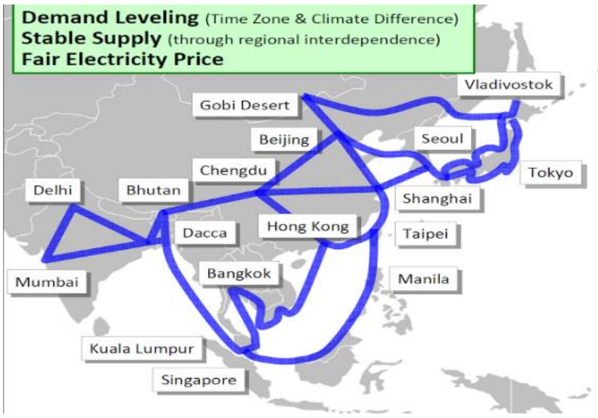


Figure 4 - East Asia Super Grid Plan

3.3. Latest technologies facilitating the strategy

Grid modernization is one of the major concerns in Korea to handle the ever-increasing level of renewable electricity into the existing grid infrastructure. It involves an introduction of a new 70 kV transmission lines, development of two-way HVDC lines with multi-level converter based on voltage source converter, etc. Big-data based electricity supply and demand management will also be developed to facilitate the high-level of renewable electricity penetration into the existing grid as well as new business incubation.

4. Storing electricity

4.1. Status quo – current national situation

Currently Korea has a pumped hydro storage with the capacity of 4.7 GW which serves as a single electricity storage system in the national grid. Historically Korea's electricity is managed by the precise control of demand and supply with backup generators (mostly LNG with small amount of diesel). With the recent increase in renewable electricity penetration into the existing grid, other storage options such as lithium battery storage are under consideration and testing.

4.2. Challenges, future plans/strategies

Energy storage system (ESS) is the capture of energy for use at a later time. It consists of energy storage, such as traditional lead acid batteries and lithium ion batteries, and controlling parts, such as the EMS and power conditioning system (PCS). Installation of the world's ESS has increased from 700 MWh in 2014 to 1,629 MWh in 2016. As of 2016, Korea's ESS installation level increased by 52.4 MWh and reached 291.4 MWh which is 18% of the world market share. Its share is slightly over half of the United States' market share. Even other developed countries such as Japan, Germany and Italy are far behind Korea. Korea's lithium ion battery production is one of the world's highest and continues to increase rapidly. In particular, major Korean companies like LG Chem produces 591 MWh, while Samsung SDI's production level is 544 MWh, which is larger than those of other global major companies like China's BYD (188 MWh) and the U.S.' Tesla (186 MWh). The domestic ESS market increased to USD 263.1 million in 2016 and the country's ESS export also grew rapidly to USD 400 million last year.

Especially, Korea's ESS industry leads the frequency regulation market in the world. KEPCO had installed the country's first energy storage system for power system frequency regulation at the West-Ansung substation in Gyeonggi Province in 2015. With the installation of ESS for frequency regulation, KEPCO expected to be able not only to reduce power purchasing costs, but also to lay the foundations for the development of related industries. Starting with the 56-MW ESS in the West-Ansung sub-station, KEPCO with Korean battery provider Kokam built ESS units to a scale of 500 MW in total with an investment of 568 billion KRW ($503 million) for frequency regulation by 2017. The ESS will enable KEPCO to improve its operational efficiency by reducing the need for spinning power generation reserve. This will allow KEPCO to shift energy generation to lower cost and decrease abrasion on all its power plants. This accounts for about 40% of the FR market in Korea and will save power purchasing costs by 320 billion KRW a year. In addition, the ESS will reduce CO_2 emitted by the utility.

4.3. Latest technologies facilitating the strategy

Furthermore, Korea will create 440 billion KRW ($390 million) for new demand ESS by 2020. From 2017, the Korean MOTIE allocated additional points on operators' renewable energy certificates for establishing bulk ESS. The stimulus follows a similar government initiative for wind farms last year. The Ministry said the benefit programme is aimed at encouraging local power operators to save energy in large-scale batteries and distributing the power efficiently.

Switzerland Contribution: SATW

The Swiss Academy of Engineering Sciences,
Rolf Hügli

1. Going towards an all-electric society?

Today 25% of the energy used in Switzerland is delivered by electricity. In 2017 the voters have accepted a new legislation, called Energy Strategy 2050. With this strategy Switzerland is moving towards a higher share of (renewable) electricity (from 25% to 50%) and yearly energy related CO2-emissions of 1-1,5 ton/capita (a reduction of 70-80% as compared to today).

During this period nuclear power which today covers 40% of the nation's consumption will be abandoned. There is however no defined end of service date. The law allows for a continuation as long the operation is safe. This calls for a replacement of up to 24 TWh/a which is supposed to come largely from new renewables (not including hydropower). Hydro power which today amounts to 37 TWh/a, can be increased by 5-10% only.

While on a yearly balance, the amount of electricity produced in Switzerland is sufficient, there is a mismatch between production and consumption both during summer and winter time. As a consequence, there will have to be either imports or new seasonal storage facilities have to be built.

Switzerland's "Energy Strategy 2050" also calls for an overall energy consumption per capita that is reduced by 43% in 2035 and 54% by 2050 (reference year 2000). This is equivalent to reduce the country's overall energy consumption to 549 PJ (or 152 TWh) by 2035 and 451 PJ (or 125 TWh) by 2050, down from about 980 PJ (272 TWh) today.

Each Sector – Building, Industry, Transportation – will have to contribute to the sector specific target: CO2-emissions regulations similar to EU for transportation and electrification of cars, ambitious targets for the building sector facilitated by a CO2-tax for heating oil and subsidies for thermal insulation measures, and Industry by options to avoid CO2-taxes by technical improvement that help reduce emissions.

Conclusions:

All targets for 2050 – efficiency, renewable power, and CO2 emissions reduction – are considered to be very ambitious. The individual challenges are:

- to reduce the final energy per capita (and also per unit of BIP) at rates that have never been seen,
- to reduce the amount of electricity consumed per capita given the electrification of the whole society (electrical vesicles, electrical heat pumps, expansion of ICT, etc.) and to maintain the total of the current level of electricity consumption for the nation, given the population growth we have seen in the past years (ca. 1%/a)
- to find large and small storage capacity for electricity storage that allow to store summer electricity and to make it available for the use during the winter months.
- to clarify our relation with the EU, in particular regarding the electricity market (trade and for a full participation

- -to find ways of effective CO2 emissions in the transportation areas, given the stagnation in the recent years (and the preference of Swiss consumers for heavy cars).

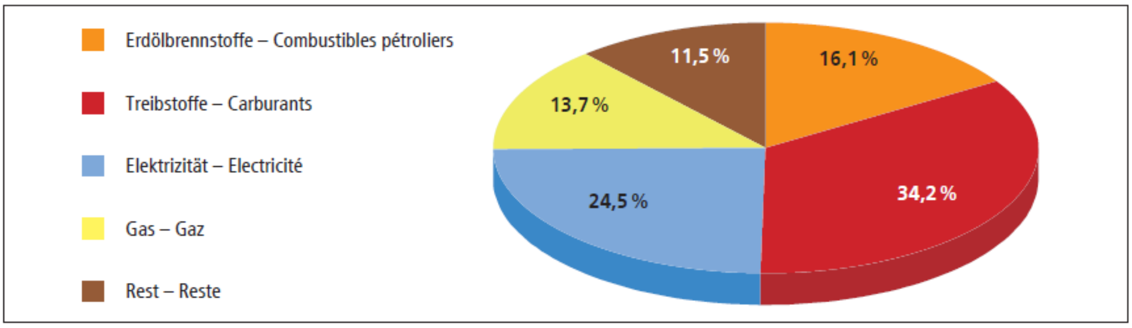


Figure 1 - Distribution of energy consumption by primary energy sources in Switzerland (2016)

2. Generating electricity

2.1. Generating electricity from sustainable resources

2.1.1. Status quo: current national energy mix

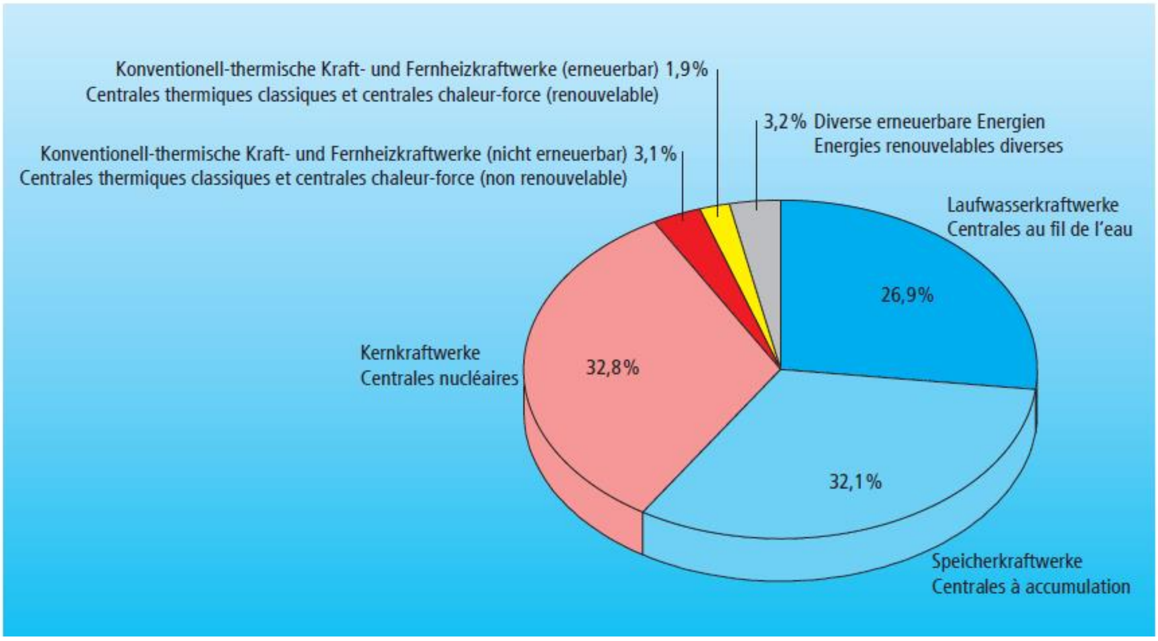


Figure 2 - Electricity production by power plant category

Sustainable Resources for generation of electricity in Switzerland:

Hydro, PV, wind energy, geothermal (heat and electricity), ambient heat, waste heat, biomass, waste incineration (50% defined to be sustainable), Biogas (from fermentation processes).

2.1.2. Energy mix –future goals and national strategy

The average electricity consumption per person per year is expected to decrease by 13% (18%) by 2035 (2050) against the base year 2000. This corresponds to an estimated power consumption of 55 TWh and a national consumption of 60 TWh (including grid and pumping losses)

The average annual production of electricity from new renewable energies should be at least 14.5 (24.2) TWh in 2035 (2050) (without water power, i.e. PV, wind, biomass, possibly geothermal) .The individual annual contributions in 2050 are : 11.1 TWh from PV, 4.3 TWh from Wind, 1.2 TWh from Biomass; 4.4 TWh from Geothermal and 3.2 TWh from Incineration (renewable share) and Biogas together.

The average annual production of electricity from hydropower in 2035 (2050) should be at least 37.4 (38.6) TWh (for pumped storage plants, only production is expected due to the natural inflow of water).

Additional information:

The average final energy consumption per person and year until 2035 (2050) shall be reduced by 43% (54%) as compared to 2000 (final energy consumption in 2000: 980 PJ or 272 TWh).

Switzerland's CO_2 targets are the following:

- By 2050, the energy related CO_2 emissions are set to be 1-1.5 t CO_2/person and year (down from about 5 t/person and year today.
- By 2030, minus 30% domestically as compared to 1990, (minus 50% in total, i.e. 20% contribution from actions abroad, CH commitment by Paris Agreement from October 2017)
- Target for cars: target 2015 was 130 g/km; target 2020 is 95 g/km
- Building sector: CO_2 tax on heating oil up to 210 CHF/ton; subsidies for "energetic refurbishment"
- Industry: Reduced CO_2 taxes in compensation for technical measures to reduce CO_2 emissions
- Coupling of the Swiss CO_2 trading system with the EU emissions trading

Comment:

With all the projections of electric vehicles, heat pump diffusion, ICT etc. it is questionable whether the electricity targets 2035 and 2050 can be achieved.

It's also questionable whether the aimed at 4 TWh/a of wind energy and 4 TWh geothermal power will materialize. A large contribution of PV (14 TWh/a) to the electricity mix however seems feasible.

2.1.3. Latest technologies facilitating the strategy

With the Energy Strategy 2015 Switzerland has decided to phase out Nuclear Energy; no new Nuclear Power Plant can be approved anymore. The existing nuclear plants currently contribute 24 TWh/a (or 40% of the domestic consumption) and can stay in operation as long as they are safe; there is no predefined exit date. The first plant (Mühleberg) will be taken out of service in 2019; none of the remaining 4 plants have been assigned a definite deadline so far.

The nuclear power is supposed to be compensated partly by power from PV, Wind, Geothermal and Biomass. Partly, it's supposed to be compensated by efficiency gains of electrical equipment, partly by imports from the EU (during the winter season)

2.2. Carbon Capture and Storage (CCS): binding carbon dioxide (CO_2) emissions when dealing with carbon

2.2.1. Status quo and relevance for the country

CCS is not considered in Switzerland as a practical option. However, there is some academic work (Prof. M. Mazzotti, ETH and his group) with public finanzing (BFE) and Prof. L. Diamond, University of Bern.

Industrial work (by former Alstom in Baden) has been discontinued.

2.2.2. Challenges, future plans/strategies

No plans for CCS, just discussions, in Switzerland. Sequestration of CO_2 in Switzerland is most probably politically not an option.

2.2.3. Latest technologies facilitating the strategy

Technologies in pilot and demonstration projects:

Power-to-gas, Batteries for grid services, Adiabatic Compressed Air Storage, Smart grids, new storage lakes where glacier retreat/melt down, new HV-lines (AC/DC hybrid lines)

3. Distributing electricity – Grids

3.1. Status quo – current national situation

New HV lines within the country are being planned. However, realizatin is difficult due to resistance.

3.2. Challenges, future plans/strategies

The grid strategy (Strategie Netze) aims to accelerate the enhancement of the grid (new high-voltage lines should be realized within 4-8 years instead of 5-13 years, in extreme cases up to 30 years) For buried cables criteria have been defined for the first time. (see Pt. 3.1.2)

4. Storing electricity

4.1. Status quo – current national situation

Switzerland has a long history of hydro dams for topographic reasons. There are 53 Storage lakes (for Hydropower) containing 10 billion m^3 of water.

In some of them pump storage is implemented to provide peak power.

4.2. Latest technologies facilitating the strategy

There are big battery storage tests (EKZ/ABB in Dietikon und EKZ in Volketswil) going on for providing grid services (primary, secondary reserve) and Power-to-Gas test plants in various places.

USA Contribution: NAE

National Academy of Engineering
Alton D. Romig Jr.

1. Going towards an all-electric society?

In the absence of any major policy initiatives, production and consumption of liquid fuels and petroleum products will remain widespread across the U.S. economy (Figure 1), with the largest use in transportation. Although electrification of transport will continue, market penetration of electrified vehicles (defined as hybrid electric, plug-in hybrid, and battery electric vehicles) has been slow in the U.S. (~ 4% of new vehicle sales in 2017) and is projected to increase modestly over the next 30 years (~ 20% by 2050) according the Energy Information Agency's 2018 Annual Energy Outlook.[45] Of that 4% of new vehicle sales, only about 1% are the types of vehicles (plug-in hybrids and battery electric vehicles) that are solely or partially fueled by electricity.

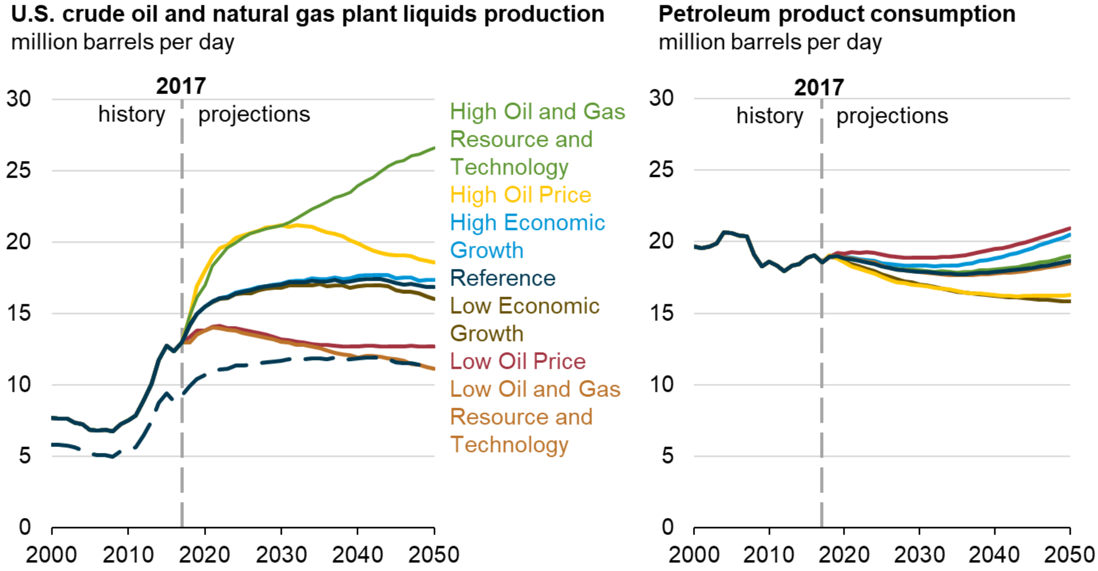


Figure 1 - Production (left) and consumption of petroleum products (right) in the U.S is projected to increase or remain steady under most future scenarios over the next 30 years, with model forecasts sensitive to oil price. [From EIA AEO 2018]

2. Generating electricity

2.1. Generating electricity from sustainable resources

2.1.1. Status quo: current national energy mix

In 2017, U.S. electricity generation was split into approximately 30% coal, 32% natural gas, 20% nuclear, and the remainder was renewable generation (~ 17%). Renewable generation is dominated by hydroelectric facilities (~ 7.5%), followed by wind (~ 6%), biomass (~ 1.6%), and solar photovoltaics (~ 1.2%). Historically coal was a much larger fraction of total U.S. electricity generation (Figure 2), but coal use has declined substantially with increasing market share of low-cost natural gas. Renewables, and particularly large wind power, have benefitted from federal and state policies to encourage devel-

45 https://www.eia.gov/outlooks/aeo/

opment of low carbon resources (e.g., Federal Production Tax Credit, State Renewable Portfolio Standards), and are increasingly cost competitive with conventional generation sources, which underlies their projections of continued growth.

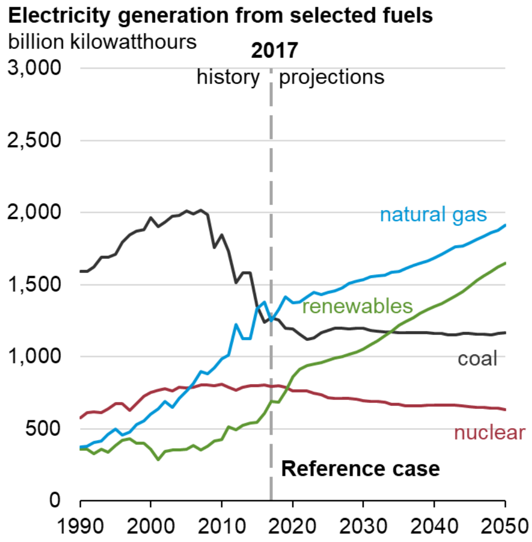


Figure 2 - The current and future electricity fuel mix is generated from natural gas, coal, renewables, and nuclear, with natural gas and renewables projected to continue their growth over the next 30 years. [From EIA AEO 2018].

The primary driver of change in the generation resource mix in the U.S. is the relative cost (including both capital expenditure and operational costs) of different generation facilities and fuels. As most generation is regulated by state public utility commissions or procured in competitive markets, economic forces drive towards the lowest cost resource. As discussed more below, various tax incentives and state and federal policies also play in role in the current and future generation mix.

2.1.2. Energy mix – future goals and national strategy

The current administration maintains an “all of the above” energy strategy that supports diverse fuel sources for electricity generation. Previous administrations have more aggressively pursued emissions reductions, for example former President Obama’s Clean Power Plan, which called for more than 30% reductions of carbon dioxide emissions from 2005 levels by 2030. At the sub-national level, there is wide variability in the renewable energy goals of individual states as shown in Figure 3, with some (e.g., Hawaii) striving for 100% renewable energy production by 2045, while others have no goals/mandates for renewable generation (Figure 3).

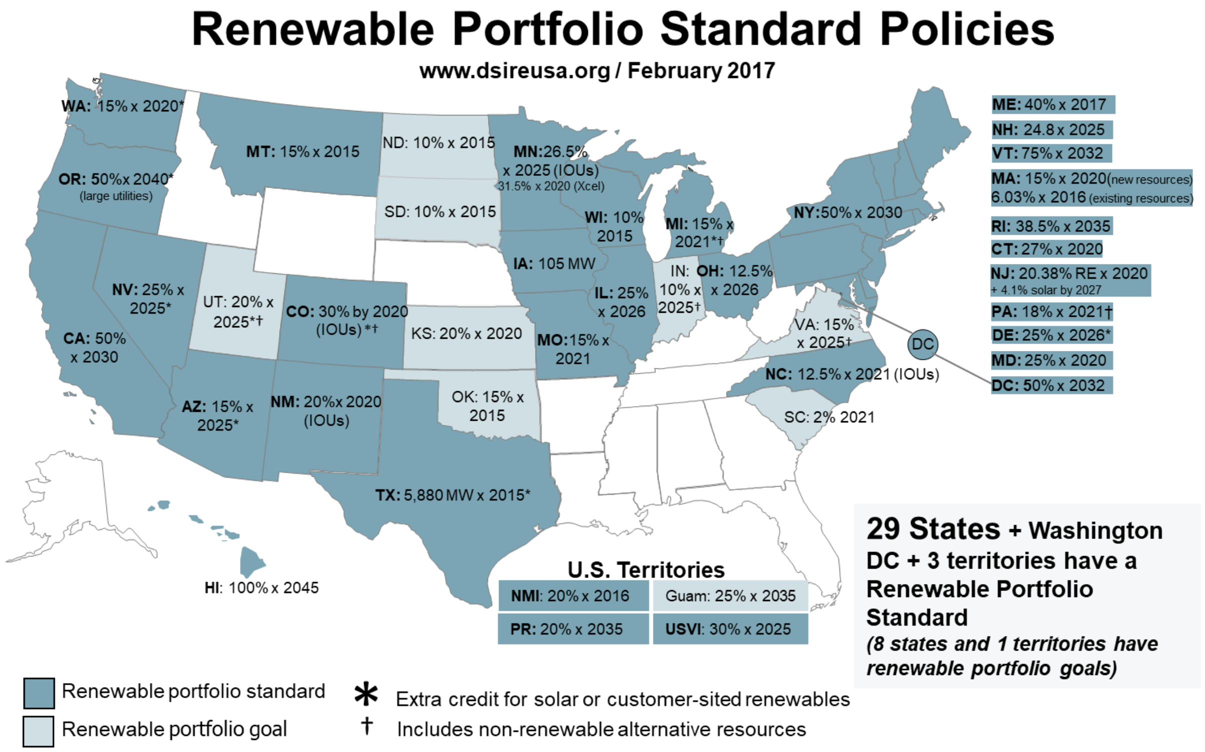


Figure 3 - Summary of state renewable portfolio standards that require electric utilities to meet minimum thresholds for renewable generation. [From DSIRE database, last update February 2017]

Referring to Figure 2, the share of electricity produced from natural gas is projected to continue increasing over the coming decades, as well as production from renewables (particularly wind and solar). Both coal and nuclear are forecast to have modest declines in generation capacity and almost all new capacity additions are expected to be natural gas or renewable. Changes in the generation mix are driven largely by the relative cost of different sources with the goal of providing lowest cost electricity to the end consumer.

Although there is no singular national strategy guiding the evolution of the electric generation portfolio, an array of federal and state policy tools are used. The federal production tax credit is a per-kilowatt-hour tax credit for electricity generated by qualified renewable energy resource and has been particularly successful in bringing more utility-scale wind power into the mix. Similarly, the federal investment tax credit for solar has been successful in bringing more residential and commercial solar on-line. The individual state renewable portfolio standards also have brought more renewable electricity into the system. Further, many states also provide some tax credits for installation of solar and other renewable electricity. The current administration has demonstrated concern regarding closure of coal and nuclear generators. The Secretary of Energy and others have explored mechanisms to guarantee profits for coal and nuclear plants operating in competitive markets.

The U.S. National Academies of Sciences, Engineering, and Medicine (the Academies) has produced numerous reports related to clean energy technologies, but has not advocated for a specific generation mix as most appropriate. Instead, Academies' reports call attention to large emissions reductions achievable through technology and policy changes—for example, the consensus report *America's Energy Future (2009)* concluded that:

> …substantial reductions in greenhouse gas emissions from the electricity sector are achievable over the next two to three decades through a portfolio approach involving the widespread deployment of energy efficiency technologies; renewable energy; coal, natural gas, and biomass with carbon capture and storage; and nuclear technologies...

More recently, the consensus report *America's Climate Choices (2011)* recommended that the nation strive to reduce emissions substantially over the coming decades, but again did not specify what electricity generation resources should be pursued and instead emphasized the importance of proper price signals for carbon emissions.

2.1.3. Latest technologies facilitating the strategy

Operators and asset owners rely on a diverse set of technologies to accommodate changes in the generation portfolio (technologies related to transmission and distribution are discussed below), including utility-scale battery storage, demand response programs, time of use rates, and advanced metering infrastructure (so called "smart meters").

While distributed generation (DG) (e.g., rooftop photovoltaics) accounts for a relatively small fraction of overall electricity production, select locations such as Hawaii and some distribution circuits in California have large fractions of DG installed which can require investments and upgrades to hardware. As DG grows, inverter technologies and standards are evolving and increasingly important to system performance.

2.1.4. Phasing-out technologies

There are currently no official programs to phase out specific technologies or fuels in generation. Liquid fuels (fuel oil and diesel), however, have largely phased out of the generation mix due to cost and environmental concerns, and are only used rarely for electricity generation. The exception to this are islands such as Puerto Rico and Hawaii and remote areas such as in Alaska. Some of these areas have tried to eliminate reliance on liquid fuels for generation (e.g., Hawaii pursuing 100% renewables by 2045). But in many cases, this is not feasible, for example Alaska's low population densities and limited renewable resource potential result in widespread reliance on diesel generators for remote populations.

Although not driven by a coordinated national policy, the higher cost of coal and nuclear generation has led to numerous retirements. These retirements are projected to continue, affecting the existing coal fleet most significantly, and there are essentially zero projected additions of coal and very limited additions of nuclear in the next 30 years (Figure 4).

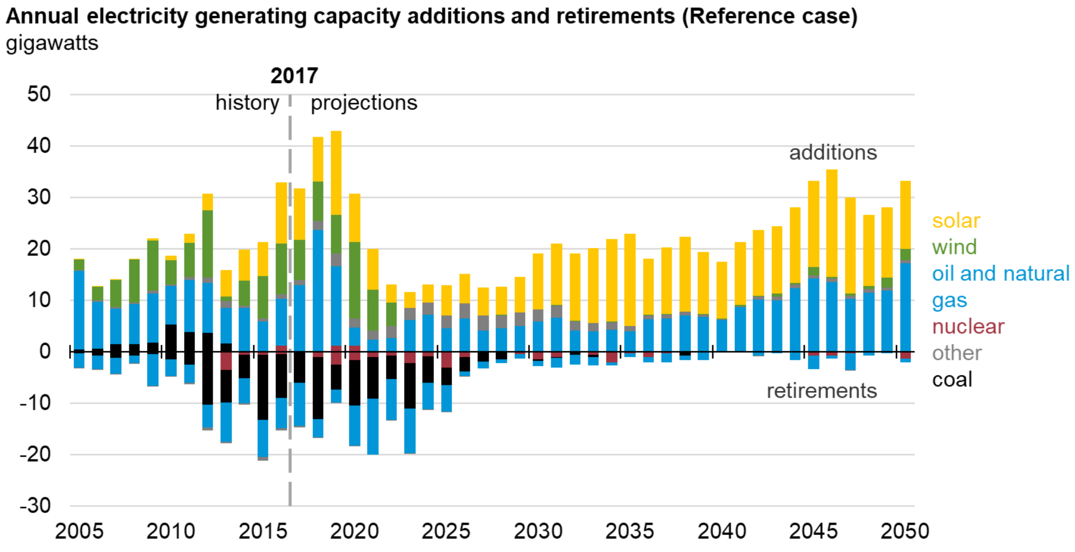


Figure 4 - Numerous coal and several nuclear plants have retired over the past 10 years, with retirements projected to continue due to their relatively high capital and operational cost compared to natural gas and renewables. The majority of future capacity additions are projected to be solar and natural gas. [From EIA AEO 2018]

2.2. Carbon Capture and Storage (CCS): binding carbon dioxide (CO_2) emissions when dealing with carbon

2.2.1. Status quo and relevance for the country

The United States has long considered CCS as an important component of its approach to mitigating climate change. Since the late 1990s, the United States has invested billions of dollars in developing CCS technologies, and several demonstration projects have been supported through the Department of Energy.

- Beginning in 2017, the Petra Nova plant in Texas became the first US fossil-fueled power plant that generates electricity and captures CO2 in large quantities.
- Also, in 2017 there was deployment of carbon capture and sequestration at a plant producing ethanol in Decatur, Illinois.
- A third fossil-fueled electricity-generating operation, the Kemper County Energy Facility in Mississippi, was scheduled to begin CCS operations by now, but cost overruns and delays in construction and operations led to the suspension of the plant's CCS component on June 28, 2017.
- Many other demonstrations have also failed, including FutureGen, which was initially planned to use integrated gasification combined cycle technology with CCS to produce both electricity and hydrogen

The Academies, in its consensus report *America's Energy Future (2009)* concluded that to enable this portfolio approach in the electricity sector, the viability of CCS must be demonstrated during the next decade to allow for their widespread deployment starting around 2020. However, this recommendation has not been fulfilled sufficiently to know the prospects for widespread deployment of CCS.

2.2.2. Challenges, future plans/strategies

The greatest challenge facing CCS deployment is the significant cost of equipment and operation with little economic incentive (e.g., no carbon tax). Recently enacted federal legislation (known as the "45Q" tax credit) expands and increases the tax credit available per ton of CO_2 with the goal of improving the economic returns of CCS.

2.2.3. Latest technologies facilitating the strategy

The U.S. Department of Energy's Office of Fossil Energy continues to spend hundreds of millions of dollars on carbon capture, carbon sequestration, and supercritical CO_2 research. The carbon capture work includes research into both post-combustion capture in conventional pulverized coal-fired power plants and pre-combustion capture applicable to integrated gasification in combined cycle power plants. The carbon storage work focuses on early-stage R&D to develop coupled simulation tools, characterization methods, and monitoring technologies and developing assessments of overall storage potential in various regions of the United States.

3. Distributing electricity – Grids

3.1. Status quo – current national situation

The U.S. transmission system is composed of three asynchronous interconnects (western, eastern, and Texas) that operate with alternating current at 60 Hz. There are relatively few direct current transmission lines that allow small transfers of power between interconnects or directly from a single generator to high load area. Many of the components of the transmission system are old and typically only replaced at failure. Over the past decade (and accelerated specifically by investments from the American Recovery and Reinvestment Act of 2009, ARRA), significant deployment of synchrophasors on the high voltage transmission system have improved real time monitoring of grid operational conditions and stability.

For distribution systems, there is wide heterogeneity in deployed technologies, with densely populated areas generally having more sophisticated monitoring and control compared to low density rural areas. This is because cost recovery is challenging without a sufficient customer base. The most common technologies are traditional relays and fault detecting relays. Some areas concerned about electricity system resilience (e.g., Manhattan following Superstorm Sandy) have encouraged development of microgrids with local generation attached to distribution systems.

Across transmission and distribution systems, there is general and growing concern about vulnerability and security of the grid to cyber and physical threats. There are numerous initiatives underway in industry and government to increase the resilience and reliability of the grid, including confidential information sharing, equipment and transformer sharing programs, and mutual assistance agreements.

3.2. Challenges, future plans/strategies

There is no coordinated national plan or roadmap for electricity transmission and distribution system improvements from the U.S. government. In part this is because the federal government has limited regulatory authority in this area; most grid planning and investment is conducted at the local or state level. Federal involvement is in basic and applied research (e.g., through the DOE Office of Electricity Delivery and Energy Reliability) and through the Federal Energy Regulatory Commission, which enforces mandatory security and operational standards.

Recent Academies reports describe a variety of technologies and institutional changes that can improve the functioning and resilience of transmission and distribution (T&D) systems (see for example, *Enhancing the Resilience of the Nation's Electricity System, 2017).* However, the principal challenge faced in wider deployment of T&D technologies relates to their cost and quantifying the value they provide to customers. Furthermore, in the context of rapidly changing generation resources and business models, existing utility planning processes are becoming more challenging (e.g., load growth forecasting and transmission planning with uncertain deployments of customer owned solar on distribution systems).

3.3. Latest technologies facilitating the strategy

Advanced distribution system automation is one of the latest technologies to be used, which can greatly improve restoration time and savings associated with outages. However, the largest demonstration of this technology (Chattanooga Electric Power Board) was only made possible with large grants affiliated with ARRA, and it is generally considered cost prohibitive without this scale of support.

4. Storing electricity

4.1. Status quo – current national situation

The majority of storage available is through pumped hydroelectric energy storage; however, few viable sites remain for further expansion of this alternative. Battery storage has grown substantially over the past decade. Storage additions are largely concentrated in PJM (mid-Atlantic), ERCOT (Texas), CAISO (California) regions, and the majority of utility-scale battery storage is Li ion chemistry (Figure 5).

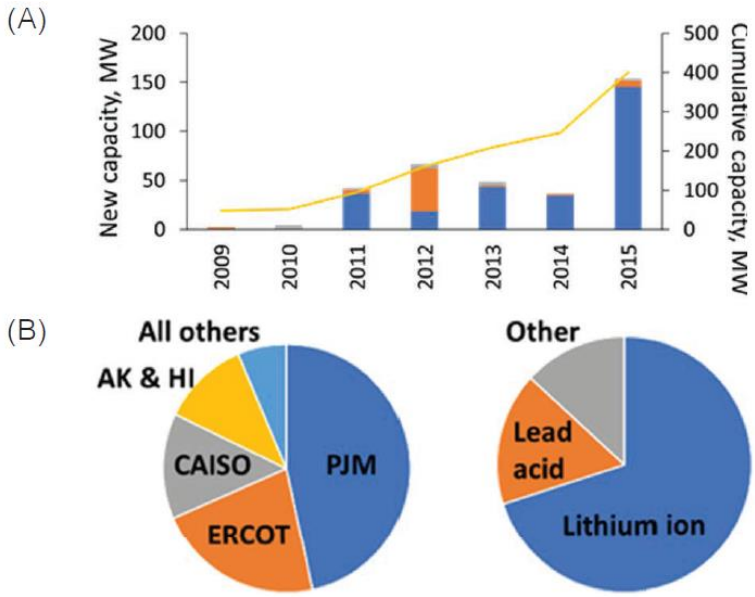


Figure 5 - (A) Growth of utility-scale battery storage in the U.S., (B) is concentrated in the PJM, CAISO, and ERCOT regions of the U.S. grid and is predominantly lithium ion chemistries. [From *Enhancing the Resilience of the Nation's Electricity System, National Academies of Sciences, Engineering, and Medicine. 2017. Washington, DC: The National Academies Press.]*

Several states have developed mandates/procurement targets to encourage deployment of electricity storage technologies, including California (1.325 GW utility, 500 MW customer owned), New York (1,500 MW by 2025), Oregon, and Massachusetts. Furthermore, many utilities are now including storage in their integrated resource planning processes submitted to regulators and state energy officials. At the federal scale, Federal Energy Regulatory Commission order 841 (Feb 2018) allowed storage to participate in energy, capacity, and ancillary services markets.

4.2. Challenges, future plans/strategies

Further expansions of both utility scale and behind the meter batteries are expected in the future; however, cost remains a critical barrier to wider deployment despite projected cost reductions in lithium ion batteries. Even where batteries participate in multiple markets, they may not be cost competitive.

There are also numerous operational and performance challenges, particularly as lithium ion batteries are not best suited for grid operation. New battery chemistries and storage technologies that have greater efficiency and ability to charge/discharge over long periods would be preferable to lithium ion. However, given the relatively low cost of lithium ion compared to other battery chemistries, it is difficult for alternatives to enter the market.

At the federal level, there are significant investments in basic research and early development, predominantly through the Department of Energy. The strategy going forward is to fund basic and early phase research aimed at improving materials, configurations, and battery systems while creating favorable market and institutional conditions through policy interventions.

4.3. Latest technologies facilitating the strategy

Many of the battery and storage technologies being funded by the federal government (e.g., see storage portfolio in DOE's Advanced Research Projects Agency-Energy or DOE's *Joint Center for Energy Storage Research*) are in relatively early phases of development and may not be commercially available for some time. There are few demonstrations of technologies better suited to grid operation, such as vanadium redox batteries.

Annex I: CAETS Energy Committee

Contributions to this report

ATSE	Australian Academy of Technology and Engineering	Australia	Dominic Banfield, Bruce Godefrey, Matt Wenham
CAE	Canadian Academy of Engineering	Canada	Robert L. Evans
CAE	Chinese Academy of Engineering	China	Peng Suping, Wei Yi-Ming
EA CR	Engineering Academy of the Czech Republic	Czech	Stanislav Mišák
NATF	National Academy of Technologies of France	France	Bernard Tardieu
acatech	National Academy of Science and Engineering	Germany	Frank Behrendt
EAJ	Engineering Academy of Japan	Japan	Masakazu Sugiyama
SAAE	South African Academy of Engineering	South Africa	Philip Lloyd
NAEK	The National Academy of Engineering of Korea	South Korea	Chinho Park, Seung-il Moon
SATW	The Swiss Academy of Engineering Sciences	Switzerland	Rolf Hügli
NAE	National Academy of Engineering	USA	Alton D. Romig Jr.

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In silent remembrance of Baldev Raj (INEA) and Philip (Taffy) Lloyd (SAAE).

Annex II: Concurring Academies

ANI	Academia Nacional de Ingeniería	Argentina
ATSE	Australian Academy of Technology and Engineering	Australia
BACAS	Royal Belgian Academy Council of Applied Sciences	Belgium
CAE	Canadian Academy of Engineering	Canada
CAE	Chinese Academy of Engineering	China
HATZ	Croatian Academy of Engineering	Croatia
EACR	Engineering Academy of the Czech Republic	Czech Republic
ATV	Danish Academy of Technical Sciences	Denmark
CoFA	Council of Finnish Academies	Finland
NATF	National Academy of Technologies of France	France
acatech	National Academy of Science and Engineering	Germany
HAE	Hungarian Academy of Engineering	Hungary
INAE	Indian National Academy of Engineering	India
EAJ	The Engineering Academy of Japan	Japan
NAEK	The National Academy of Engineering of Korea	Korea
AIM	Academy of Engineering of Mexico	Mexico
ACTI.nl	Netherlands Academy of Technology and Innovation	Netherlands
NAE	Nigerian Academy of Engineering	Nigeria
NTVA	Norwegian Academy of Technological Sciences	Norway
PAE	Pakistan Academy of Engineering	Pakistan
AESS	Academy of Engineering Sciences of Serbia	Serbia
IAS	Slovenian Academy of Engineering	Slovenia
SAAE	South African Academy of Engineering	South Africa
RAI	Real Academia de Ingenieria	Spain
IVA	Royal Swedish Academy of Engineering Sciences	Sweden
SATW	Swiss Academy of Engineering Sciences	Switzerland
RAEng	Royal Academy of Engineering	United Kingdom
NAE	National Academy of Engineering	United States
ANIU	National Academy of Engineering of Uruguay	Uruguay

Annex III: Questionnaire

CAETS Energy Committee Report – Country Contributions

Working title: Clean Energy Technologies – Challenges and Solutions

*A synopsis of the national perspectives given as an answer to the question, sketchy as they may be, will provide all of us with valuable insights in the diversity of global energy policies, in national and also global opportunities and challenges. Please provide an **unbiased view** of your country perspective. If applicable, you may indicate where scientific evidence or assessments by your academy differ from the official national policy.*

1. Going towards an all-electric society?

Can you (as a nation) or will you attempt to go all-electric? (1 page max.)

2. Generating electricity

All questions asked below referring to the electricity context, not to the energy sector in general.

2.1. Generating electricity from sustainable resources

2.1.1. Status quo: current national energy mix

If applicable, please insert a chart or data describing the actual energy mix of your country and the relevant conditions (geographical, political etc.). What resources are defined as sustainable resources for your country?

2.1.2. Energy mix –future goals and national strategy

Aiming for 2035, what are the goals and strategies of your government in the electricity sector? What does your academy suggest? If applicable, give further details on key policies, time frame, economic situation (implementation, cost/benefit calculation) and other relevant information. What are the major learnings from the country experience that could be of relevance for other countries as well?

2.1.3. Latest technologies facilitating the strategy

What are the latest technologies used or to be implemented in your country? Why did the government decide for and/or your academy recommend these technologies? What are enabling/ hindering context factors (political/social/economic) for the technologies?

2.1.4. Phasing-out technologies

Are there measures in place or plans to actively phase-out any technologies? If yes, please describe the strategy/policies for this. If no, please provide an assessment of whether (and in which timeframe) this will become an issue in the context of promoting a clean energy mix.

2.2. Carbon Capture and Storage (CCS): binding carbon dioxide (CO_2) emissions when dealing with carbon

2.2.1. Status quo and relevance for the country

Does your country/academy work with CCS? Why (not)?

2.2.2. Challenges, future plans/strategies

Aiming for 2035, are there any plans/strategies or recommendations to use CCS technologies? What are the major learnings from the country experience that could be of relevance for other countries as well?

2.2.3. Latest technologies facilitating the strategy

What are the latest technologies used or to be implemented in your country? Why did the government decide for and/or your academy recommend this technology? What are enabling/ hindering context factors (political/social/economic) for this technology?

3. Distributing electricity – Grids

3.1. Status quo – current national situation

If applicable, what kind of grid technologies does your country use to transmit and distribute electricity? For each technology, please specify whether it is used at a local, national and/or regional scale How is the energy security situation? What are the most important challenges for guaranteeing a secure and stable supply of electricity?

3.2. Challenges, future plans/strategies

Aiming for 2035, what are the plans of your country and/or the recommendations of your academy to improve grid technologies? What are the major learnings from the country experience that could be of relevance for other countries as well?

3.3. Latest technologies facilitating the strategy

What are the latest technologies used or to be implemented in your country? Why did the government decide for and/or your academy recommend these technologies? What are enabling/ hindering context factors (political/social/economic) for these technologies?

4. Storing electricity

4.1. Status quo – current national situation

If applicable, what kind of storage technologies does your country use? Why did your country decide for these technologies? Alternatively, why are there no storage solutions?

4.2. Challenges, future plans/strategies

Aiming for 2035, what are the plans of your country and/or the recommendations of your academy to improve and/or use storage technologies? What are the major learnings from the country experience that could be of relevance for other countries as well?

4.3. Latest technologies facilitating the strategy

What are the latest technologies used or to be implemented in your country? Why did the government decide for and/or your academy recommend these technologies? What are enabling/ hindering context factors (political/social/economic) for these technologies?