CHINA DEVELOPMENT FORUM 2020

NEW ENERGY, NEW ECONOMY: TAKING A SYSTEM-WIDE APPROACH[1]

Royal Dutch Shell plc

I. Introduction

Current energy systems are undergoing a process of rapid decarbonisation, driven by decentralised sources of low carbon energy and enabled by new digital technologies. This transition to 'New Energies' will have wide ranging impacts and create new opportunities. It will involve both the adoption of low-carbon energy carriers and the development of technologies, infrastructures, and policies to enable the change. It will create and grow high-value industries in new energy production, delivery, and end use.

There are three large global trends driving the energy transition: decarbonisation, decentralisation, and digitalisation. These trends will affect how energy is produced, delivered, and used. The trend towards decarbonisation will shift energy production at scale towards low carbon technologies and fuels, like renewables and low carbon hydrogen. The nature of new energies will drive the trend towards greater decentralisation of energy production, and hence a critical role for infrastructure to transport and deliver the energy. For example, solar power generation needs to occur in areas with high solar potential, compared to coal-fired power generation which can be located closer to

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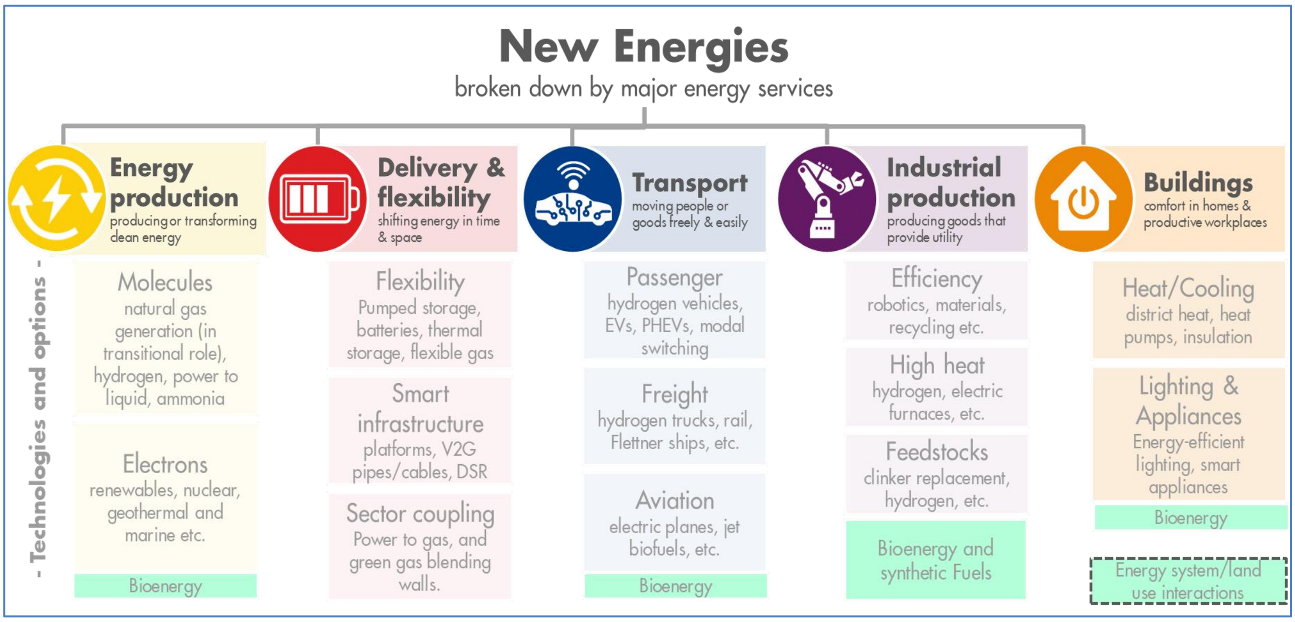
This document contains data and analysis from Shell's Sky scenario. Unlike Shell's previously published Mountains and Oceans exploratory scenarios, the Sky scenario is based on the assumption that society reaches the Paris Agreement's goal of holding the rise in global average temperatures this century to well below two degrees Celsius (2°C) above pre-industrial levels. Unlike Shell's Mountains and Oceans scenarios, which unfolded in an open-ended way based upon plausible assumptions and quantifications, the Sky scenario was specifically designed to reach the Paris Agreement's goal in a technically possible manner. These scenarios are a part of an ongoing process used in Shell for over 40 years to challenge executives' perspectives on the future business environment. They are designed to stretch management to consider even events that may only be remotely possible. Scenarios, therefore, are not intended to be predictions of likely future events or outcomes.

demand centres. Digitalisation will facilitate new ways to deliver and use these new energies, making greater use of digital technologies and sector connectivity to optimise efficiency. highlighting a critical role for infrastructure.

Figure 1: Range of new energy fuels and technologies, by the energy service they provide



Source: Vivid Economics

Taking a system-wide view is essential to recognise the full range of new energy technologies and fuels required to create a new energy economy (Figure 1). This requires not just looking at new energy supply, but also at the energy services and needs of end-use sectors in transport, industry, and buildings and at infrastructure and networks required for delivering and scaling up its adoption. Greater electrification and low carbon electrons are key elements of a new energy economy. However, some sectors will continue to require energy-dense fuels and low carbon molecules such as hydrogen and bioenergy. Combined with the trend towards greater decentralisation and greater digitalisation, the new energy system will be radically different from today.

The role of different new energy technology and fuel options will depend on country context and circumstances. For example:

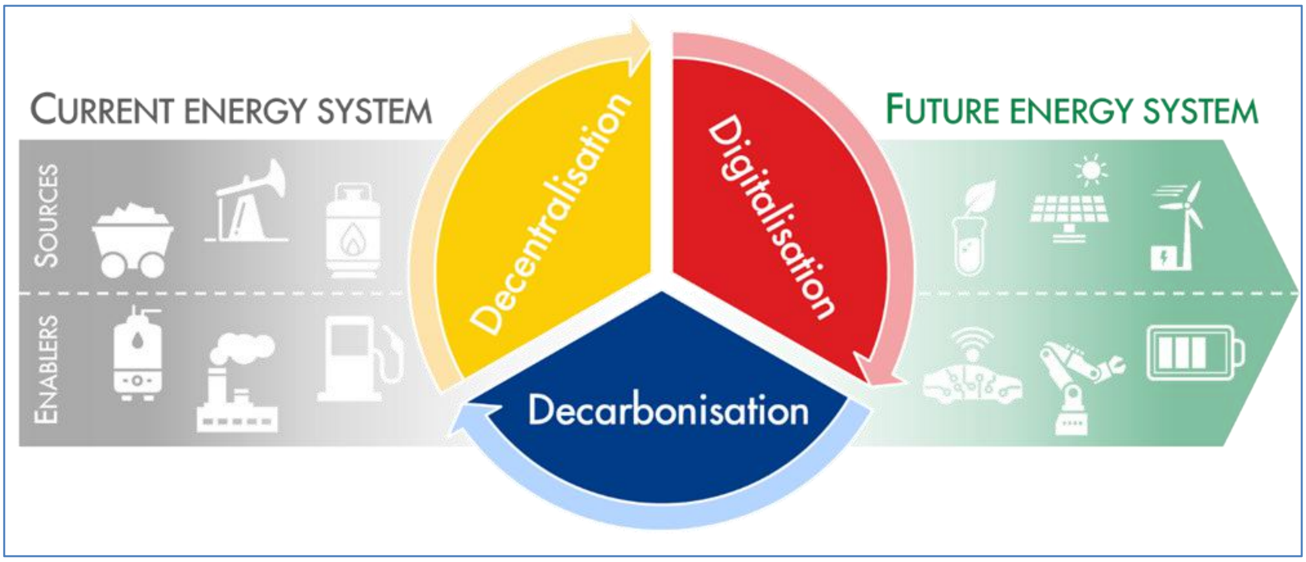
- *Availability and type of renewables:* In Europe, the focus is on electrification fuelled by zero carbon technologies such as wind and solar, with a supporting role for gas and low carbon molecules such as hydrogen. However, in countries with high domestic availability of bioenergy, such as Brazil, the emphasis is on developing biofuels in a way that manages the potential impacts of these fuels on land use patterns.

- *Fossil fuel endowment and existing infrastructure:* In countries with a historic endowment of oil and gas, and large gas distribution networks, the focus is on new energies that can utilise existing infrastructure (such as hydrogen replacing natural gas in heating). For countries where a transition away from coal is a near-term priority (e.g., for local air quality reasons), switching to gas – eventually with the application of carbon capture, utilisation, and storage (CCUS) – is a step towards a low carbon economy.

However, across all countries, reducing and managing demand in new ways will be essential to maximise value from low and no carbon fuels and technologies. For example, driving greater energy efficiency in industry and buildings and increasing the productivity of energy through greater materials efficiency in industry.

II. Drivers of energy system change

Figure 2: Decarbonisation, decentralisation, digitalisation will radically change the energy system



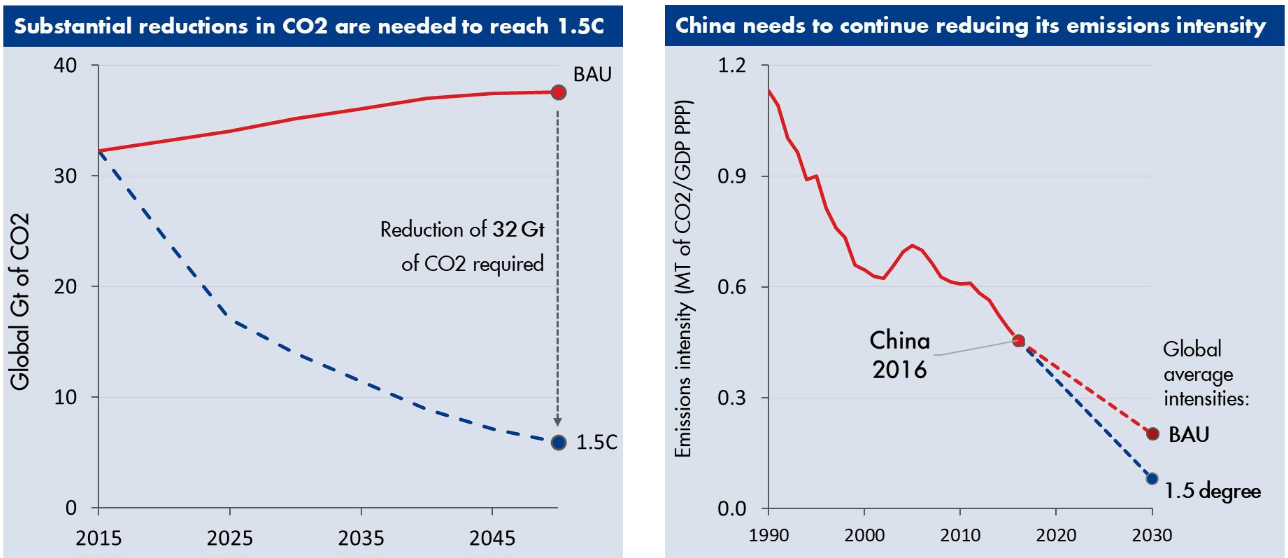
Source: Vivid Economics

Decarbonisation, decentralisation, and digitisation will fundamentally alter the energy system (Figure 2). These trends will transform the energy system, from a predominantly fossil fuel-based energy system today to an energy system based on new low carbon sources of energy, new ways to transport and distribute the energy, and new ways in which the energy is used and managed.

a. Decarbonisation

The Intergovernmental Panel on Climate Change (IPCC) has identified that temperature rise must be kept to well below 2 degrees centigrade above pre-industrial levels in order to avoid dangerous climate change. The 2018 IPCC special report found significant benefits from avoided climate change by limiting the temperature rise to 1.5 degrees centigrade. Assuming current policy settings, the world will overshoot 1.5 degrees centigrade by 32Gt in 2050 (Figure 3). More needs to be done globally in order to meet climate goals.

Figure 3: The decarbonisation challenge



Source: IEA ETP (2017a); IPCC (2018); IEA WEB (2018a)

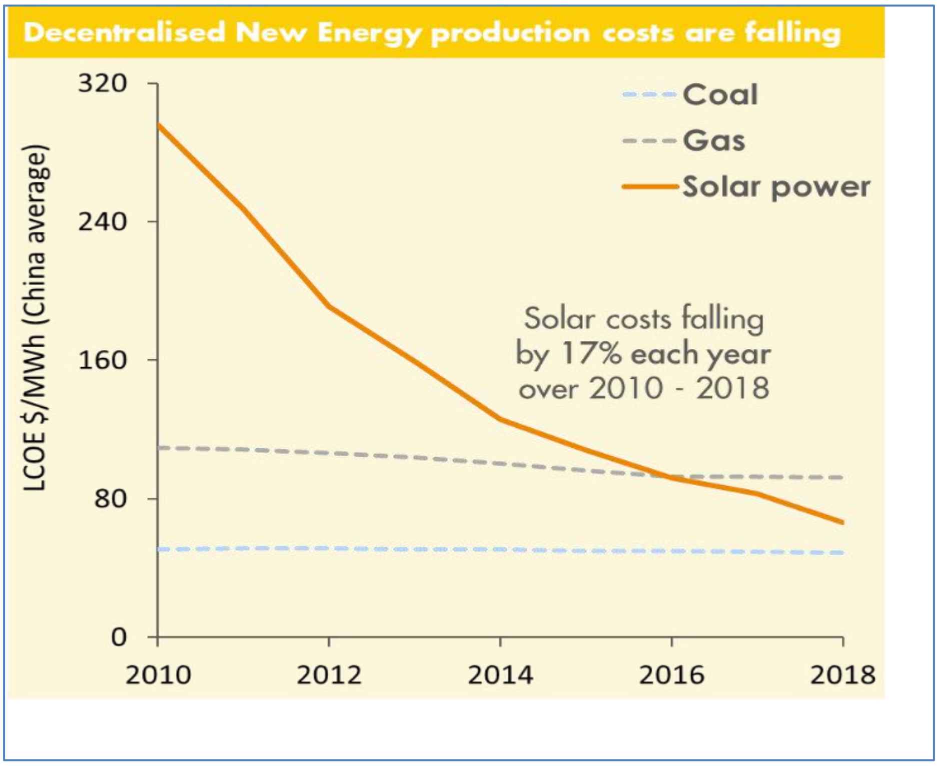
China has taken significant steps towards decarbonising, with emissions intensity falling continuously for more than a decade. Progress needs to continue – and accelerate – to be consistent with declining global average carbon intensities required for limiting temperature rise to 1.5 degrees centigrade.

b. Decentralisation

New energies, such as renewable energy, tend to be more decentralised than existing fuel sources. Responding to this change will require the energy system to chase the resource rather than the other way around; for example, shifting away from large centralised energy creation that currently dominates the energy system to a patchwork of decentralised low carbon energy sources. In turn, this creates new opportunities and areas of value.

Solar is an example of how new technologies are driving decentralisation and creating new areas of value. The cost of solar has fallen by 17% each year between 2010 to 2018, and generation costs are now below that of gas in several geographies (Figure 4). However, the nature of solar means that it needs flexibility options, such as storage and back-up generation, for times when the sun is not shining. It must also be in areas that have high solar potential. Thermal power generation and other centralised sources of power, on the other hand, are generally located close to demand centres which minimise costs of transmission and distribution. For example, gas-fired power plants in China closely track cities in the east where much of the population live, whereas areas with solar potential tend to be in more sparsely populated areas in the west. Decentralisation of the energy system through greater solar deployment can shift value; for example, as services such as power transmission, distribution, and system balancing become more important.

Figure 4: Solar generation costs are below gas in several geographies



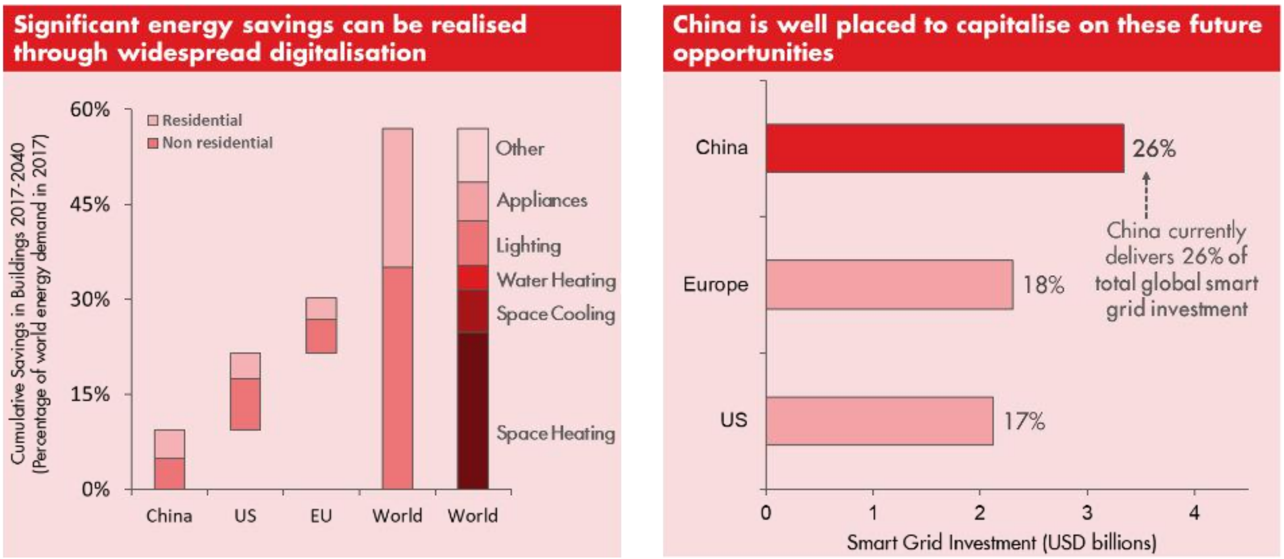
Source: Vivid Economics based on WRI (2019); IRENA (2019)

c. Digitalisation

Digitalisation will enable greater data utilisation to unlock new services and new efficiency gains and enable a smarter energy system which can respond better to changes in demand and supply. Improvements in the performance and price of technology will continue to drive wide-spread digitalisation across the economy, and new digital technologies can create new types of services. For example, digitalisation creates the ability to respond in real time to changing circumstances. This can drive significant efficiency gains across all end-use sectors. In buildings, cumulative energy savings over the next 20 years is estimated to be nearly 10% of current world energy demand, through more efficient use of power and better balancing of supply and demand (Figure 5).

Current global smart grid investment is only around $13 billion, and investment levels need to increase significantly to capitalise on the digitalisation trend. Currently, China delivers 26% of total global smart grid investment, and is well-placed to realise future opportunities in this area.

Figure 5: Digitalisation will drive significant energy savings, with China well-placed to benefit



Source: IEA Digitalisation and Energy Report (2017b)

III. Taking a system-wide lens

The transition towards New Energies is underway in each part of the energy system, although progress to date is at different stages. The trends of decarbonisation, decentralisation, and digitalisation are already shaping the components of the energy system. However, not all energy services will transition at the same speed as they each face different barriers and enablers. This section considers what the 'New Energy' future may be, in terms of energy production, delivery and flexibility of the energy system, and energy end-use sectors, and progress to-date in each.

a. New energy production

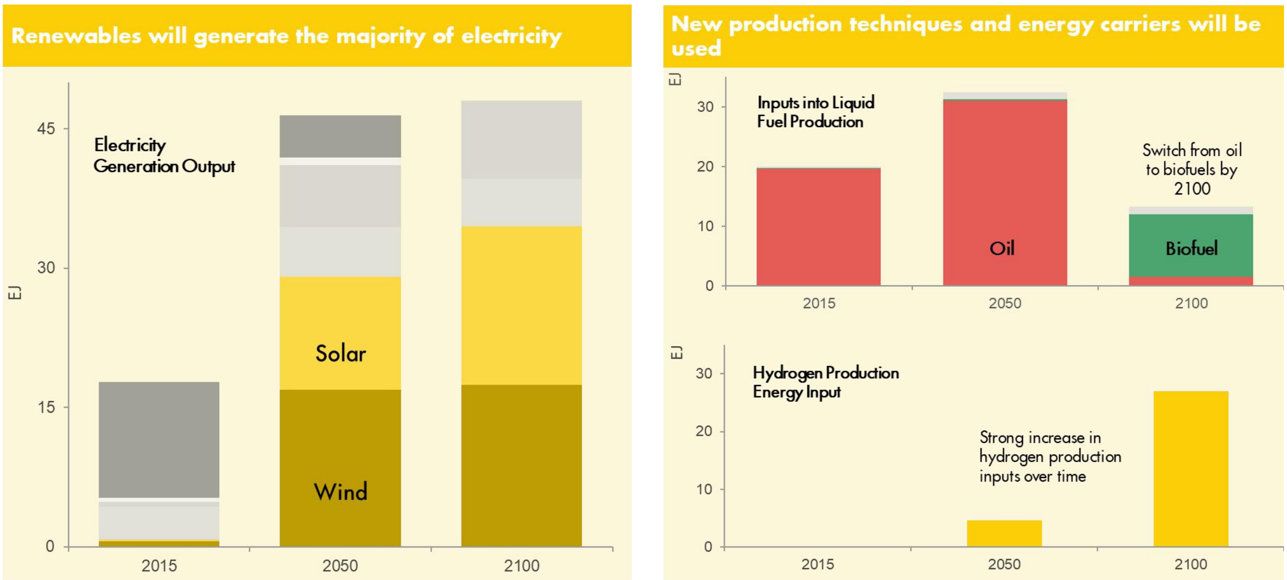
New energies take the form of either electrons or molecules (Figure 6). Electrons have the advantage of being cost-effective to produce in a low-carbon way, through wind and solar, but are difficult to store and transport long distances. In contrast, molecules such as hydrogen, ammonia, and biofuels, have a higher energy density and can be more easily stored, but low-carbon molecules are more costly to produce. Decarbonising the economy will require both electrons and molecules.

Most of China's power production (or electrons) will be derived from wind and solar. China's fossil fuel-based electricity generation is set to change considerably going forward, both in scale and composition. Shell's ***Sky*** scenario[2] estimates that global electricity generation will roughly triple by 2050, with around half of this output coming from solar and wind. Renewables share continues to increase in the second half of the century. Over this period, coal-fired generation falls dramatically.

The physical fuels (or molecules) consumed by end use sectors will also be derived in new ways. Liquid hydrocarbon fuels, which traditionally are sourced from oil, will shift to a biofuel-led supply. Gaseous hydrocarbons fuels, such as natural gas, will increasingly be replaced by hydrogen (produced from electrolysis, from natural gas with CCUS). Hydrogen is expected to grow from negligible volumes today into an important energy carrier, particularly for hard-to-abate energy end-use sectors in industry and transport. Natural gas is expected to remain an important source of energy over the next few decades, particularly in combination with CCUS. Combined with biomass e.g., in power generation), CCUS can also be a source of negative emissions, to balance unavoidable emissions from hard-to-abate sectors.

[2] A Paris-compliant scenario that keeps global temperature rise to well below 2 degrees centigrade above ore-industrial levels.

Figure 6: New energy production includes both low carbon electrons and low carbon molecules



Source: Shell (2018); IEA WEB (2018a)

Key to this will be delivering upscaled renewable generation capacity and pursuing new methods of producing molecules. The role of renewables will need to be increased by over 700% by 2050 compared to today. A key challenge is harnessing large scale solar and wind capacity, which are often far from major demand centres and require additional transmission, storage, and distribution infrastructure. Additional technologies are also required to manage the intermittent nature of renewables. This scale of change is matched by the change required in molecules, in developing the necessary technologies, infrastructure, and policies to support the commercialisation and at-scale adoption of new fuels like hydrogen and advanced biofuels. A range of new technologies and fuels will be required for realising the benefits of New Energies (Table 1).

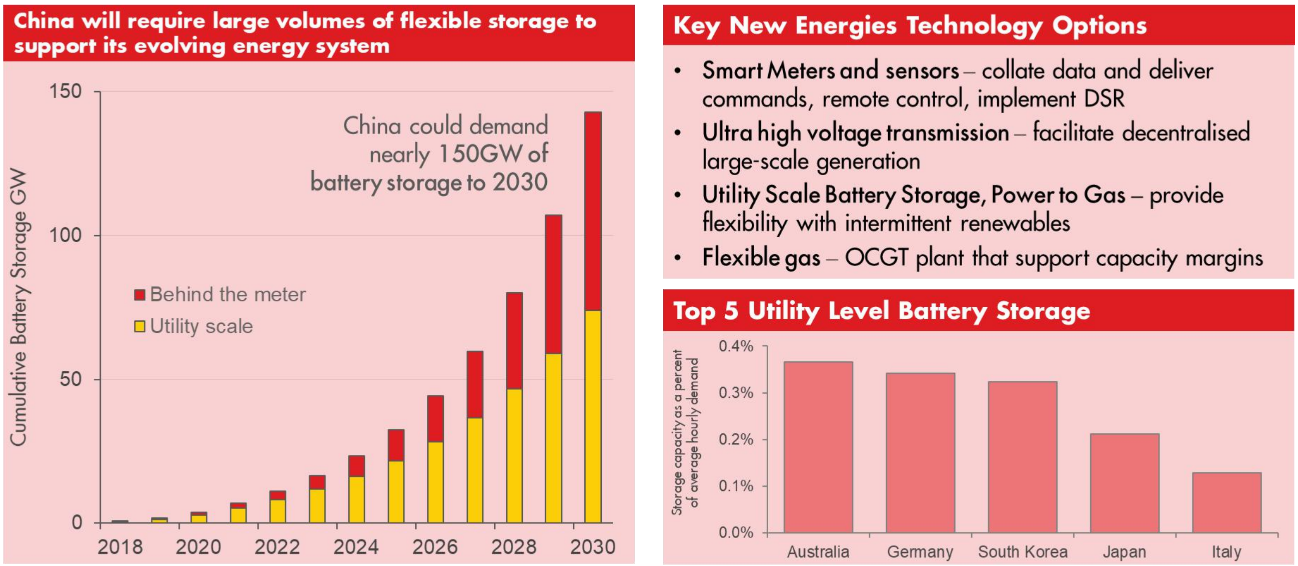
Table 1: Key new energy production technology and fuel options

Key sources of *electrons*	**Key sources of *molecules***
• Renewables – Onshore and offshore wind, solar (including large scale concentrated solar power), marine (including tidal and wave) • Nuclear • Thermal generation (gas, coal, biomass) with CCUS	• Hydrogen (from electrolysis, natural gas with CCUS) • Liquid biofuels/gaseous bio-methane • Ammonia and synthetic fuels • Power-to-liquid

b. New energy delivery and flexibility

The future energy system will place a higher premium on flexibility and create more opportunities for smart delivery and balancing of energy needs. As energy systems pivot increasingly towards renewables and electrification, both opportunities and challenges will be created. Solar and wind delivering a larger share of China's future generation will bring with it the obvious challenge of balancing demand with intermittent supply. The flexibility offered by battery storage could be key in addressing this and allowing intermittent renewables to supply a larger share of overall power demand (Figure 7). Indeed, China is expected to require large volumes of energy storage, whether in the form of utility battery storage or hydrogen for seasonal storage.

Figure 7: Large growth in energy storage required for a high-renewables power system



Source: IEA (2017c), World Energy Council (2016)

Future system flexibility depends on more than storage alone – new digital technologies will create the ability to shape demand and decentralise generation. A more electrified and interlinked energy system through digitalisation brings opportunities to optimise energy demand across sectors and for 'prosumers' to both provide their own decentralised generation and storage capacity. For example, smart charging of electric vehicles can reduce levels of peak demand and capacity and can also potentially provide a source of decentralised storage.

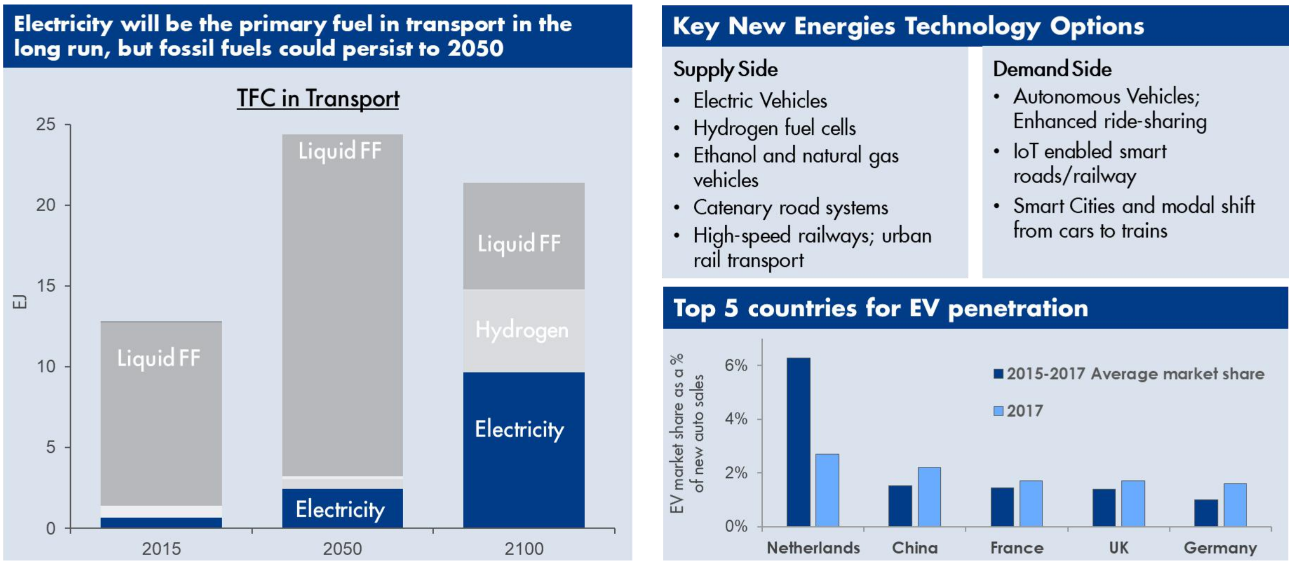
A flexible energy system has many components. Smart meters can allow for better coordination of what energy is being supplied and how much is being demanded by end use consumers. Smart devices allow for demand response which can be coordinated automatically by smart meters and offer a new source of flexibility in the energy system. 'Internet of Things' technologies will need to spread across the various levels of the gird to ensure that these opportunities are harnessed effectively. China currently is a leader in smart meter roll-out and has an increasing number of smart devices, and this will need to be maintained as the distribution of these devices continues to rise.

Finally, high efficiency transmissions lines will be critical to new energy delivery and flexibility, allowing for greater decentralisation of generation from demand centres and for balancing across regional power markets to manage renewables intermittency, both of which will enable greater renewables uptake.

c. New energy fuels and technologies in transport

Transport is a challenging sector for energy transition due to the requirement for very energy-dense fuels, particularly in long distance transport, shipping, and aviation. Transport in China is today predominantly powered by liquid fossil fuels, as it is in almost every other part of the world. According to Shell's ***Sky*** scenario, electricity and alternative fuels (hydrogen, biofuels) will have an increasing role to play in decarbonising transport, particularly in the latter half of the century (Figure 8). As China continues its economic growth and development, transport demand is expected to increase, with energy use in the transport sector expected to roughly double by 2050. However, while aviation is likely to continue to rely on liquid hydrocarbons (in the form of advanced biofuels), passenger and light duty vehicles are likely to be almost completely electrified and heavy-duty vehicles and shipping are likely to rely on low carbon hydrogen molecules.

Figure 8: New energies in transport, electricity, hydrogen, and biofuels replacing liquid fossil fuels and improved energy efficiency through application of digital technologies



Source: Shell (2018); IEA (2018b)

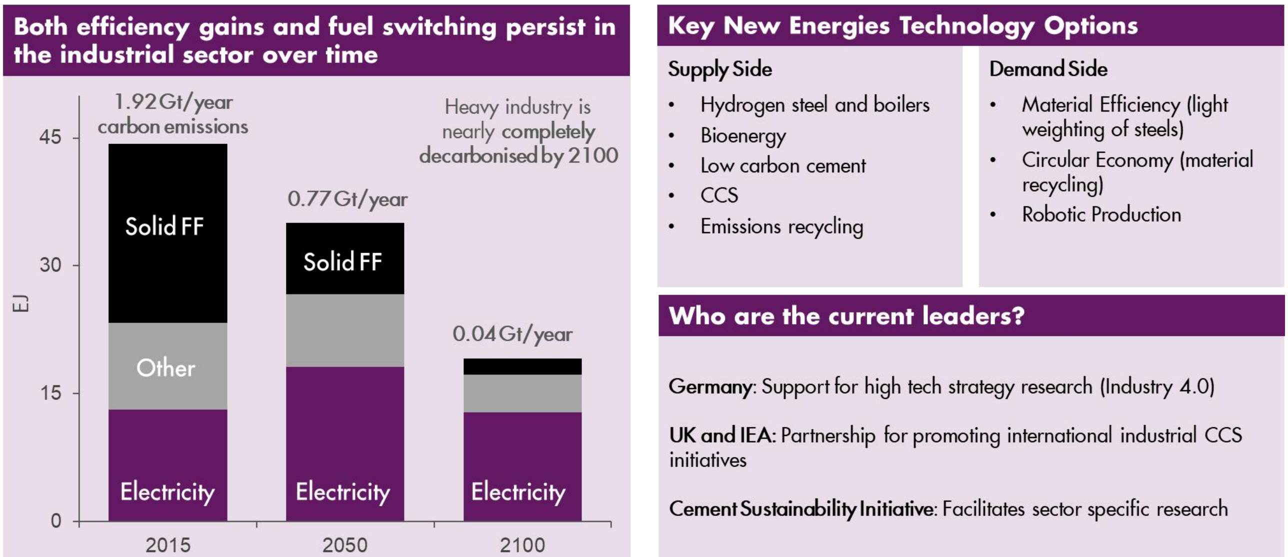
The appropriate technologies exist for electrification of large segments of road transport, yet global uptake is still low and supporting infrastructure remains underdeveloped. Despite rapidly evolving technology and cost reductions in batteries and electric vehicles (EVs), EV uptake remains low. What China does could drastically increase uptake. In both absolute and relative terms, China is a global leader both in EV adoption and in battery production. It is also worth bearing in mind that there are many unrealised efficiency gains on the demand side – as digital technologies become increasingly common it may be possible, for example, to increase the utilisation of cars and deliver more service for the same energy inputs.

Technologies for the production and use of low carbon molecules are further behind. They still remain some distance from commercialisation, requiring policy frameworks and support to incentivise investment and drive cost reductions – for example, in hydrogen produced from electrolysis, in fuel cell technologies – as we have seen for renewable technologies.

d. New energy fuels and technologies for industrial production

Industry is also a challenging sector for energy transition, particularly heavy industries which are difficult to electrify, as decarbonisation options differ across industries such as iron and steel, cement, chemicals, and light manufacturing. Over half of industry energy input in China today is from coal, leading to high carbon emissions. However, based on Shell's ***Sky*** scenario, coal dependence in industry can decline rapidly as alternative energy carriers and technology improvements make it possible to improve and alter industrial processes (Figure 9). A combination of energy efficiency gains, electrification (in light industry), and new fuels (in heavy industry) is required to decarbonise the industrial sector.

Figure 9: Industry will need low carbon electrons, molecules and new industrial processes



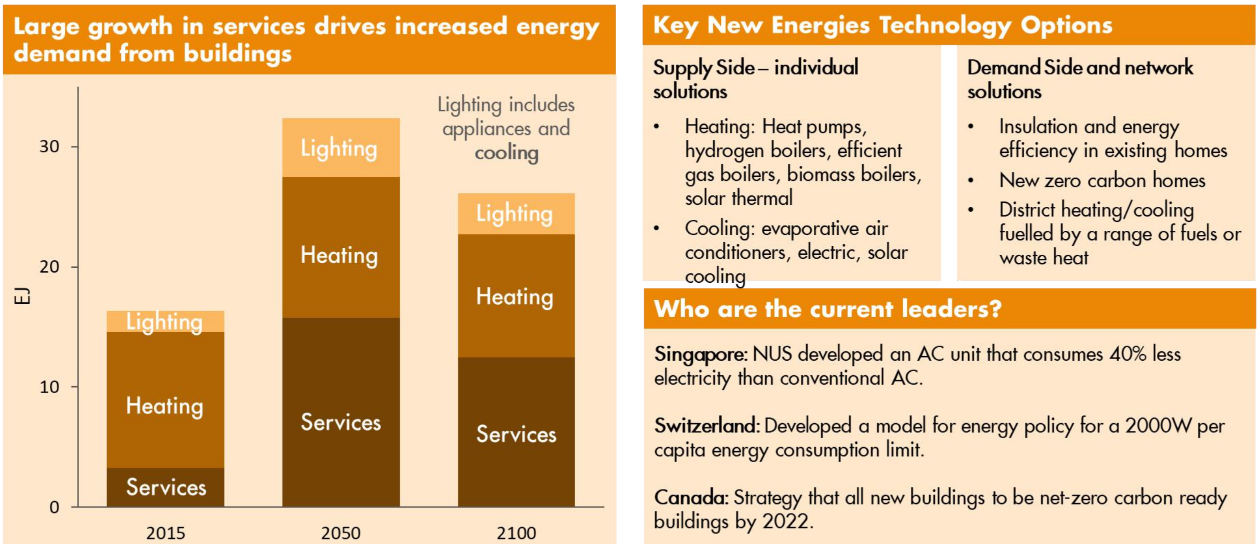
Source: Shell (2018)

The transition to new energies in the industrial sector will require research and innovation, to change production methods which have been largely unchanged historically. Within industry, fuels are used in many ways. Alterations in one industrial process may not necessarily apply to another process, and consequently there is a need for research to evaluate and test the potential for new fuels in different industrial processes. For example, heavy industrial processes tend to rely on high heat, and have limited substitutes to fossil fuels for generating the high-quality heat that is needed. There are cases where new low carbon molecules can be used, such as hydrogen-based steel, but for many others this is not feasible. For these industries, such as cement, CCUS provides a route to decarbonisation. Currently, there is a low incentive for sequestration of carbon, so current projects rely on a use case like Enhanced Oil Recovery to generate a revenue stream and be financially viable. Finally, circular economy approaches – to improve energy and materials recycling – can also deliver significant emissions reductions from industry.

e. New energy technologies for buildings

Energy demand from buildings is correlated with economic development. It is expected to double in China between today and 2050, driven almost entirely by an increase in demand for energy services as levels of income and prosperity rise. For example, demand for household appliances and cooling more than doubles between now and 2050. Improving the thermal efficiency of buildings has an important role to play, particularly for existing building stock. However, as illustrated by the ***Sky*** scenario, electrification of energy consumption from buildings and decarbonisation of electricity supply is the primary route for reducing emissions from buildings.

Figure 10: Low carbon and efficiency improving technologies required for decarbonising buildings



Source: Shell (2018), GlobalABC (2018)

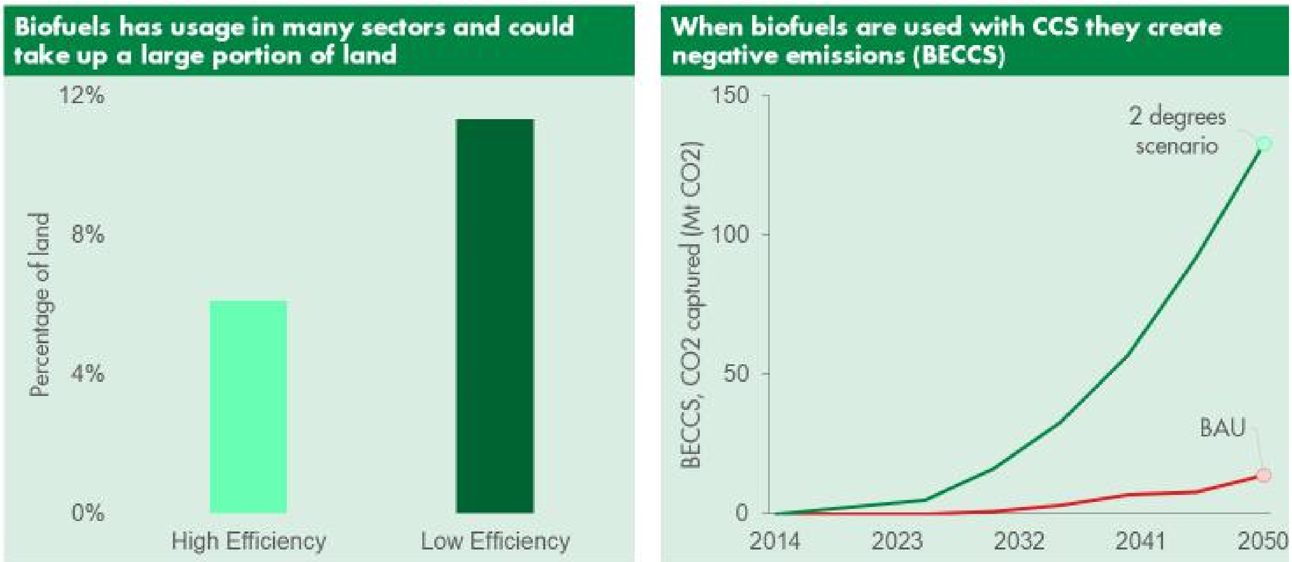
Key technologies to decarbonise buildings involve both individual and networked solutions (Figure 10). At an individual level, buildings can be fitted with a range of low carbon and efficient technologies. Cooling energy demand has been the fastest growing end use in buildings (IEA, 2019b), and passive cooling technologies and cooling sourced from renewable energies will be important going forward. On the demand side, creating a more energy efficient network will help the transition. Upgrading the insulation of existing homes and ensuring new builds are net-zero carbon will reduce energy demand and emissions. Taking advantage of waste heat and surplus fuel to provide district heating/cooling will further help to improve efficiency and reduce the environmental impact of housing's energy demand.

f. New energies and land use

The land use sector is an important source of new energy fuels and technologies; for example, liquid biofuels in transport, solid biomass for power generation. However, biofuels have the potential to use a considerable amount of land, with potential trade-offs with food supply and wider environmental outcomes. The predicted growth in biofuels for total primary energy is such that up to 11% of China's surface area could be dedicated to the production of bio-feedstock – as a percentage of arable land this could be considerably higher.

Prioritising bio-feedstock for sectors with limited other options for decarbonisation, such as aviation and chemicals, and for negative emissions technologies, such as bioenergy combined with CCS (BECCS) for power generation, could play a vital role in reducing emissions. Negative emissions technologies, such as BECCS, provide a way of offsetting unavoidable emissions from the energy sector and are expected to grow rapidly. For example, the International Energy Agency predicts a need of around 120 million tonnes of CO_2 sequestered in 2050 through BECCS (Figure 11).

Figure 11: The future new energy system will require bioenergy for numerous energy services, including negative emissions



Source: Shell (2018); IEA (2017a); CCC (2011)

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