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Energy Harnessing: New Solutions for Sustainability and Growing Demand

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Executive Summary

Energy is the fuel of the global economy. Without sufficient energy to heat and light our houses, run our businesses, power our manufacturing plants, and stoke our cars and planes, our world would come to a standstill. Energy is provided via an Energy Harnessing Network – a complex system that starts with extraction from a variety of sources and then moves to transformation, storage, distribution and finally utilization. Global megatrends such as climate change and resource scarcity force a rethinking of this crucial network, especially in the light of a reshuffling of global economic activity and significant demand growth in the developing world. Innovative solutions are required to ensure that the world's economy is fuelled in a socially and environmentally responsible way that is also economic.

A global restructuring with so many constraints is highly complex, and demands innovative solutions from businesses and governments. A select group of specialists from industry, civil society, government and academia have therefore analysed this global challenge from different viewpoints and determined critically important requirements for a successful rearrangement of the Energy Harnessing Network. The findings of this holistic analysis are described in detail in this report.

Fossil fuels are still the main energy source for the world's economic engine. Unconventional resources such as shale gas have already had a dramatic impact on the energy market in the United States (US) and have the potential to affect others, for instance, China. While environmentally less favourable than conventional natural gas, shale gas can reduce emissions by crowding out highly polluting coal-fired power generation. This report details how and to what extent shale-gas reserves can change the energy harnessing landscape in different parts of the world, and visualizes the landscape in a comprehensive map.

Provision of renewables will have to dominate the future energy architecture on a global level, to supplement and eventually substitute the more-polluting traditional energy sources. But renewables such as solar and wind power have a major drawback – they must be tailored to a certain area to make best use of local conditions (for example, high irradiation or significant winds). Yet technologies and best practices developed in one region can, and should, be leveraged in another.

The true challenge for renewables is intermittency, the periodic availability of supply that will have an enormous impact on energy security when renewables are deployed on a large scale. In the short term, natural gas can be used to balance this intermittency and hence the development in shale-gas production globally is linked intrinsically to the success of renewables. In the medium to long term, smart grids and electricity storage are necessary to provide a large share of the energy demand from renewables. This report details different technologies and their stages of development to give a comprehensive overview of the state-of-play in renewable energy's provision and storage.

Smart integration of renewables into existing electricity grids will be of paramount importance; so-called smart grids could help with the incorporation of intermittent renewable technology. This report assesses key technologies that must be developed in order to convert current, out-dated grids to smart grids, which are essential for a critical area of energy harnessing – using energy efficiently.

Energy-efficiency measures will be vital for energy security, and smart policies and smart grids must be put in place to support this. Developed countries have already succeeded in levelling demand, mainly by becoming more energy efficient; the developing world has the opportunity to leapfrog various stages to start at a more energy-efficient point. Efficiency measures are the most cost- effective way to mitigate greenhouse gas emissions and ease energy demand.

Technological developments alone will not be sufficient to transform the energy harnessing landscape. New business models, capital and, most importantly, political will are required as well. Moreover, a collaborative innovation approach is needed. Many technologies that could be game-changing need to be developed in different areas, ranging from advances in computational management to advanced materials and marketization.

Introduction

The energy landscape faces enormous challenges, triggered by several global megatrends. Climate change, limited resources and growing demand, to name a few, have had a dramatic influence on the way the global society will use energy in the future. To ease the impact of ongoing climate change and stay within the widely accepted range of a maximum of 2°C (3.6°F) of warming, solutions must be found now. The Energy Harnessing value network is a major emitter of greenhouse gas (GHG) and must drastically reduce its current impact on the climate. The stakeholders within the Energy Harnessing value network can still prevent a potentially disastrous global warming. But time is short.

Planned energy supply is likely to be insufficient to meet rapidly expanding global energy demand, especially in the developing world, which is forecast to experience 80.5% of demand growth between 2012 and 2035.[1] China alone will account for 35.5% of total global demand growth and India for 11.1%, according to current trend scenarios.[2] Fossil fuels will remain the dominant energy source in the near term. However, their quantity is limited, and regional availability and infrastructure will determine how various countries expand their domestic energy supplies.

Stakeholders across the value network have the opportunity to develop innovative technologies to enable a more viable long-term source mix that meets future demand growth in a way that is economically, socially and environmentally sustainable. Renewables and other alternative energy sources could provide lasting supplies, and thereby address the concerns of regional shortages and energy security. In today's economic environment, however, investments in enabling infrastructure and technology are limited, making it difficult for innovations to take off and reach cost parity with fossil fuels.

Geographic, geo-economic and geopolitical considerations have a significant impact on Energy Harnessing. Building domestic energy supplies enhances a country's energy security and mitigates the geopolitical risks in relying on energy imports. Harnessing locally available resources also reduces transmission costs and increases control over setting of policy. To further address energy security and resource-shortage concerns, many countries have sought to change their energy mix to capitalize on domestically available and economically viable sources.

As a consumer of one-third of the world's energy, industry faces a number of energy risks and opportunities. Since the oil embargo of the 1970s, industries such as chemicals and steel have slowly enhanced their output per unit of energy consumed, in response to supply and cost issues. Industry innovation for both fossil fuels and renewable sources will continue to increase energy supply and energy efficiency, thereby improving energy security, managing demand growth, lowering costs and cutting GHG emissions.

Today's energy landscape does not equip any single entity to provide the entire solution to the world's energy challenges. Collaborative innovation – the partnering of different entities across the value network to develop and introduce new energy solutions – is one way to address these difficulties. A cooperative approach allows for shared risks and diversified perspectives, and has the potential to enable the development and execution of innovative solutions to the challenges associated with mounting global energy demand.

The Energy Harnessing Value Chain: From Capturing to Consuming Energy

The Energy Harnessing value network encompasses the process of capturing, transforming, transmitting and using energy. Figure 1 depicts the Energy Harnessing value network for different energy sources and illustrates the high degree of cross linking.

For electricity generation, the value network is more complex than with fuels, and innovation is needed to raise performance efficiency and lower costs. Electricity must be converted to another form of energy before it can be stored (for example, transformed to chemical energy in a battery, or potential energy in a pumped hydraulic storage system). However, conversion introduces additional loss of efficiencies to the value network.

Figure 1: Current Energy Harnessing Value Network

Source: A.T. Kearney analysis

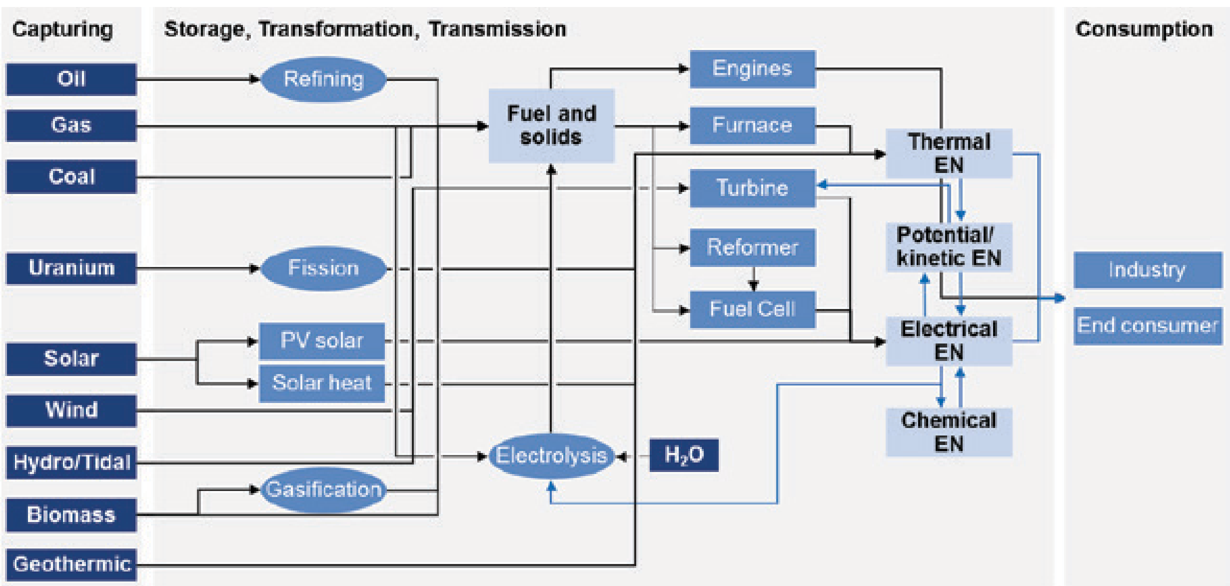


Figure 2: Nine Global Megatrends Influencing the Energy Harnessing Value Network

Energy Harnessing Is Highly Influenced by Several of the Nine Global Megatrends

Energy Harnessing is closely linked to and influenced by several of the nine global megatrends identified by the Community of Chief Innovation Officers of the Chemicals Industry Community at the World Economic Forum (see Figure 2). The first megatrend is ongoing climate change and the need for sustainable solutions pose major challenges for most industries and society as a whole. Transformation of the energy landscape will be critical to reduce global GHG emissions and the negative impact on the environment of today's energy production.

This target has to be achieved against a surging demand for energy, the second megatrend driven largely by emerging countries, which have the highest population growth and an increasing middle class. Most emerging countries lack suitable energy infrastructure, like reliable transmission grids or efficient power plants. Limited availability of resources is the third megatrend. As many conventional oil and gas fields are exploited, supplies in the future will become more difficult and more expensive. Access to other resources, such as freshwater and rare earth metals, also is increasingly limited in many parts of the world. Unequal distribution of water poses a particular challenge, as does the uncertain future supply of certain rare earths that are used in the production of electric engines, solar panels and batteries. It remains unclear if enough deposits can be explored at reasonable costs, or if those minerals need to be substituted in the future. Moreover, the shift of economic activity hubs from the West to countries such as China, India and Brazil will require new solutions to meet the specific energy needs of these new centres.

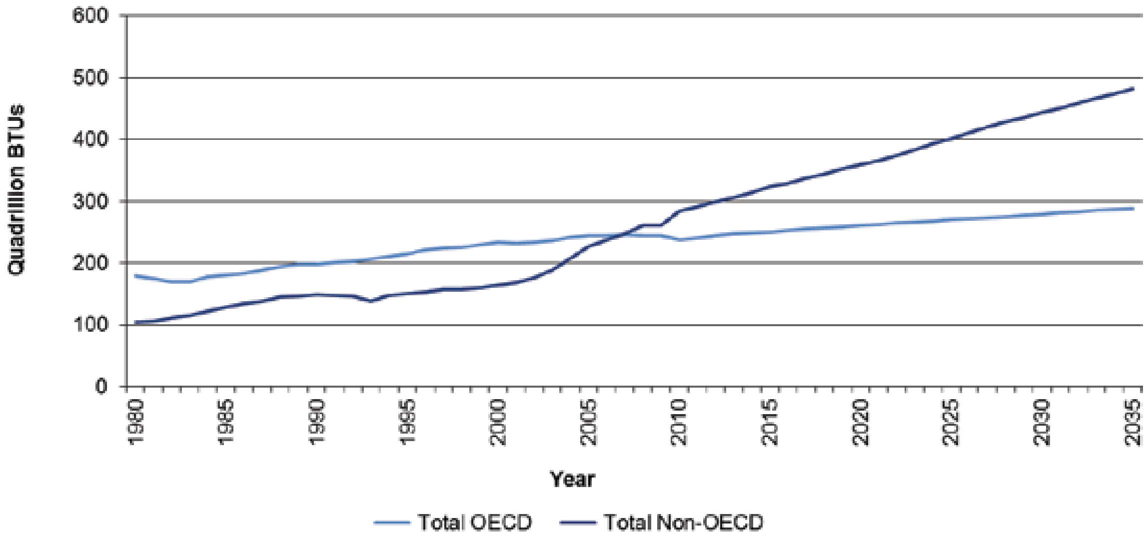
This chapter highlights some of the consequences for Energy Harnessing derived from the megatrends.

Climate change, environment and sustainability. In 1987, the United Nations' Brundtland Commission defined sustainable development as that "which meets the needs of current generations without compromising the ability of future generations to meet their own needs". This definition of sustainability includes three pillars: economic, social and environmental. From an environmental perspective, it means that humankind needs to stay within certain "planetary boundaries". Johan Rockström from the Stockholm Resilience Centre and other scientists suggested nine such planetary boundaries in 2009.[3] Listed are climate change, carbon dioxide (CO_2) emission, biodiversity, land use and other boundaries that, if not adequately addressed, will have a detrimental impact on the planet.[4] Any future development in the Energy Harnessing value network must be mindful to ensure that society at large stays within these boundaries.

Growing demand for energy. Since 1980, global primary energy consumption has nearly doubled from 283 quadrillion British thermal units (Btu) to 542 quadrillion Btu in 2012.[5] During the same period, the world's population surged by more than half to about seven billion.[6] Figure 3 illustrates that countries outside the Organisation for Economic Co-operation and Development (OECD) have driven much of the demand and have nearly tripled their energy consumption since 1980.

Figure 3: World Total Primary Energy Consumption, 1980-2035 (in quadrillion Btu)

Source: *International Energy Statistics 2010* and *International Energy Outlook 2011,* US Energy Information Administration

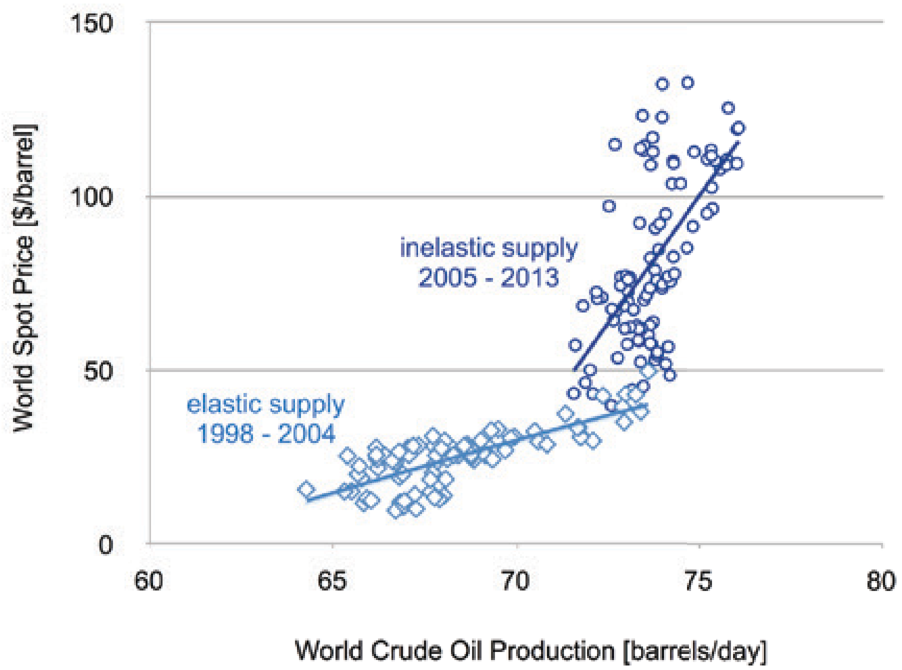


Energy consumption forecasts anticipate that these sturdy trends will continue. From 2009 through 2035, the growth rate of the world's gross domestic product (GDP) is expected to average 3.6% per year, driven largely by non-OECD countries.[7] This growth, combined with a projected 26% increase during the same period in the world's population – 90% of which will occur in non-OECD regions with emerging middle classes and rapid urbanization patterns – will cause global energy demand to soar.[8] Median estimates suggest that between 2009 and 2035, the world's primary energy demand will climb by 52.5% to about 770 quadrillion Btu; in non-OECD countries, it will surge by 65.8%.[9] The regional stakeholders of the Energy Harnessing value network have to ensure that the necessary investments, primarily in infrastructure, will be carried out in a timely manner to ensure the world has an environmentally sustainable and reliable energy supply.

In a seminal publication, J. Murray and D.A. King exemplified the latter issue, using oil as an example resource. In 2005 production of conventional crude oil reached maximum capacity and from that year onwards the supply curve has gone from elastic (bright) to inelastic (dark), which means increased demand is not met by increased supply but regulated by price increases (Figure 4)[10]. This effect is referred to as price volatility. Additional supply could come from unconventional energy resources, but these are capital intense, have significant lead times and their environmental impact is detrimental beyond questioning, compared with conventional resources[11]. Moreover, it has been proved that the effect of resource price volatility on ailing global economies is significantly detrimental.[12] Hence, energy harnessing must be a top agenda point for the economic recovery process.

Increasing scarcity and unequal distribution of water. Water is an essential component of the Energy Harnessing value network. In the United States (US), fossil fuels and nuclear sources use 190,000 million gallons of water per day for electricity production, accounting for 39% of all freshwater withdrawals in the country.[13] For example, coal-fired power plants require 25 gallons of water per kilowatt-hour (kWh) of power generated. Additionally, according to the US Department of Energy (DOE), drilling and hydraulic fracturing of horizontal shale-gas wells requires two to four million gallons of water over a well's lifetime. However, for every million Btu of natural gas produced from shale, only 0.6-1.8 gallons of water are required – 85% less than the amount required to produce the equivalent amount of energy from coal.[14] Despite higher water efficiency relative to coal production, countries like China with more immediate water scarcity issues have been slower to develop shale-gas reserves with this technology. Solutions are beginning to come online to capture shale gas by using less water. Technologies are being tested to either recycle the water used or substitute it, with liquid petroleum gas gel, for example.

Figure 4: World Total Primary Energy Consumption, 1980-2035 (in quadrillion Btu)



Freshwater is already scarce in many regions due to agricultural, industrial and residential withdrawals, pollution and geography. As these competing demands on water increase, its availability for energy capture of shale gas, biomass, coal and other sources will be limited. Figure 5 demonstrates the spread of water scarcity since 1975 and projections by 2025, when every continent will suffer extreme water scarcity. By 2025, 1.8 billion people will be living with water scarcity and two-thirds of the world's population will lack access to water for basic consumption.[15] Between 2011 and 2025, water withdrawals are forecast to surge 50% in emerging countries and 18% in developed countries.[16] Scarcity could limit the potential for countries to expand their energy supply infrastructures to sources that rely heavily on water as a feedstock.[17]

To reduce the strain of Energy Harnessing on clean water reserves, the US Department of Energy recommends possible innovations to help to extend water supplies.[18] These include:

- Treating and reusing non-potable water in energy capture
- Accessing unused water sources such as saline aquifers and flooded underground mine workings
- Delivering water more efficiently to minimize losses
- Minimizing the use of water for mining, energy capture and use, disposal of by-products, water treatment and distribution

Cooling power plants by utilizing air or wastewater instead of freshwater also can minimize water use, but it is an expensive solution and decreases net electricity output. [19] Additional innovations will be required for this solution to become more widely adopted. Another possible solution currently under development through the US National Aeronautics and Space Administration's Offshore Membrane Enclosures for Growing Algae or OMEGA project, explores using algae to clean wastewater, capture carbon dioxide and ultimately produce biofuels without competing with agriculture for water, fertilizer, or land.[20]

Demographics, including shifting populations and mobility. In emerging countries with limited infrastructure, rapid population growth and socioeconomic changes will lift millions from poverty into the middle class, building demand for a "middle class lifestyle", which includes access to electricity, automobiles and other energy-consuming goods. These changes will increase per-capita energy consumption and will require novel solutions to provide low-cost access for the 1.4 billion people (approximately 20% of the world's population) who currently lack access to electricity.[21] The International Energy Agency (IEA) estimates that US$ 9.1 billion was spent in 2009 to extend energy services to previously un-served populations; it projects that an average of US$ 14 billion per year will be spent on such infrastructure investment between 2010 and 2014.[22] Providing worldwide universal energy access, however, would require investment of US$ 48 billion per year between 2011 and 2030.[23] Developed energy infrastructure – which provides reliable access to electricity and fuel – fosters economic and social development, and allows regions with a more developed energy infrastructure to attract industries like manufacturing, which create jobs and economic growth.

Figure 5: Global Water Availability, 1975, 2000 and 2025

Source: Center for Environmental Systems Research, University of Kessel

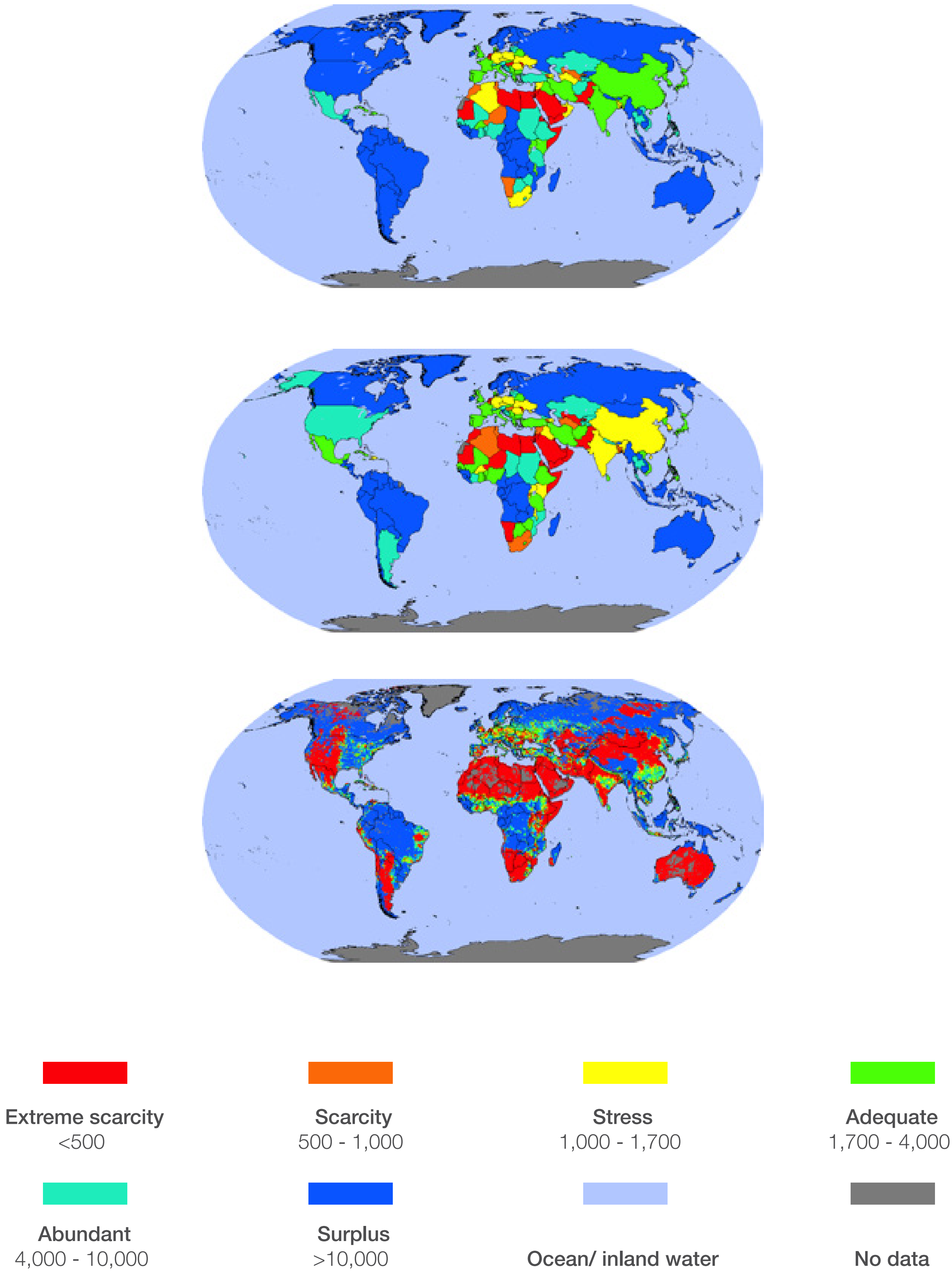
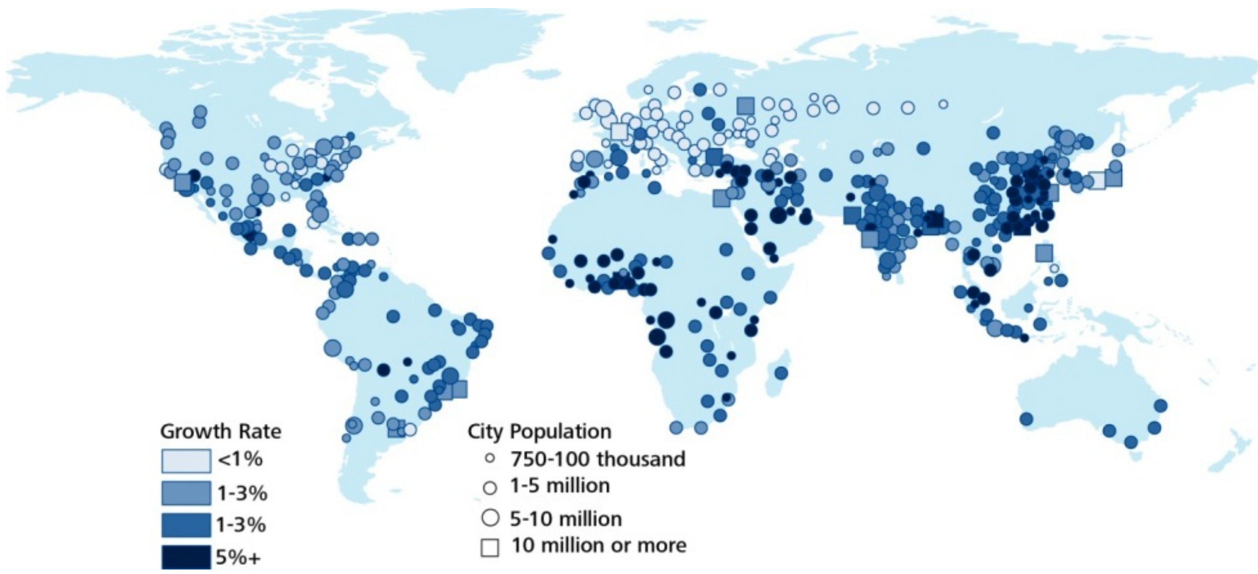


Figure 6: Growth Rates of Urban Agglomeration, 1970–2011

Source: *World Urbanization Prospects: The 2011 Revision*, 2012, New York, Department of Economic and Social Affairs, Population Division, United Nations



Shifting centres of economic activity. The growing trend for urbanization has several consequences for the Energy Harnessing value network. Urbanization has raised energy demand and will continue to do so. Between 1965 and 2010, the percentage of people living in urban areas increased from 33.6% to 51.6%.[24] As illustrated in Figure 6, the urbanization rate is highest in developing regions like South-East Asia and Sub-Saharan Africa. Higher urbanization in emerging countries will influence energy demand through changes in the economy, mobility and transport, infrastructure and population density, and household consumption patterns.[25] Compared to its agrarian counterpart, an urban economy tends to be more energy-intensive. Urbanization drastically increases use of motorized transport and places greater demands on infrastructure. The urban lifestyle also heightens consumption of goods and services, which in turn escalates per capita energy intensity. Therefore, sustainable mobility solutions, higher energy-efficiency and extension of the energy infrastructure are necessary to mitigate the consequences of this megatrend.

Growing Demand for Energy Summary

- Several of the global megatrends, such as climate change, growing demand for energy and demographics influence the Energy Harnessing value network.
- Any future development in the Energy Harnessing value network has to be mindful of the nine planetary boundaries, and must ensure that society does not cross any of them.
- Global primary energy consumption has nearly doubled since 1980 and is expected to increase 52.5% between 2009 and 2035, driven by population and GDP growth. Growth will occur mostly in non-OECD countries.
- Constrained conventional resources, as well as the high capital intensity and long planning times of unconventional and alternative resources affect macroeconomic stability and environmental security.
- Water usage is a crucial component of energy extraction, storage and usage. Concerns about freshwater availability will be one driver for technologies used across the Energy Harnessing value network.
- The growth of the global middle class will increase per-capita energy consumption. Providing universal energy access would cost US$ 48 billion annually between 2011 and 2030.
- Growing urbanization strains urban energy resources and requires additional improvements in energy efficiency and infrastructure.
- Energy demand and economic development are interconnected. Energy access strengthens economic growth and higher standards of living increase energy demand, especially in emerging countries.[26]
- Collaborative innovation will be needed to develop new technologies to meet the growing demand for energy.

The Future Mix of Energy Sources Will Diversify

In 2012, global primary energy consumption reached 542 quadrillion Btu (see Figure 3). Liquid fuels were the most important type of fuel, accounting for 33.2% of total energy consumption, followed by coal, natural gas and renewable energy (see Figure 7). The main energy-consuming regions were Asia-Pacific (38.4%) and a combined Europe and Eurasia (24.4%), followed by North America (21.8%).

Several questions need to be answered to find a suitable energy mix for future demand:

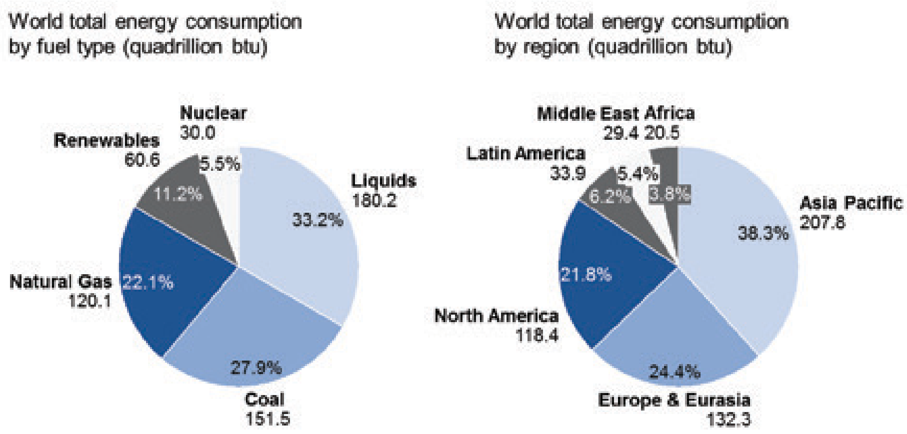
– What energy sources are most capable of fulfilling large demand requirements in a sustainable manner, for example, in a cost-effective, environmentally responsible and socially acceptable way?
– What are the essential drivers for the future energy mix?
– How do we best incentivize energy sources that are not yet economically viable but are essential to meet the requirements of the nine global megatrends?
– How can energy security be ensured?

These questions begin to outline the myriad energy-related considerations that must be taken into account by governments, regulators and private sector stakeholders. **No one "right" answer exists in most cases**.

A multitude of sources will be required to meet the growing energy demand. Coal, crude oil and natural gas will continue to dominate the energy mix in the short-term, as they have the most well-established infrastructures and are currently in many locations and applications. Inequitable global distribution of natural resources, specific resource attributes and trade-offs, varying end uses and simple risk management principles suggest that developing more diversified and renewable energy resources will be needed to supplement and supplant crude oil and coal. In fact, in certain site-specific conditions, various renewable energy technologies already compete with traditional fuel sources. The key drivers for varying the energy mix: cost-efficient supply, energy security and –currently only in a minor way – environmental protection, including climate change.

Figure 7: Global Primary Energy Consumption, by Fuel Type and Sector, 2012

Source: International Energy Outlook 2011, US Energy Information Administration



New technologies that enable other carbon sources, such as shale gas, to be used more cheaply will help shift demand away from crude oil. In the wake of the Arab Spring and European Union (EU) sanctions on Iran, this variation protects the energy value network while strengthening the energy supply chain. It also permits more stable global economic and energy security for nations with varied access to natural energy resources. Nevertheless, the development of shale-gas reserves outside North America is still in a start-up phase and significant environmental implications have to be addressed.[27]

Increasing renewable energy's share of the energy mix poses some difficulties. Such sources are the most likely candidates to replace fossil fuels in the long term, but they are often less cost-effective. A full, macroeconomic evaluation of cost and benefits that also takes into account environmental and social aspects might lead to a different result. However, as these valuations are not translated into market prices, they are not a key driver of development.

An increasing number of applications of renewable energy are already competitive today. Hydropower is well established and onshore wind can, in good locations such as the Mid-West in the US or coastal areas in Europe, reach levelized cost of energy (LCOE)[28] at, or below, the level of new conventional capacity. Even less mature technologies such as solar photovoltaic are already prevalent without support in remote industrial applications or as financially viable alternatives in rural micro-grids. Nevertheless, because their value chains and learning curves are still maturing, renewable energy applications will continue to require financial and regulatory incentives in the short-term to ensure their cost-competitiveness. These incentives should be structured to avoid overly generous support, so that continued pressure will be felt to reduce costs until these sources become competitive.

The most frequent applied types of incentives are feed-in tariffs (FiTs) and renewable portfolio standards (RPSs), although special renewable energy certificates (RECs) also have a role. FiTs are a type of economic policy that offers long-term contracts for electricity generated by renewable sources. Generally, these contracts are based on the cost of each technology rather than the prevailing cost of electricity. FiTs often also include a "tariff degression" that lowers the tariff over time, encouraging cost reduction. RPSs, on the other hand, mandate that electricity supply companies produce a certain percentage of electricity from renewable sources. Such a policy puts the burden of implementation entirely on the private sector. In theory, this should allow greater competition and, ultimately, lower cost. In practice, however, empirical studies show that private-sector risks associated with RPSs are charged back to the projects, making them frequently more expensive than those in FiT systems. Experience in Europe shows, that many countries that started with RPS systems modified these significantly to support the various technologies (e.g. the technology "carve outs" supported by regulations in the US or various bands in the United Kingdom's renewable obligation certificate or ROC system). Others supplement their RPS system with FiTs (e.g. Italy, United Kingdom), which leads overall to a diversification of the incentives used in Europe. For their part, RECs have been implemented as voluntary / industry-led certification systems. Under this system, entities may be obligated to buy RECs to prove their compliance with renewable portfolio standards. Alternatively, companies and/or consumers seeking to reduce their carbon footprints can buy RECs voluntarily.

Germany has strongly supported the use of FiTs to boost its solar industry. The country has repeatedly exceeded its goals to expand solar capacity by between 2.5 and 3.5 gigawatts (GW) per year, due to better-than-expected cost reduction in photovoltaics (PVs), leading to higher-than-predicted cost of the policy, which is rolled over to the final electricity consumers. In response, the German government has repeatedly cut the subsidies, sometimes at short notice, reducing them by nearly 30% as of 1 April 2013, with plans to eliminate them entirely when the government target of 52 GW installed is reached.

To enable renewables on a large scale, technical problems need to be mitigated. For example, many renewable sources, such as solar and wind, produce energy at volatile intervals and intensity; system-wide improvements are needed in the ability to absorb volatile generation (e.g. advanced energy storage technology and demand response mechanisms). In heat generation, however, renewable energy already makes a substantial contribution worldwide. Biomass is widely used as a heat source in low- and high-tech applications. In fact, biomass co-firing and boiler conversion of coal-fired capacities to biomass is a low-cost way to add sizeable renewable energy capacity. For its part, biofuel has an inferior energy density compared to crude oil, and this is an issue for end-markets such as the automotive and aviation industries.

Another future challenge is the vulnerability of the energy infrastructure to environmental change. In a paper published by Chatham House in 2009, Cleo Paskal explains why environmental changes might pose a major challenge to the energy infrastructure. The report notes that a major portion of the global energy infrastructure lies in areas projected to become physically unstable due to a changing environment. [29] The latter is already posing challenges to the existing energy infrastructure. Nuclear power plants, for example, had to be powered down in France, Spain and Germany in the summer of 2006 because of heat and water problems.[30] In 2008 and 2009, inadequate rainfall was blamed for the decline of more than 8% in hydroelectricity production in India.[31] Disruptions will rise in the future. For example, Russian natural gas pipelines undermined by melting permafrost would cause concerns for the country's natural gas sector.[32] Future investments in energy infrastructure, therefore, should find ways to alleviate the impact of a changing environment.

The future energy mix and the role of renewable energy sources often generate disagreement. The IEA's *World Energy Outlook 2010* presents different scenarios for the percentage of renewable energy in total global primary energy demand.[33] In the Current Policy scenario, renewables will account for about 15% of the total in 2035. In the 450 scenario, which follows an energy path consistent with the 2°C global warming limit, will account for about 26% in 2035. Renewable energy's share of electricity generation reaches 23% in 2035 in the Current Policy scenario, and 46% in the 450 Scenario. For its part, Greenpeace in a 2010 report estimates that renewable energy resources will account for 39% of global energy consumption by 2030 and 80% in 2050.[34] In this projection, almost the entire global electricity supply would come from renewable sources in 2050, and transport, including shipping and aviation, would be among the last sectors to become fossil-fuel free. However, enabling such a high share of intermittent renewable power requires large-scale storage.

Potential storage solutions are discussed in the section, *Advanced Energy Storage Solutions Will Be a Key Enabler for the Further Growth of Renewable Energy Sources,* later in the report.

Crude oil. Crude oil is the world's most important source of liquid fuel. It has a high energy density and its refined products like gasoline and diesel are vital fuel for mobility applications. Although many countries do not have large domestic crude oil supplies, its high energy density makes transporting it cost-effective. Since most countries already have built-in infrastructure that relies on crude oil, especially within the transportation sector, worldwide demand will continue to climb, especially in China and the rest of the developing world.

Despite a continued dominance of the energy mix in the near-term, crude oil faces emerging challenges, which support trends to diversify away from it as a primary fuel source. For a start, existing conventional low-cost sources of oil are maturing. The IEA estimates that non-OPEC (Organization of the Petroleum Exporting Countries) implied

annual decline rates for crude oil are about 6.4%.[35] At that rate, crude oil production at a given site could be reduced to about 50% in 10 years and to 25% in 22 years, although decline rates often increase with time.[36]

Many existing oil reserves are located in politically unstable regions, so producers are increasingly developing harder-to-extract, higher-cost supplies. Tar sands extraction, deep-water drilling and pre-salt formations all present environmental and regulatory issues that must be addressed, and that add cost to extraction. Increasingly heavier and sourer, i.e. more sulphur-rich, oil will require more complex refineries for processing into gasoline and diesel. Moreover, geopolitical and regional security issues continue to raise concerns about crude oil, prompting countries to look at expanding their energy sources. In North America, significant unconventional oil reserves will change the energy landscape drastically as it is suggested that the US will be independent of oil imports.[37]

Coal. Coal is currently the most important energy source for electricity generation, accounting for approximately 36.7% of global electricity generation due its abundance, low cost and ability to generate base load electricity.[38] These factors make coal among the most suitable sources for meeting high demand across a variety of regions in the near-term. However, coal is the most polluting of fossil fuels and emits the most GHG, and could contaminate water with toxic by-products such as coal ash. These traits render coal an unappealing source with respect to environmental sustainability. Recent regulatory trends and abundant natural gas supplies, e.g. in the US, may well ease demand for coal as a low-cost, high-volume electricity provider. Coal will increasingly be substituted by natural gas in countries with significant natural gas reservoirs. Countries like India, without those resource alternatives, will rely largely on coal as a primary energy source in the foreseeable future.

Current attempts are under way to mitigate coal's environmental impact through carbon capture and storage (CCS) technologies. While CCS technologies could theoretically reduce CO_2 emissions significantly, most current strategies are expensive[39]. Public perception poses another challenge. The German government recently announced that the storage of CO_2 in underground caverns is doomed to fail, due to popular resistance. Furthermore, the combination of coal combustion with CCS technologies increases the LCOE of this energy source.

Coal can be converted to liquid fuel via direct or indirect liquefaction processes. Both processes enable the creation of a variety of coal-to-liquid (CTL) products, including: petroleum, diesel, synthetic waxes, lubricants, chemical feedstock, methanol and dimethyl ether (DME). CTL products can present economically viable alternatives for countries that are heavily dependent on oil imports and have abundant coal reserves. According to a study in May 2011 by the Massachusetts Institute of Technology (MIT) Joint Program on the Science and Policy of Global Change, in the absence of environmental policy, CTL fuels could provide up to 33.3% of global liquid fuel supply by 2050. In this scenario, CTL products could become cost-effective in the US, China, India and Africa, if the price of crude oil reaches or exceeds US$ 91 per barrel. One drawback of CTL products is that they have a significantly higher carbon footprint than does crude oil. CCS technology used in conjunction with CTL production could substantially lower the carbon footprint.

Despite the environmental challenges and the new technologies aimed at diversifying away from coal, demand for this source will continue to grow, especially in emerging countries. From 2010 to 2035, coal use in OECD countries will increase only slightly (7.4%), but in non-OECD countries will increase by 53.4%, led almost exclusively by growth in Asia, especially China.[40]

Natural gas. Natural gas is used for industrial, residential and commercial applications, electricity generation and increasingly, for transport. Compared to coal, natural gas emits almost 50% less GHG, making it a relatively more attractive source of electricity in terms of carbon footprint. Additionally, natural gas-fired plants have the ability to run intermittently, which enables them to better supplement renewable energy sources, such as wind and solar.

New advances in horizontal drilling and hydraulic fracturing – the process of extracting natural gas from hard rock – enable the exploitation of large reserves of shale gas in North America. This new extraction technology has also boosted the potential for natural gas to meet growing electricity demand with a meaningfully reduced carbon footprint.

Oversupply of shale gas has driven down the price of US natural gas, making it an extremely cost-competitive source of fuel. With abundant gas supplies in the US, some companies are considering liquefying gas for export. Oil and gas companies have been studying liquefied natural gas (LNG) projects to compete with natural gas producers such as Russia, Qatar, Norway, Indonesia, Malaysia and Algeria.

The current development and consequences of shale-gas exploration are described in the section, *Shale Gas Has and Will Continue to Shape Energy Markets,* later in this chapter.

South Asia and Brazil are experiencing greater use of natural gas in the form of compressed natural gas (CNG) as transportation fuel. Some commercial fleets (e.g. waste management) in the US already have converted diesel trucks to use natural gas. Companies like Clean Energy Fuels have been promoting natural gas as an alternative to imported oil-derived fuels.

Natural gas can also be used as an affordable feedstock for conversion to synthetic crude oil directly or indirectly via synthesis gas, a fuel gas mixture. These gas-to-liquid (GTL) technologies have advantages over crude oil and CTL that may help to move this source forward as a contributor to a more diversified energy mix. First, it allows gas producers to convert a portion of their gaseous waste (e.g. flare gas) into liquid fuel, which can be shipped worldwide using the petroleum-shipping infrastructure. Second, it may allow for the extraction of "stranded" natural gas that cannot currently be extracted because of the prohibitive cost of extraction and/or transportation. Third, GTL plants generally make cleaner products than those using crude oil or the CTL process; these fuels are free from sulphur, nitrogen and aromatics. They also have a higher octane number than CTL products, which means that they are higher-quality fuels and will produce significantly less pollutants during combustion.

Technologies that enable the conversions of natural gas to fuel within the existing energy infrastructure are already in place across the world. Compact GTL, a British company, has worked with Petrobras, a semi-public Brazilian multinational energy corporation, to create the type of modular GTL technology that will enable its products to be incorporated into existing oil and gas infrastructure and operations. It uses natural gas that would otherwise be burned off as a feedstock and turns it into high-value synthetic crude oil without the same emissions or supply issues as traditional crude oil. If this technology can be expanded and commercialized, this affordable feedstock could address demand for transportation fuels in the existing infrastructure of countries like the US. It also could enhance energy security by alleviating the reliance of many countries on foreign oil and creating a highly transportable source with export potential. Moreover, as the price of crude oil climbs and natural gas supplies continue to emerge, investment in these technologies will become more attractive and will enhance the potential of natural gas to become a major fuel source in coming decades.

Nuclear. The potential is enormous for nuclear production as a low-carbon energy source. The availability of uranium also is favourable – the International Atomic Energy Agency (IAEA) estimates that conventional uranium resources at a cost of less than US$ 130/kg are available for the next 90 years, calculated at a 2009 rate of consumption.[41] Third Generation Nuclear, spent-fuel recycling and fast-breeding uranium-238 into new fissile material, could extend already-mined uranium resources for centuries and dramatically reduce the volume and long-term toxicity of wastes.[42]

But concerns about safety, waste disposal, high up-front capital costs and insurance have slowed demand for investment in large nuclear plants. The recent Fukushima accident in Japan has amplified scepticism in many countries. As a result of public perception, Germany and Switzerland will phase out all their nuclear energy; in Italy, a referendum rejected restarting a nuclear power programme. Worries about safety also are a trial for nuclear-dependent France, which generated 76.3% of its electricity from nuclear sources in 2010.[43]

The question of final disposal of nuclear waste also remains unanswered. Most countries that produce nuclear energy have final disposal facilities for low- and intermediate-level waste but none has a complete system to store high-level nuclear waste permanently. Many countries are investing heavily in the exploration of feasible concepts, techniques and locations to safely store radioactive waste. The issue of safe, secure long-term storage is rather complex. The waste needs to be isolated from the biosphere for at least 100,000 years. Deep geological disposal can provide a safe means, but which type of geological formation is suitable? Furthermore, it is argued whether the waste should be stored or re-used. One technical solution to cut the amount of high-level nuclear waste could be neutron irradiation to transform long-lived radionuclides into short-living ones. It remains to be seen if this technique will mature and if it will be suitable to reduce the large amounts of radioactive waste.

Security and proliferation fears are other barriers to nuclear development. Some countries are seen as posing risks in terms of political and economic instability, thereby raising concerns about their having access to nuclear materials and the technology to enrich uranium that could be used for military purposes.

While some countries are reviewing their nuclear programmes, it is unlikely that the expansion of this industry will completely cease. Between 2012 and 2020, total worldwide nuclear-generating capacity is still expected to grow approximately 28%, largely driven by countries like China, Russia, India and South Korea, which are moving forward cautiously despite the potential safety risks.[44]

Fusion power, power generated through nuclear fusion, could provide another energy source in the future. This technology is still very experimental and many technical problems still need to be solved. Costs for development also will be high. China, the EU, India, Japan, South Korea, Russia and the US are mutually developing the technology and are currently constructing the International Thermonuclear Experimental Reactor (ITER) in southern France. The goal of the ITER project will be to explore if, and how, it would be physically and technically possible to use nuclear fusion to produce power.

Solar. Solar power is a promising, carbon-neutral energy source. Solar power is produced in two ways: concentrating solar power (CSP) and photovoltaic. CSP utilizes focused sunlight to generate heat and steam that powers a standard turbine. When coupled with storage solutions, CSP may be able to provide dispatchable energy, for example, energy that can be stored for a several hours and called upon when needed. Solar PV systems convert sunlight directly into electricity.

Starting in the early 2000s, demand for PV systems grew significantly when Germany and later Spain instituted significant FiTs for solar-generated electricity. As considerable poly-silicon capacity has been added (largely in China) to serve such demand, PV module prices have fallen by 75%. As these costs have declined in recent years, solar capacity has grown dramatically. However, other costs remain – associated with the installation and efficient grid integration of this type of energy (e.g., permits, installation costs and materials).

The growth of solar PV might be affected by inexpensive shale gas in the US. At the same time, however, many parts of the world show favourable irradiation conditions where the quick cost- reduction of PV is likely to lead to competitiveness in the short term.[45] Also, as the industry continues to cut the costs of installation and the total system, PV will reach cost-levels that are financially viable for final consumers to displace some electricity purchased from the grid with power generated in their own PV systems. The better the match between load profile and solar irradiation, the higher will be the share of self-consumed output and the better will be the business case.[46]

While solar is not expected in the near term to take a large share of the energy portfolio due to its low capacity, it is projected to continue to grow in the foreseeable future. Lower costs, government incentives and subsidies, and new, more efficient PV materials (such as organics, ceramics and dye-sensitized cells) will make solar an attractive energy source to meet growing demand, especially in households and off-grid communities. Nevertheless, organic PVs are not as efficient as their conventional counterparts and hence, further research and development is needed.

Wind. Wind power has enormous potential for electricity generation,[47] and power generated using wind technology is often competitive with conventional energy sources. However, wind energy can vary greatly, depending on volatile environmental conditions, which can create supply and demand problems. Additionally, as with solar energy, wind faces challenges such as high installation costs, intermittence and challenges connecting to the electrical grid. Despite these issues, from 1998 to 2010, cumulative installed wind capacity increased by a compound annual growth rate (CAGR) of 28.1%, from 10.2 GW to 199.5 GW, led by China and the US, which represent 22.4% and 20.2%, respectively, of total wind capacity.[48] New turbine technologies are enabling more efficient wind capture and innovations are under way to allow for residential-scale wind turbines to supplement large-scale wind farms, but these, as well as even higher-potential off-shore farms, still have high installation costs that have slowed production.

As scale and economics continue to drive demand, wind will likely expand as a component of the electricity portfolio, but will struggle to achieve a significant share of the world's energy mix. Grid-scale storage and integration are required to enable wind to meet its potential as a low-emission source. Wind also has potential for distributed generation via micro-turbines and mobile solutions. On this scale, wind could be a viable solution for populations in emerging countries with limited infrastructure and access to electricity.

Biomass/biofuels. Biofuels, which include bioethanol, biodiesel and other liquids from biomass, are created from biological feedstock such as crops, woody biomass or algae. Many of these biomass-to-liquid (BTL) fuels are created through a process of gasification that produces syngas. Once biomass is gasified, the conversion to liquid fuels shares the same processing steps as CTL and GTL technologies.[49]

Demand for biofuels, created in biorefineries via biochemical or thermochemical processing, is driven largely by the desire to increase energy security and reduce GHG emissions. Especially for countries with a wide availability of natural feedstock and minimal access to crude oil deposits, this fuel source holds promise. In integrated biorefineries, the possibility exists to generate co-product biochemicals and generate electricity from heat produced in the conversion process.

Biofuels have the potential to replace fossil fuels for transportation, including in aviation; many countries already have biofuel-blending programmes that require a certain percentage of their fuels to be blended with biofuels. Estimates show the supply of gasoline substitutes such as ethanol, which is popular in Brazil, increasing from 100 billion litres in 2010 to 190 billion litres in 2020 and 300 billion litres in 2030.[50] In what is considered a conservative estimate, biodiesel will grow from 50 billion litres in 2010 to 100 billion litres in 2020 and 300 billion litres in 2030.[51] The US Renewable Fuel Standard 2 (RFS2) mandates that 137 billion litres of biofuels be consumed in 2022.

Not only biomass converted into biofuels is used. Unconverted biomass is also used (e.g. for power generation) in combined heat and power (CHP) application or in pure biomass-firing plants. According to EU projections, the use of biomass and waste in power generation will more than double until 2030.[52]

Key success criteria are essential to allow a successful development of biomass and biorefineries. These criteria include:

- **Biomass**. The food-versus-fuel tension has received a lot of attention. For example, one statistic notes that in 2009, the amount of corn required for ethanol to fill the fuel tank of a sport-utility vehicle could feed two people in a developing country for a year.[53] However, production of food AND fuel is possible. While the food versus fuel debate is vivid and emotional, new technologies and new available feedstock offer the opportunity to produce bio-based products without disturbing the supply of food. New technologies increasingly allow the use of agricultural, forest and household garbage as feedstock for biorefineries. Algae can potentially provide almost unlimited biomass supply of various types in the future. According to data from the US DOE, the oil yield of algae could be up to 6,500 gallons per acre per year, while palm oil only offers 635 gallons and jatropha only 202 gallons per acre per year.[54]
- **Public perception**. This varies largely by region. For example, in Brazil, which has a mature biofuels industry and the largest flex-fuel vehicle fleet globally, public perception is rather positive. In Europe, on the other hand, public perception is dominated by the food versus fuel and genetically modified organism debates as biofuel production currently relies mainly on first-generation biomass. To enhance positive public perception, it will be crucial to move from food crops to second- and third-generation biomass, and to educate the public on this development.
- **Profitability**. While first-generation biofuels production is largely mature and profitable, second-generation biofuels lack profitability. While subsidies can, and should, be an initial lever for the industry, in the long term boosting plant productivity and cheap feedstock supply should be crucial to make a profitable business case. Plant productivity can be increased by various mechanisms:
  - Greater use of valuable by-products
  - Metabolic engineering, which allows development of highly efficient microbes and enzymes; with synthetic biology, enzymes and pathways can now be created from which even non-natural chemicals can be derived, offering huge opportunities for biorefineries in the future
  - Reduction of costs of enzymes
  - Decreasing costs for the development of new bio-based processes from scratch, which can be up to several hundred million US dollars

- **Collaboration**. The fragmented nature of the value network seems highly challenging, if nearly impossible, for biorefineries to develop a fully self-integrated business model. Downstream and upstream players require a collective approach to achieve industry progress. Leaders of different parts of the value network need to engage with one another to foster innovation, reduce costs and increase the competitiveness of bio-based products.
- **Policy framework**. As in the case of most innovative technologies, large-scale commercialization is hampered by funding-related challenges. Enhanced access to capital could bring benefits, particularly to small and medium-sized enterprises. Incentives to farmers, such as FiTs, should be rethought. Subsidies should be linked to skills and innovation, and should be limited over time to support the development of profitable business cases. Second- and third-generation biomass-based biorefineries in particular will need public funding and a suitable policy framework to ease initial risks and allow stakeholders to develop profitable solutions.

Hydropower. Hydroelectric power produces relatively inexpensive electricity and has one of the lowest rates of GHG emissions of any energy source. However, since the most economical sites for creating dams and plants have already been developed, further expansion of this renewable energy source will be limited.[55]

Water in reservoirs is used to store energy and can be used to dispatch electricity when demand is high and kept in the reservoir when it is low. In 2011, the US had approximately 78,000 megawatts (MW) of conventional hydro-generating capacity, which is equivalent to about 80 nuclear power plants.[56] However, dams can affect the environment – by disrupting or displacing large ecosystems, hurting fish migration and killing animals trying to move downriver. Additionally, their plant operations may affect water quality by churning up metal deposits and changing water temperatures and oxygen levels.

Geothermal. Geothermal energy captures natural sub-surface heat and uses it to generate electricity. Unlike many renewables, this type of energy is available at a constant rate, which minimizes some of the storage concerns associated with other renewables. Regions located close to rift zones or harbouring active volcanoes have a huge potential for capturing this type of energy. This includes areas of the Pacific and western US, as well as Iceland, where geothermal power stations produce about 25% of the country's electricity.[57] According to the Geothermal Energy Association in the US, conventional geothermal power stations have a worldwide capacity of 10.7 GW and can generate 67,250 gigawatt-hours (GWh) of power in a year, or enough to supply electricity to more than 52.5 million people in 24 countries.[58]

One way to harness geothermal energy in other regions is to establish enhanced geothermal systems (EGSs) that would drill deeper into the ground to mimic the design of natural hot-water and steam reservoirs. Foro Energy, a US-based company, is working to develop this technology. It has created a transformational drilling platform enabled by technologies for transmitting high power lasers over long distances and focuses on step-change drilling performance in ultra-hard rocks to enable economical geothermal energy production. If technology can be developed that would enable this to be a cost-effective solution, the potential is massive. According to *The Future of Geothermal Energy,* an MIT report in 2007, geothermal energy available in the US in rocks from two to six miles (three to ten kilometres) under the earth's surface is nearly 140,000 times greater than the country's annual energy consumption. Even conservative estimates suggest that EGS could harness 2% of that energy, which could supply all of America's electricity, illustrating the massive potential if this can be implemented broadly.[59]

Only a few EGS plants exist today, but utility companies across Europe, the US and Australia have been among the first to invest in this technology. The biggest barrier at the moment is cost – electricity from EGS currently costs around 19 US cents/kWh, which is approximately 9 US cents/kWh more expensive than conventional geothermal power, making it uncompetitive with more common electricity sources.[60] As technology for drilling so deep into the earth's core becomes cheaper, investment in this area will become more attractive.

Ocean tidal and wave. This refers to energy that can be generated from the changing tides and waves in the ocean – a promising source for the future. As of now, however, challenges with how to store and transport this energy in an efficient manner have prohibited it from becoming a viable source. Additionally, in the case of tidal plants, only certain sites across the globe, particularly in France, Canada and Russia, would have the potential to produce this type of energy economically. But even in those regions, construction costs would need to be lowered and output efficiency increased for tidal energy plants to become a worthwhile investment. Glasgow-headquartered ScottishPower Renewables is leading the way by investigating a 50-MW wave energy site[61] and establishing the world's first commercial tidal energy project in the United Kingdom, which will provide up to 26 GWh of energy to the electrical grid per year, enough to power 5,000 households in that country.[62]

Summary of sources. The energy value network requires multiple sources in response to demand, and these sources are interdependent in terms of usage and cost. As the price of petroleum increases, renewable sources become more competitive and attract investment; new innovations and discoveries, such as the extraction of shale gas in the US, have the potential to disrupt markets. Figure 8 provides an overview of each source, including its benefits and drawbacks.

Source: *BP Statistical Review of World Energy 2011*, 2011, BP; *The Limits of Energy Storage Technology*, web edition, 2009 Bulletin of the Atomic Scientists; Deloitte Touche Tohmatsu Limited Global Manufacturing Industry group analysis

Figure 8: Characteristics of Energy Sources

Source	Pros	Cons
Crude oil	Proven, effective transportation fuel Basis of many products, from prescription drugs to plastics Economical to produce Easy to transport	High CO2 emissions Found in limited areas Supply may be exhausted before natural gas / coal resources Possible environmental impact from drilling / transporting
Coal	Abundant supply Currently inexpensive to extract Reliable and capable of generating large amounts of power	Highest greenhouse gas (GHG) intensity of all fossil resources (CO2eq/kWh) and various pollutants High environmental impact from mining and burning, although improved technology is being developed
Natural gas	Widely available, new unconventional resources offer opportunities Cleanest-burning fossil fuel Currently cheap prices	High transportation costs Lack of infrastructure makes gas resources unavailable in some areas Burns cleanly, low GHG intensity (CO2eq/kWh) Pipelines impact ecosystems
Nuclear	No direct greenhouse gases or C02 emissions Reserves are abundant Re-fuelled yearly (unlike coal plants that need trainloads of coal every day)	Higher capital costs due to safety, emergency, containment, radioactive waste and storage systems Problem of long-term storage of radioactive waste Negative public perception in parts of the world Safety issue
Solar	Non-polluting Most abundant energy source available Systems last 15–30 years	High initial investment, not yet cost-competitive Supplemental energy might be needed in low sunlight areas Limited availability of poly-silicon for panels Energy-intense and polluting manufacturing process; novel technology has the potential to improve this
Wind	No emissions Affordable Limited disruption of ecosystems Relatively high output Offshore facilities circumvent land-use constraints	Output proportional to wind speed Not feasible for all geographic locations High initial investment and significant maintenance costs

Biomass/ biofuels	Significant supply Often fewer emissions than fossil fuel equivalents Vehicle engines easily converted to run on biomass-derived fuels	Intense fuel versus food debate for first-generation biomass/ biofuels Life-cycle emissions not yet fully understood
Hydropower	No emissions Reliable Capable of generating large amounts of power Output can be regulated to meet demand	Environmental impact by changing the environment in the dam area Hydroelectric dams are expensive to build Dams may be affected by drought Potential for floods
Geothermal	Minimal environmental impact Efficient Power plants have low emissions Low cost after the initial investment	Easy to access geothermal fields found in few areas around the world Expensive start-up costs
Ocean tidal and wave	Minimal environmental impact No emissions	Expensive Challenges with storage and transport of the energy High construction costs make this viable in only certain regions

Energy Sources Summary

- Oil, coal and natural gas are currently the dominant fuels; however, the energy mix will diversify to meet growing energy demand
- Crude oil is the most important resource for liquid fuels because of its high energy density and the use of refined products, such as gasoline and diesel, as transportation fuels. Due to geopolitical risk, declining reserves and increasingly heavier and sourer crude, producers are developing harder-to-extract supplies and using more complex refining processes, which increases costs.
- Globally, coal is the largest source of electricity generation. It is abundant, low-cost and able to generate base load electricity. It also emits more GHGs than any other fuel source.
- The development of hydraulic fracturing has significantly expanded recoverable natural gas reserves and reduced prices, especially in the US. Relative to coal-fired power plants, GHG emissions by natural gas-fired power plants is about 50% lower.
- Technological advances in the exploration of unconventional oil resources are increasing the amount of technical recoverable oil reserves.
- The Fukushima accident has increased scepticism in many countries about nuclear technology. Germany and Switzerland, for example, have decided to phase out nuclear power; however, other countries, such as China, Russia, India and South Korea, plan to continue developing nuclear capacity.
- Solar- and wind-power facilities will continue to expand their shares of global energy production and will increase their efficiency.
- Biofuels have the potential to partly replace fossil fuels in transportation, but face major drawbacks.

Shale Gas Has and Will Continue to Shape Energy Markets

Shale gas is a hot topic and has the potential to change the energy industry not only in the short- to mid-term but also the long-term, as current estimates suggest that US shale-gas reserves might last for more than 100 years. Numerous articles in the popular press have described the current boom of shale gas in the US, with decreasing natural gas prices and decreasing energy imports.

The following chapter gives an overview of current and future developments in shale gas in the US and the world, and describes the most important challenges facing production.

United States. Currently the US is the main producer of shale gas. US production from shale has increased to 982 million barrels of oil equivalent (mmboe) in 2010, from 312 mmboe in 2007; thereof ~78% natural gas.[63] The two main reasons for this remarkable development are: well characterized basins and technically recoverable shale-gas reserves of 593 trillion cubic feet; and technical advances such as horizontal drilling and hydraulic fracturing processes. Gas producers have managed to drive impressive levels of efficiency and have cut costs of drilling and completion by 50% in 2009, with further reductions in the following years.[64] In the face of this unprecedented domestic gas production, a warm winter in the US and the global economic crisis, gas prices have significantly dropped (since 2007) and have reached about US$ 2-3/mmbtu (million Btu) currently. Furthermore, net imports of natural gas into the US fell by 25% in 2011, while gas exports are rising.[65]

The US will continue to race ahead in terms of developing shale gas, which might trigger up to US$ 400 billion in downstream investments over the next five years. According to the US Energy Information Administration, the country will become a net exporter of natural gas by around 2022.[66] This will have a tremendous impact on the US economy, especially the chemicals and energy industries, the US trade deficit and energy security. Shale-gas development will, without doubt, boost the US economy and reinforce economic growth. Especially in states with large resource endowments, a whole new industry is rising and thousands of jobs are being generated.

A resurrection of the US chemicals industry also is realistic, as liquid-rich shale gas contains not only methane but also feedstock for the chemicals industry (mainly ethane, propane, butane and condensate) at low prices. Furthermore, export of LNG and lower dependency on oil will contribute towards shrinking the US trade deficit – which has significant macroeconomic implications. Due to promising potential profits for oil and gas companies, it seems possible that LNG will be exported on a large scale. However, several economic and environmental interest groups want to use shale gas domestically to become independent of energy imports and to reduce the possible negative impact on the environment.

This glance at a bright future ahead should not obscure several challenges that might interfere with the development of shale gas in the US. If low prices of natural gas persist in the US, shale gas producers, especially independent ones, might go out of business, as they will not recover their costs for developing wells and extracting shale. At prices below US$ 4/mmbtu only wells containing significant proportion of liquids are profitable.

The industry ecosystem is highly complex; it includes independent and major global producers drilling for gas, mid-stream players investing in pipeline and gas processing infrastructure, as well as gas exporters investing in gas liquefaction facilities. Sabine Pass Liquefaction is the first terminal to receive approval from the US Department of Energy (DOE) to export domestic LNG not only to Free Trade Agreement countries but also globally. As of 16 July 2012, eight other terminals were under review by the DOE for approval.[67]

Furthermore, chemicals companies are taking advantage of the cheap feedstock available, while utility companies are currently operating gas plants at higher rates of capacity. Last but not least, potential new uses of natural gas, such as CNG for fuelling cars and trucks, need to be considered. Analysing the industry and taking the complexity of the industry into account, A.T. Kearney has developed several scenarios showing a natural gas price of US$ 4-8 by 2020, with a favourite scenario showing a natural gas price of US$ 6-7.[68]

Different investment cycles of the downstream, midstream and upstream segments pose a challenge for the shale-gas market. On the one hand, oil and gas companies, with short investment cycles, produce large amounts of shale gas and invest to further increase production volume, leading to low natural gas prices. Midstream and upstream players, on the other hand, have long investment cycles, taking the current price of feedstock and other factors into account. For instance, utility companies can consume more natural gas and increase the capacity utilization of their gas-fired power plants. However, this higher consumption is limited to total capacity available. A further increase causes a significant need for investment in new gas-fired power plants. The same is true for other downstream players such as the chemicals industry, which will need to invest in new cracker capacity to benefit from the availability of natural gas liquids. These different investment cycles, as well as the volume of investments and associated risk, are key reasons why it is difficult to reach equilibrium in natural gas supply and demand in the short- to mid-term.

The consumers of shale gas and in particular the utility companies, have to consider the future price for natural gas. If prices reach US$ 6-7, investments in gas-fired capacity is economically favourable. A potential future carbon tax makes gas-fired capacity a good investment, compared to coal, at even higher prices. Because of many wildcards – such as the global economy, volatile oil prices, energy and environmental policies, global gas supply and future technological developments – that might drive natural gas prices up or down, utility companies are still hesitating to heavily invest in new gas-fired power plants. Forecast gas prices are not the only factor influencing the strategic investment choices of utility companies. Other factors to consider include long-term contracts with coal suppliers, environmental regulations on coal and the flexibility of gas to cope with intermittent demand. It remains to be seen if gas will significantly substitute coal as the major source of electricity in the mid-term.

Global. Other countries with major shale-gas reserves include China, Poland, South Africa, Argentina and Mexico (see Figure 9). However, those countries lag behind in developing their reserves and doubts are increasing about their starting significant production of shale gas in the near future. China, for example, offers great potential and has added shale development to its current five-year plan. But the country faces significant challenges and it is unclear how successful production of shale gas will be overall.

An in-depth look at shale gas and other unconventional fossil resources can be seen in the chapter, *The Future Energy Landscape: Europe and China.*

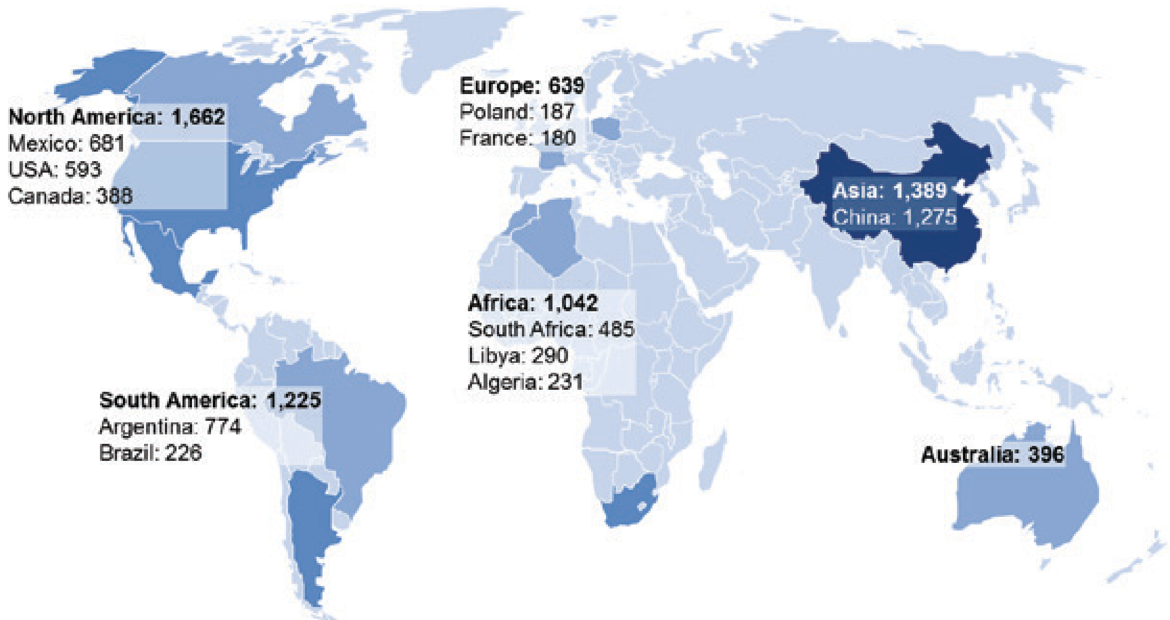
In Europe, relatively few activities in shale gas have been started, apart from significant reserves in France, and offshore in the United Kingdom. Major challenges are difficult geological formations to produce the gas and a negative public perception (see Figure 10). Environmental concerns related to the chemicals used to fracture the rock are preventing development in several European countries. In France and Bulgaria, authorities still ban drilling for shale gas using the widely used hydraulic fracturing or fracking method. Bulgaria revoked the permit given in January 2013 to Chevron to drill for shale gas after street protests, claiming that shale gas drilling can cause earth tremors and poison underground water.[69]

In Poland it is not yet clear if the country holds the reserves estimated. ExxonMobil stopped drilling in Poland after unsatisfactory flow rates, although other companies are still in the race. As in China, a critical issue seems to be difficult geological formation, which might require new technologies to produce shale gas efficiently.

Europe is currently preparing for an expected increase of LNG imports from the US and Qatar. In Rotterdam, a new terminal for LNG imports called GATE (gas access to Europe) was opened in 2011. Even without significant own-production capacities, Europe can increase its energy security by diversifying its supplier base.

Figure 9: Estimation of Technically Recoverable Global Shale-Gas Resources (trillion cubic feet)

Source: US Energy Information Administration



Environment. The environmental assessment of shale gas is rather complex and the environmental concerns need to be elaborated carefully. The increasing use of shale gas, substituting coal, can be beneficial due to the significantly lower GHG emissions from burning of natural gas compared to burning of coal. However, recent studies published by the European Commission show that extracting shale gas imposes a larger environmental impact than conventional gas production.[70,71] European shale gas causes more GHG emissions than conventional natural gas produced in Europe. The additional emissions mostly derive in the well completion phase, when the fracturing fluid, together with the methane released, is brought back to the surface. On the other hand, if managed well, European shale gas causes fewer emissions than natural gas from outside the EU, imported via LNG terminals or pipelines, mainly because of emissions from liquefaction, long-distance gas transport and regasification.[72]

The International Energy Agency in a recent report reviewed the environmental and social impact of the production of unconventional gas, including the potential for air pollution, contamination of groundwater as well as water and land use, and implications for local communities.[73] The report, titled *Golden Rules for a Golden Age of Gas*, elaborates rules to address those influences: integrate engagement with local communities, isolate wells, prevent leaks and minimize emissions, for example. New technologies for shale-gas production that consume less water and chemicals need to be developed and can address some of the environmental concerns.

As a potentially cheap source of energy, shale gas might threaten future investments in renewable energies with "front heavy" economics, leading to increased GHG emission overall. On the other hand, due to its flexibility, natural gas can supplement the transformation of the energy landscape. Gas-fired power plants are very flexible and could provide a suitable backup to cope with intermittent power supply from solar and wind sources. It will be important to find the right balance to gain maximum benefit for the climate.

Figure 10: Challenges for Development of Shale-Gas Production

Challenge	Description
Low natural gas prices	Persisting low natural gas prices would cause many producers to go out of the business
High investment needs	E.g. investment into new gas-fired power plants and pipeline infrastructure. Especially China is lacking an infrastructure to transport shale gas
Different geological formations	Shale gas reserves are located in different geological formations, making it difficult to apply the knowledge gained in other regions
Estimation of technical recoverable shale gas reserves	Models for conventional natural gas reserves do not apply; production rate per well is dropping faster on average than for conventional gas reserves
Water consumption	Drilling and production of shale gas requires two to four million gallons of water over the lifetime of the well; this poses a challenge especially in regions where shale reserves meet water scarcity, as in China
Environmental concerns and public perception	Environmental concerns and the negative public perceptions is a major challenge in some European countries (e.g. France and Bulgaria)
Technological expertise	China is currently investing in US to gain the expertise needed to drill and produce shale gas domestically

Fuel for transportation. Natural gas has the potential to become a major transportation fuel as CNG, LNG, absorbed natural gas, or as a liquid fuel using GTL conversion technology. One current impediment, however, is the paucity of distribution infrastructure relative to gasoline. As a result, early adopters of CNG technology have included city transportation systems or delivery fleets that can create their own centralized distribution centres. For example, Frito-Lay, a division of PepsiCo, which operates the seventh-largest private delivery fleet in the US, announced that it would convert the majority of its fleet to CNG power. Eventually, the company plans to convert part of its long-haul fleet to LNG power. Estimates indicate that the CNG-powered trucks will save approximately US$ 2.50 per gallon compared to current diesel prices and will reduce GHG emissions by 23%. Similarly in India, the CNG-powered vehicle market is experiencing strong growth and is helping to drive the expected boost of the country's CNG market's CAGR of approximately 22% from 2011 through 2014 to reach approximately Rs 30 billion (US$ 572.5 million).

While large-scale adoption of CNG or LNG requires large investment in infrastructure and the conversion of all or part of the vehicle fleet, GTL technology allows natural gas to fit into the existing transportation infrastructure. In the US, the most immediate effect of large-scale GTL technology would be the development of big domestic fuel sources that would ease the country's dependence on foreign oil. However, GTL's capital costs are significantly higher than that for an equivalent petroleum refinery. GTL's success therefore requires hedging of the current natural gas-crude oil spread for the next 20 years, at a differential that would justify the capital. As more such deals are done, the capital cost could decline due to learning-curve effects. Nevertheless, due to the geographic concentration of shale-gas reserves, cost-effective GTL technology could significantly revolutionize the global oil trade.

Shale Gas Summary

- The key drivers for the development of shale gas are the availability of the gas, especially in the US, energy security and potentially stricter policies for GHG emissions in the future.
- Increasing production of shale gas will significantly alter the energy landscape at a global level, and at a regional level in countries having technically recoverable shale-gas reserves.
- Natural gas has the potential to substitute coal as a source of electricity generation. However, significant hurdles remain, so when and if this will happen is unclear.
- Low gas prices and different investment cycles for downstream, midstream and upstream players pose a challenge for the shale-gas market in the US.
- China has large shale-gas reserves, but faces significant challenges in exploitation.
- In Europe, public perception and difficult geological formations are critical issues for development of a shale-gas industry.
- With political and economic will, natural gas can play an important role in the future transportation landscape.

Renewable Energies Will Be a Key Enabler to Transform the Current Energy Landscape

Renewable energies for electricity, heat and transportation are not only rapidly gaining market share in end-user energy consumption, but they are also spurring a need for, or bringing about, paradigm shifts in additional aspects of today's Energy Harnessing value chain. This does not happen without friction. Every structural change has winners and losers. As the penetration level of renewable energies becomes more than marginal and adoption rates accelerate, this friction becomes more apparent. At the same time, renewable energies are mostly new technologies and need to further reduce costs and integrate with the energy market.

Key areas in which renewables transform the current energy landscape:

- Carbon intensity of energy provision
- Overall cost of supplying energy to consumers
- Working and dynamics of established market mechanisms for trading energy
- Complexities and technical solutions needed in grids and networks
- Degree of distribution (decentralization) of power generation
- Composition and type of energy player
- Availability of capital to finance energy investment
- Level of involvement and impact of political decision-making on the energy value chain
- Acceptance by, and involvement of, citizens in the Energy Harnessing value chain

As is clear, comparing renewables merely along technical properties, as "alternative" sources of energy, while necessary, is perhaps too narrow a look at their impact on overall demand and supply. Full treatment of the interlocking topics mentioned requires a comprehensive coverage that is not feasible in this report, which covers only selected aspects to illustrate the main ways that renewables can transform the energy landscape.

Carbon intensity of energy provision. Renewables are generally regarded as "carbon free" or "low carbon". However, a full life-cycle analysis is necessary, including the supply chain, to judge a realistic carbon footprint of renewables. Some renewables hold this promise (e.g. wind and PV) while others (e.g. biofuels) greatly depend on the particular resource used.[74] By and large, it is true that renewables are "low carbon", as emissions from fossil fuels are often higher in a life-cycle analysis than their carbon content suggests.

Growth of renewables thus affects carbon-trading regimes such as the EU Emission Trading System (EU ETS). Also, due to the faster-than-expected growth of renewables, fossil power generation capacities had a lot less load hours than projected. This leads to a slackening of demand for emission allowances and a dramatic decline in their price. The low carbon price has proved to be little incentive in reducing carbon emissions, thus leading some experts to call for an urgent adjustment of the current scheme.[75] The price for emission allowances was expected to be between € 25 and 30 (US$ 34 and 40) per tonne of carbon dioxide (t CO_2), and hence significantly higher than the actual € 5 /t CO_2 in August 2013.[76] The parallel existence of carbon and renewable energy policies are seen as a way to reduce emissions, and the higher share of renewable energies is an objective in itself.

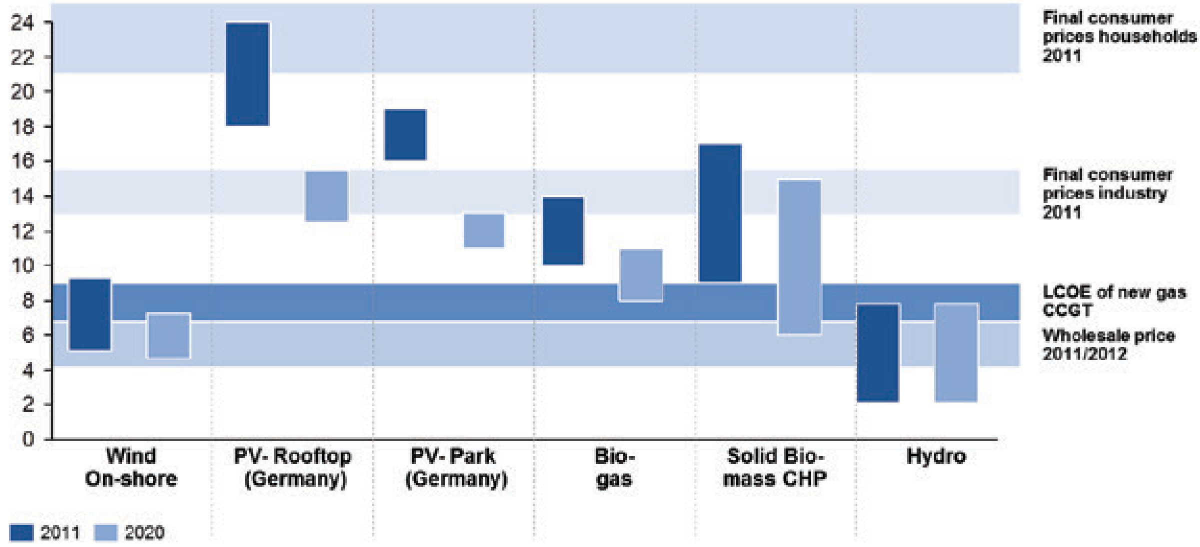
Cost of supplying energy to consumers. Most renewable energy technologies generate only at cost above the current market rates of other energy carriers. Figure 11 provides an overview of LCOEs for selected renewable energy technologies in Germany. The qualitative picture of costs is similar in other developed regions, but depends on different parameters that vary among countries. The pure consideration of current market rates is a narrow perspective, as true economic costs are not always included in the price. Willingness exists therefore to support renewables with policy support such as subsidies. This support has resulted in a huge increase of renewable energy production. The costs of supportive policies and subsidy schemes have been allocated to consumers or tax payers.

However, some technologies and applications are providing energy at, or below, "market" rates and can substitute conventional technologies in certain applications without regulatory or financial support. With the right business model, e.g. leasing solar panels instead of buying them, many renewable energy sources are cost-competitive from an end-consumer perspective even in developed countries. Furthermore, renewable energy sources are providing a backstop price for energy in many markets and are depressing prices, e.g. on power wholesale markets, as they provide energy almost for free once installed.

In many emerging countries, where a significant part of the population lives in rural areas unconnected to the national electricity grid, renewables can offer energy at lower cost than the currently used diesel generators. According to a study of the European Photovoltaic Industry Association (EPIA), solar panels already compete with diesel generators, provided the latter's fuel is not subsidized, in countries with a high solar irradiation ("sunbelt countries").[77] Instead of using diesel generation sets throughout the whole day, solar panels can offer a cheap alternative during the day, while backup diesel generators provide electricity during the night. Installation of batteries to store the electricity from the solar panels for night consumption is currently too expensive. Solar panels can provide electricity in micro-grid or off-grid solutions. Relatively high initial investment costs and generally low political will are hampering the development of solar panels in those regions.

Figure 11: Levelized Cost of Electricity of Selected Renewable Energy Technologies in Germany (€ct/kWh)78

Source: A.T. Kearney analysis



A steep cost decline of technologies (PV but also wind power) has been achieved and shows the potential of a global technological value chain. That said, renewables are still far from fully mature, so additional downward dynamics of costs can be expected and will foster the cost-competitiveness of renewable energy.

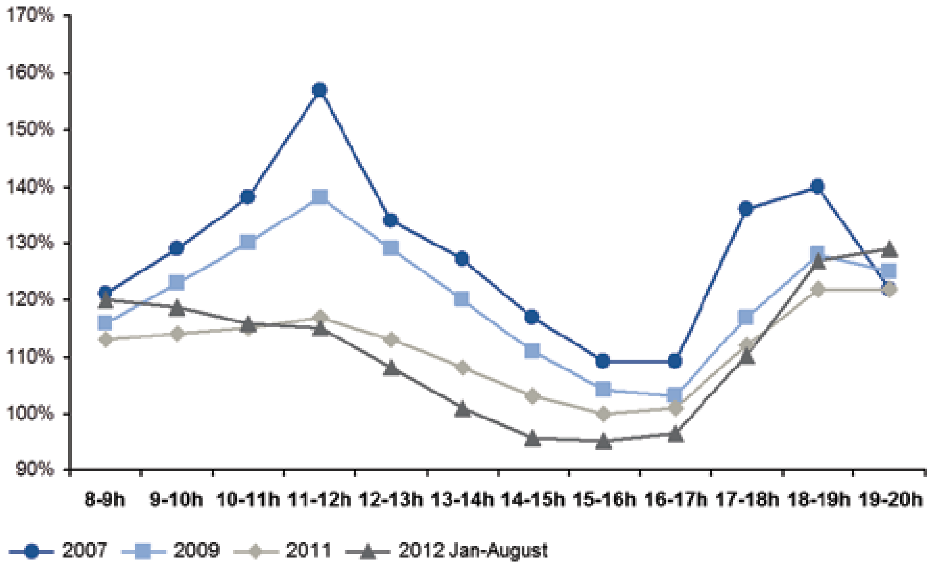
The workings and dynamics of established market mechanisms for trading energy. Power markets are feeling the impact of large installed renewable capacities. The "front heavy" economics of renewable energy technologies, such as wind and solar, pose a considerable threat to fossil capacities, which have higher costs of operation. Because their costs are "sunk" once installed and returned via the support scheme, renewables can provide "free" power that depresses the market price. As illustrated in Figure 12, renewable energy sources already influence the average price of peak hours. In Europe peak prices are coming down and the mid-day peak is almost history. This development decreases trading margins for all generation technologies.

Furthermore, the distributed nature and scalability of some renewable energy technologies, such as solar PV and solar heating, enable consumers to generate for self-consumption. The business case for consumers is driven by the alternative price at which they can purchase energy from the power, heat or gas grid to which they are connected. They might chose renewable energy self-generation also because they can avoid grid utilization charges and taxes levied on traditional energy carriers.

Complexities and technical solutions needed in grids and networks. The variable nature of some renewable energy technologies (solar and wind) test established grid infrastructures. Power grid operators have to learn to handle a much more complex stabilization task. Experiences in Germany, Spain and the US show that most operators have been up to the challenge and thus far have managed to adapt managing practices, monitoring and forecasting capabilities to digest the increased volatility. That said, there are physical limits and additional investment is needed to increase the share of volatile generation above system-specific thresholds. Apart from changes to grid infrastructure, increased volatility can be managed with increased flexibility in established power plants and by adding storage. In grids with high penetration, significant progress was made to increase the flexibility of fossil- and nuclear-powered units; significant investment and project development in new storage is ongoing. New concepts, such as power-to-gas, are being used in the first industrial applications, to provide seasonal storage solutions. While not yet cost-competitive, rapid technology development has shown that technical solutions can help to absorb volatile power sources.

Figure 12: Ratio of Average Prices of Peak Hours to the Annual Average of EEX Spot Prices

Source: IZES Kurzstudie. Kurzfristige Effekte der PV-Einspeisung auf den Großhandelsstrompreis, January 2012; EEX; A.T. Kearney Analysis



In summary, the following technical solutions are available to address the emerging imbalance:

- Increased flexibility of large generation
- Additional energy storage capacities
- Improved grid management
- Investment in grid strengthening / expansion
- Systematic demand response
- Increased share of dispatchable distributed generation
-
- Those solutions, however, face challenges that include:
- High risk for most solutions, e.g. due to uncertainty of wholesale market prices
- Changing regulatory frameworks that make strategy decisions difficult
- Multiple actors within utilities, often not aligned internally behind one strategic agenda

Besides production of electricity, renewables are used increasingly to generate heat e.g. using surface geothermal heat, solar thermal or bioenergy heating systems. These renewable heating sources, combined with the impact of improved insulation, are already negatively affecting the profitability of district heat networks.

The degree of distribution of power generation. Renewables provide a broad range of possible system size and plant configurations, ranging from large conventional power plants to small applications for domestic use. While economies of scale work in renewable energies, they are often neglected because support schemes provide incentives that are tailored to small capacities. Political will is necessary to enable small and mid-sized capacity additions.

Mostly due to their scalability and possible applications at small sizes, renewables are the key enablers for distributed generation close to consumption and in the ownership of consumers. A study by SunEdison and A.T. Kearney shows that self-generation and self-consumption in Europe is increasing and can offer benefits for the energy sector such as:

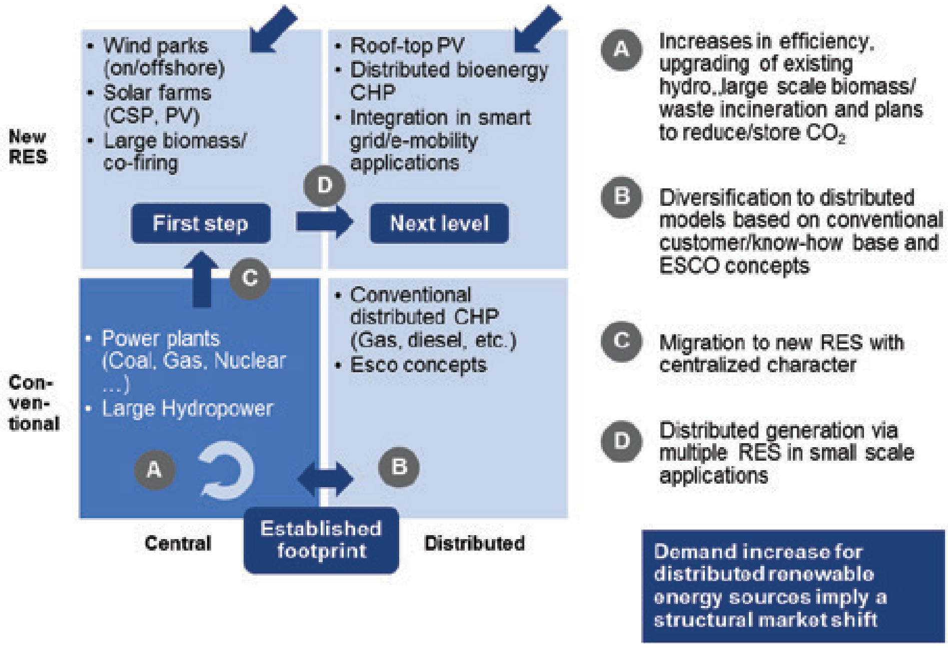
- Driving energy conservation by consumers (increasing energy efficiency)
- Leveraging private investments
- Improving grid stability
- Developing innovative solutions for export
- Enabling public participation and acceptance[79]

To further develop self-consumption, several legal and economic barriers need to be mitigated. Existing barriers differ hugely among European countries. For example, Germany and the United Kingdom have incentive schemes that actively support self-consumption, while France and Spain have significant legal hurdles.

The market shift to more distributed energy generation is forcing utility companies to change sales focus away from eroding commodity-product markets to more sophisticated distributed-application markets. Figure 13 provides an overview of the generation portfolio dynamics.

Figure 13: Power Generation Portfolio Dynamics

Source: IZES Kurzstudie. Kurzfristige Effekte der PV-Einspeisung auf den Großhandelsstrompreis, Januar 2012; EEX; A.T. Kearney Analysis



Composition and type of energy-sector players. A significant influx of new players can be seen, mainly due to the strong growth of renewable energy sources. In Germany, for example, the number of energy cooperatives has quadrupled in the past three years, reaching about 600 in 2011.[80]

Another global indicator that utilities no longer are the sole players in the market is the trend for green energy cities and communities. Sustainability is a key lever when advertising cities as a desirable place to live. The European Commission set up the "Green Capital" award to recognize the role of local authorities in increasing environmental protection. Award-winning Stockholm has set a target to become wholly independent of fossil fuels by 2050. Other cities around the world are promoting their own green initiatives: Chicago defined a Climate Change Action Plan and New York set up a GreenNYC programme. New city concepts such as Masdar in Abu Dhabi and Tianjin Eco-city in China illustrate that cities can be important players in the energy sector, and help to protect the environment and climate.

These examples show that customers, in a bottom-up approach, are demanding and realizing alternative energy supply mechanisms, and encouraging newcomers in the energy sector, including:

- Developers with a renewable focus to develop and operate projects
- Large consumers generating for their own use
- Financial investors engaged in renewables and accumulating portfolios backed by funds
- Municipal utilities re-entering generation
- Farmers diversifying their sources of income
- Residential and small commercial owners producing for FiT and / or self-consumption

Depending on the type of renewable energy source, different business models will be predominant in the future. For wind power, the trend is towards larger wind turbines and wind parks; the predominant business model will favour large power producers (utilities and independent power producers). For PV and biomass, the business models are different. Investment competitiveness for PV will be achieved first for residential applications, and dispersed markets will have to be actively developed. Entry of large utilities is currently confined to a few players, while regional utilities develop local potential. Project developers will dominate the market. For biomass, the mid-size segment dominates, as the availability of heat sinks and a limited local biomass supply at acceptable prices restrict plant sizes. Farmers and forestry players own and operate small plants, while cooperatives, municipal utilities and industrial users dominate the segments greater than 500 kW/ year.

The availability of capital to finance energy-sector investment. Renewable energy has led to an enormous inflow of private capital into the energy sector, from small investors to home owners. In 2010, they were the second-largest group of investors in global clean-tech investment.[81] The German solar PV market mostly drove growth in small, distributed capacity from 2009 to 2010. Funds and institutional investors also are making capital available to renewables due to the securities that many support policies provide the investor. At the same time, the increased volatility in market prices, the erosion of peak-power pricing (see Figure 12) and the rapid deployment of renewable energy sources have significantly weakened the business case and availability of financing for conventional power plants.

The risk/return profile varies significantly between different renewable energy technologies and regions. In general, offshore wind has a higher risk than onshore wind and PV. The latter has mostly an attractive risk/return profile. To ensure the economic appeal of renewable energies certain criteria need to be fulfilled. Due to the high investment costs, a reliable and stable political and policy framework is essential to ensure achievement of the business case. Moreover, the quality of grid infrastructure, the experience of the project, and overall investment conditions are vital to increase the returns and decrease the risks.

The level of involvement and impact of political decision-making on the energy value chain. Politics often heavily influences the energy system and incentivizes energy sources. Oil and gas pipelines, nuclear infrastructure and coal mining were all the subject of political decision-making and support. Renewables are no different. They are a policy-driven "new entrant", which crowds out some technologies that were previously in the liberalized energy market, and emerging in some countries towards the latter part of the 1990s.

Markets that liberalized in the 1990s (for example, the United Kingdom) face the challenge that renewable energies are undermining the liberalized market mechanisms. The success of renewable energies causes a partial re-regulation of those markets. Either this re-regulation is accepted or new ways to integrate renewable energies into the liberalized market need to be established. In non-liberalized markets (e.g. China and several African countries) the integration of renewable energies is less a question of the market and more one of political will. In both cases, a political decision on renewable energy's role in the future energy landscape is required.

Acceptance by, and involvement of, citizens in the energy harnessing value chain. Public perception is a vital factor in energy infrastructure development; it affects renewable energies as much as large coal-fired stations. By revealing the idea of an alternative solution for energy supply, renewables have made it harder to establish conventional power plants. In some parts of the world, citizens are no longer simply "against" a certain development in their backyard; they are attacking the very premise that certain types of conventional technologies are even necessary. Greater transparency, enabling active participation in decision-making and investment by citizens, are means to increase acceptance. That said, renewable energies are often subject to significant scrutiny for their impact on the landscape (e.g. wind turbines) or local olfactory consequences (e.g. biogas or biomass).

The impact of renewable energies on the energy sector is ongoing, but the degree varies by region and segment. To enable transformation of the current energy landscape, certain hurdles need to be overcome. As shown in Figure 14, continued cost reduction is a critical issue for renewable energies. In the wind industry, for example, production processes are often inefficient. Economy of scale and optimized production processes offer substantial cost-reduction potential. In the PV sector, consolidation and continued research and development (R&D) will leverage cost reductions. Other difficulties include grid integration, safeguarding public perception, easing reliance on subsidies, developing integrated business models and managing social and environmental impacts.

Renewable Energy Sources Summary

- Renewables are changing the energy market in numerous ways: private capital is flowing into the energy sector, mid-day price peaks in Europe are almost history, new players are entering the market and liberalized markets are facing re-regulation.
- Most renewable energies are "low carbon" in a full life-cycle view.
- Public acceptance is an important factor in energy infrastructure development, affecting renewable energies just as much as it does coal-fired stations.
- Key issues for renewable energies include cost reduction and integration with the energy market.

Figure 14: Overview of Key Challenges for the Further Development of Renewable Energies

Source: IZES Kurzstudie. Kurzfristige Effekte der PV-Einspeisung auf den Großhandelsstrompreis, January 2012; EEX; A.T. Kearney Analysis

Challenge	Description
Continued cost reduction	Industrialization of production process, especially for wind energy, offers significant cost reduction potential. Consolidation and continued R&D advances will be main drivers of cost reduction in the PV sector. For biomass, cost reduction of the fuel supply is needed to meet sustainability criteria.
Grid integration	Grid integration needs to be ensured, by use off full range of technical options to increase system flexibility
Social impact and public perception	Negative public perception, e.g. off on-shore wind parks or large scale PV plants, might pose a challenge to some renewable energies in some regions. Furthermore, the social impact of 1st generation biomass/biofuel needs to be mitigated (food vs. fuel debate), through 2nd and 3rd generation options.
Reliance on subsidies/ development of integrated business models	So far, many renewable energies rely on subsidies. New business and market models and mechanisms need to be defined to ensure their economic sustainable success
Environmental impact	The environmental impact of renewables needs to be monitored. E.g. environmental impact of biomass largely depends on the raw material used.

Advanced Energy Storage Solutions Will Be a Key Enabler for the Further Growth of Renewable Energy Sources

The rising percentage of electricity from renewable intermittent energy sources and the quest for sustainable mobility solutions lead to higher demand for advanced energy storage solutions, next to other balancing approaches and technologies (e.g. demand management or flexible conventional power plants). It will be essential to provide advanced energy storage solutions on a large scale to transform our energy landscape into a more sustainable energy market. Furthermore, the mobility sector will increasingly rely on e-mobility, to decrease the impact of mobility on the climate. Current storage technologies lack cost-effectiveness and sufficient energy density for many applications.

Grid-scale Energy Storage Poses Complex Challenges

The strong growth of intermittent power generation from renewable resources increases the demand for compensation technologies. Energy storage solutions will be a key enabler for disconnecting power generation from consumption, and therefore for the successful deployment of sustainable energy production globally. With the increasing use of renewable energy sources, the old mechanisms of producing just-in-time energy, when it is needed, is no longer valid. The production of energy from renewables depends on the availability of the sources (e.g. solar energy can only be produced during the day).

In future, the demand and supply of energy will be independent from each other. This could lead to high volatility in electricity prices. During peak-supply times, producers offer energy for no cost. Large energy storage solutions enable the use of renewable energy sources, even during peak-supply times, and can increase the price of energy during periods of high supply and decrease it during periods of low supply. In Germany, 127 GWh of renewable energy produced were lost in 2009 (thereof 98.7% from wind farms[82]) because of insufficient energy storage facilities and a lack of grid transmission capacity. An estimated 40 terawatt-hours (TWh) of energy storage capacity is needed by 2040 in Germany alone and investments of € 30 billion in new energy storage facilities are required in the next two decades.[83] Energy storage solutions are therefore vital to transform energy production into a sustainable landscape using renewable energy.

Technologies. Different technologies compete for grid-scale energy storage solutions (see Figure 15). Many of them offer solutions for small niche applications. However, it is not clear which technologies will be competitive and feasible. In general, storage solutions can be separated into electrical and non-electrical.

Today, the most important non-electrical storage technology is pumped storage hydropower (PSH). It is estimated to account for 127,000 MW of power, or 99% of bulk storage worldwide.[84] It requires a specific geography and the political means to build the required infrastructure. As a result, further development of PSH solutions vary by region, with limited options in Europe and better opportunities in parts of Asia.

Figure 15: Overview of Major Grid-scale Energy Storage Solutions

Source: A.T. Kearney analysis

	Key applications	Limitations	Potential
Pumped storage hydropower	– Centralized, large scale applications	– Specific geological requirements – Large public concerns, especially in Europe	– Limited potential in Europe – Potential mainly in parts of Asia
Power-to-Gas	– Large-scale applications	– High costs – Low efficiency of electrolysis	– Huge storage potential for H2 and CH4 in the gas grid
Compressed-air energy storage	– Mainly centralized, large scale applications	– Specific storage caverns needed – High costs – Efficiency	– A-CAES offers significant increase of efficiency compared to CAES
Hydrogen storage	– Decentralized and centralized applications	– High fugacity/ explosiveness – Low efficiency of electrolysis – Not been demonstrated on large scale yet	– H2 storage in general flexible
Batteries	– Mainly decentralized applications (e.g. in private houses to store energy producers from solar panels)	– High life-cycle costs – Rare earths – Chemicals partially harmful to the environment	– Very flexible – Used lithium-ion batteries from future e-vehicles usable

Compressed-air energy storage (CAES) is another possibility, where compressed air is stored in underground caverns or large tanks and released into a combustion turbine generator system when electricity is needed.[85] Pike Research reports that US$ 122 billion will be spent on energy-storage projects between 2011 and 2021, with the majority spent on CAES.[86] However, the process is expansive, inefficient and bears technical complications. A large CAES storage plant requires investment of between € 300 and 500 million. The efficiency is rather low, compared with other technologies. CAES uses two existing technologies: diabatic and adiabatic. Adiabatic captures the heat initially created by compressing air to high pressures and reusing it, in an approach called Advanced Adiabatic CAES (AA-CAES). Diabatic does not. Before AA-CAES can become a commercial option, however, the heat loss needs to be minimized and equipment developed that can withstand temperatures up to 650 degrees Celsius.[87]

Not only air but also hydrogen (H_2) can be stored in underground caverns or tanks. H_2 can be produced from excess electricity using electrolysis. It also can be transformed into methane (CH_4) or stored directly in the gas grid (power-to-gas). The latter offers the opportunity to store energy on a large scale without additional investments in storage technology. Germany has facilities to store up to 217 TWh of gas, one-third of the country's annual electricity consumption[88]. However, the transformation of electricity into H_2 and CH_4 is very inefficient and the technology is expensive. In addition, H_2 has a lower fuel value than natural gas. Investments in the power-to-gas concept can pay off and might offer a large solution for energy storage in the future – for example, Audi is investing in the construction of a 6.3-MW power-to-gas plant and is collaborating with partners from the energy industry and academia to further develop this storage solution.

Batteries are the most important electrical storage technology, and range from lithium-ion (Li-ion) to sodium-sulphur (NAS) and Redox flow.

– Li-ion batteries provide high energy density and are typically lighter.[89] However, the largest-scale lithium-ion batteries are expensive and can only store up to the equivalent of 1 MW of energy. In the future, the lithium-ion batteries of e-vehicles might be used after their lifespan in the vehicle for grid-scale applications still offering 80% of their capacity.
– NAS batteries were first operated more than a decade ago and by 2011, more than 300 MW have been installed globally.[90] Load levelling is the primary application, but they can also be used as a standby power source and can stabilize fluctuating power from renewable energy sources.[91]
– Redox flow batteries can store large volumes of energy – preliminary estimates are around 1 GW. Vanadium redox and Zn/Br batteries store the electrolyte in a separate container. The key advantage? Increasing the volume of the electrolyte used can easily prolong the storage system's discharge duration.[92] In addition, the electrolyte if degraded can be replaced, adding to the system's sustainability.

Grid-scale batteries must have high charge and discharge rates, as well as the ability to withstand multiple cycles in order to meet the demands of the electrical grid. Batteries are especially suitable for flexible, distributed applications, e.g. in private houses to store excess electricity produced from solar panels on the rooftop.

Figure 16: Overview of Key Challenges for Grid-scale Energy Storage Solutions

Challenge	Description
Early stage of development	Many technologies are still in an early development stage. A faster transformation from the lab to the market is needed
High costs and low efficiency	Most solutions are still too expensive and suffer from a low efficiency
No clear financial/ regulatory incentives	Clear financial and regulator incentives are still missing to support the development of large-scale, cost-effective energy storage solutions
Complex value chain	Many different stakeholders (from chemical companies producing the components, energy companies needing storage solutions to the consumers of energy) are involved
Complex business case	Many different variables need to be considered to draft a reliable business case. In most cases the business case is very weak

Challenges. Grid-scale energy storage solutions face several crucial problems (see Figure 16). Most technologies are still at an early stage of development and are not economically feasible. High costs and low efficiency of storage solutions (for CAES, H_2-storage or battery, for example) remain major hurdles. Two sites currently being built in Germany transform the electricity into thermal energy for storage or heating purposes. A simple large-scale water boiler is used, offering the advantage of low investment costs for financially weak cities, but also the disadvantage of low efficiency. Technical issues still hobble many technologies – for example, electrolysis, which can transform electricity into H_2, suffers from low efficiency.

Political will is a key enabler to transform the energy landscape. Without the right financial and regulatory incentives, it will not be possible to develop cost-effective large energy storage solutions and build a dependable business case for them. The market itself will not be able to provide the necessary incentives for companies to invest in the development of these technologies in the short term.

But politics cannot provide all the answers. The industry itself must find solutions and work across stakeholders to address the challenges of a complex value chain and decrease time to market. Industry participants such as chemicals, energy-producing and grid companies, and financial institutions need to work together to find solutions. Academia and industry also need to collaborate to scale up lab solutions and test them in demonstration projects.

Furthermore, energy storage solutions alone cannot provide the flexibility needed to base our energy system on renewable sources. The smart combination of production, transmission, storage and consumption will be required (smart grid). How this can work was demonstrated by the Offshore Grid study within the Intelligent Energy Europe programme.[93] In the future, large amounts of electricity can be produced in offshore wind parks in the North Sea, if those wind parks are embedded in the right technological system. To fully leverage the energy created, production, transmission and sufficient storage solutions have to be combined. High voltage transmission lines can connect wind parks with demand centres in neighbouring countries and with large pumped hydropower storage (PHS) facilities in Norway, amassing excess energy. Using this approach, demand and supply peaks can be balanced in the countries neighbouring the North Sea, and a reliable local energy system can be established.

E-mobility Applications Require Energy Storage Solutions that Provide a Higher Energy Density

The electrification of the powertrain landscape is seen as one option to lower air pollution in cities and even to reduce the climate change, if electricity is produced using renewable energy sources. The automotive industry is addressing this trend and investing heavily in different technologies, including strong- and plug-in hybrid, range-extender and pure electric vehicles (EVs). Today, those technologies have a very minor global market share (see Figure 17), but electrified powertrains will appreciably expand their market share in the future.

Lower case all words in legend except for "Range" and "Strong"

Powertrain landscape development. Different scenarios have been applied to estimate the global market share of electrified vehicles in 2025 (see Figure 17). The most important drivers for development of hybrid electric vehicles (HEVs) and pure EVs will be the total cost of ownership (TCO), technological maturity and regulation.[94] It is expected that HEVs will reach TCO-parity with internal combustion engines (ICEs) before 2025, while EVs will have a slightly higher TCO in 2025. Several factors, including future CO_2-based taxes for vehicles, oil prices and decreasing costs of batteries, have been considered to assess TCO. In a moderate scenario, oil prices will reach US$ 160 per barrel in 2025, battery costs will decrease by 6% per year, and taxes will be based fully on CO_2 emissions. According to this, electric vehicles and range extenders are expected to capture 8% of global market share. In the slow scenario, their market share will reach 3% only in 2025, and in the fast scenario, 12%. The fast scenario includes subsidies for EVs, which are not considered in the moderate scenario. The market share of strong- and plug-in hybrids will reach between 14% and 34% in 2025, depending on the scenario applied.

Challenges. However, multiple issues related to batteries exist that must be overcome to enable substantial growth of EVs (see Figure 18). Batteries account for a significant portion of the acquisition costs of EVs and HEVs; the battery of a compact EV car, such as Nissan's Leaf with a 24 kWh battery pack, currently costs between US$ 13,000 and US$ 18,000. A price improvement is essential to achieve TCO competitiveness with ICE powertrains, and subsequently increase their attraction for customers. A 60% decline from current prices is expected by 2025. Improving battery-cycle life is another prerequisite for the success of EV and HEV powertrains and a lever to lower the total cost per vehicle. Battery-cycle life is estimated to double to 3,000 cycles until 2025. A number of safety incidents have occurred involving fires and explosions, due to EV and HEV batteries' high energy density, poor stability of some electrode materials (towards oxygen evolution) when the cells are charged, and the use of flammable organic electrolytes. Although pack cooling and isolation of cells helps somewhat, it is difficult to reduce the flammability of a single battery cell to enhance the overall safety of the battery. Another trial is batteries' still low energy density, compared with the energy density of petroleum and diesel, for example. Higher energy density of batteries will increase the range of e-vehicles, and will be critical for their success. This is because customers typically demand vehicles with longer ranges, although 87% of the cars in Europe drive less than 60 km per day.[95] An 80% improvement of the energy density seems realistic until 2025.

Figure 17: Scenarios for Global Powertrain Landscape Development

Source: *Powertrain 2025.* May 2012. A.T. Kearney

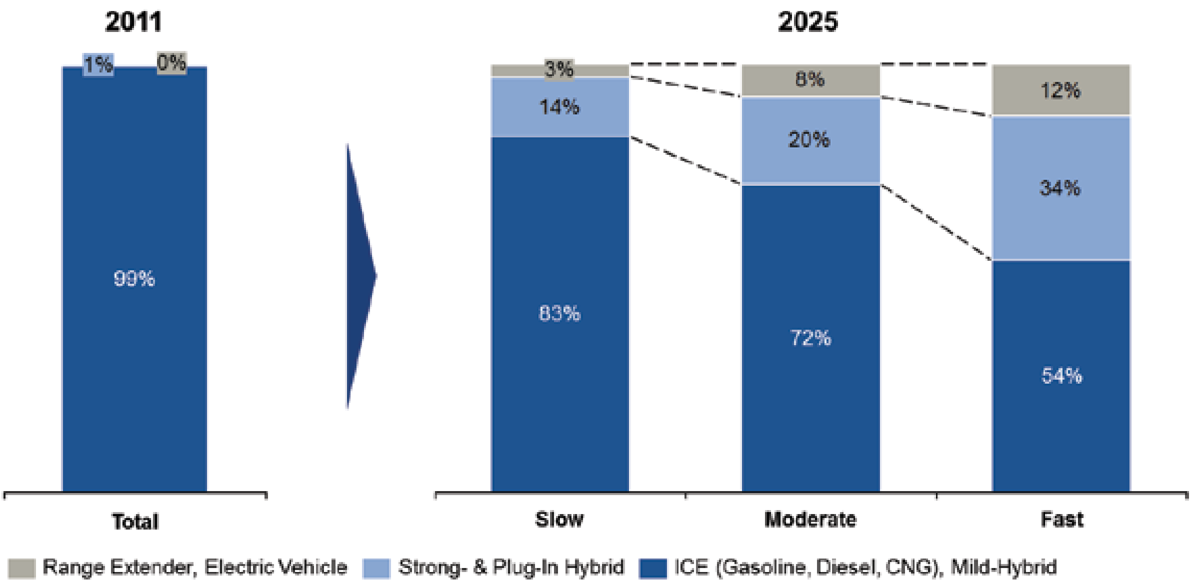


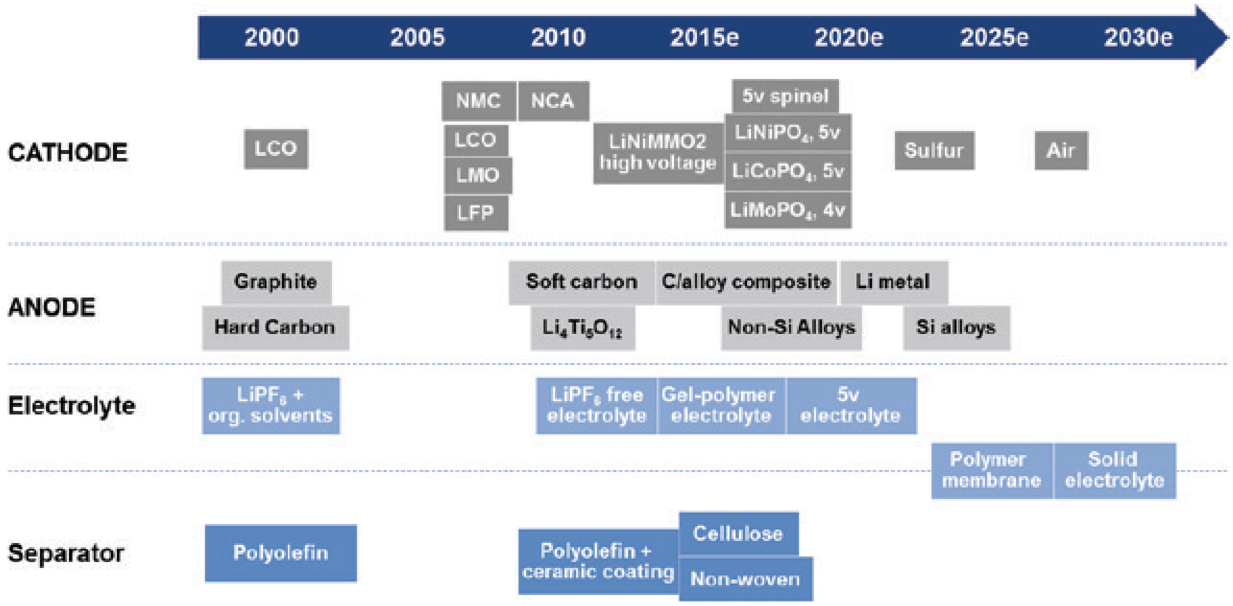
Figure 18: Overview of Key Challenges and Targets for E-Mobility

Source: *Powertrain 2025.* May 2012. A.T. Kearney

Challenges	Description	Status today	Outlook 2025
Reduce costs[1]	Costs need to be significantly improved to achieve TCO competitiveness of EV / HEV	Pack: 545 US$/kWh	Pack: 290 US$/kWh
Improve cycle life	Battery lifetime needs to achieve vehicle lifetime to be cost competitive	80% capacity @1,500 cycles[2] (4-6 years)	80% capacity @3,000 cycles (8-12 years)
Improve safety	Safety is well today on module level (cell/cell insulation + BMS measures) but needs to be improved on cell level (materials)	moderate	good
Increase energy density	Improvement of energy density is required to reduce weight of batteries, respectively to increase e-drive range	140 Wh/kg[2]	~250 Wh/kg (+80%)

Figure 19: Technology Roadmap of Lithium-ion Battery Cells

Source: Fraunhofer Institute for Systems and Innovation Research (ISI)



Technological developments. The trend for new materials to improve batteries for e-mobility applications will continue. Figure 19 shows a technology roadmap of lithium-ion battery cells until 2030. Material developments for anode and cathode will be the main drivers for improvements in energy density. A shift from graphite to silicon-graphite can increase the energy density of the anode by three times. However, the battery's other components need to be adapted accordingly to achieve a similar energy density improvement on cell level. Nickel manganese cobalt (NMC) and lithium iron phosphate (LFP) will be the dominant material used in the cathodes of lithium-ion batteries in the short- to mid-term. NMC can provide a high energy density, while LFP can offer a price advantage over NMC and will predominantly be used by Chinese battery producers. The electrolyte will shift to a gel-polymer electrolyte to improve cell safety and energy density. Lithium-air cells consist of a lithium anode and a carbon-air cathode. They can offer 10 times higher energy density and lower prices than current lithium-ion technology. However, widespread commercial use is not expected before 2025-2030 at the earliest, because major technological hurdles remain to be overcome.

Not only new material developments but also advanced battery management can mitigate some of the technical challenges of batteries. Improved safety can partly be achieved by using less flammable materials and by advanced battery management with improved sensors. Timely detection and shutting-down of cells reaching a critical temperature can dramatically enhance battery safety, and advanced charging management can improve cycle life. Finally, achieving scale in volume and automation of production will be key levers to reduce battery costs and the TCO of electrified vehicles.

Other technological developments include wireless charging of batteries. This would be hugely beneficial as vehicles can be charged while travelling on equipped driving lanes or waiting at bus stops for passengers. Several trials have already been launched worldwide, and companies such as Toyota, Nissan, General Electric and Qualcomm are investing in this technology.

Key success factors. The main factors that enable technological and volume improvements include:

- Stable boundary conditions
  - Regulations (e.g. CO_2 limits)
  - Subsidies and incentives
- Joint efforts of the automotive and battery industries, and legislation to support a rapid increase in scale
  - Clear agreements between the automotive and battery industries
  - Standardization of batteries
- Technical progress
  - Battery companies' R&D focus on most promising technologies
  - Close cooperation between value chain participants

Stable boundary conditions. A stable policy framework is a major factor for a successful transformation of the energy landscape, and especially of the e-mobility market. The policy structure must reduce the risks for the private sector and promote investment in future solutions. For example, the EU has a regulation on CO_2 emission. A recent European Commission proposal sets stringent emission targets for car fleets, cutting average emission for new cars to 95 gm of CO_2 per km in 2020.[96] An even stricter emission target of 70 gm of CO_2 per km in 2025 has been discussed, and might become a significant driver for electrified vehicles. This will foster the development of alternative powertrains. Other key enablers are regulatory and financial incentives to ensure the economical attractiveness of e-mobility solutions. An estimated € 20-30 billion will be spend globally on subsidies, of which 85% will be for direct and indirect buyer's premiums and 15% will be paid to the industry.[97] An example of a regulatory incentive: in Oslo, e-vehicles can use specific traffic lanes and use municipal car parks for free.

Joint efforts. The success of EVs and HEVs will depend not only on a policy framework and incentives. Clear agreements between the automotive and battery industries are equally important to underpin a rapid increase in scale. Battery and automotive companies have to agree on technical standards to avoid a fragmentation of the market and technologies used. The industry partners have to find mutual solutions, for example, to charging technology. Currently, fast-charging (preferred by Western original equipment manufacturers or OEMs) and battery swapping (preferred by Chinese OEMs) are two competing technologies that require different charging infrastructure and have different requirements for battery technology. Investments in infrastructure needed are expected to be worth about € 21 billion in 2020.[98] This includes charging stations, production of green electricity, and new innovative services and accounting systems. Moreover, issue exist regarding the insurance of swapped batteries.

A cross-industry approach that includes OEMs and utility companies can enable such investments. To enhance their revenue options, investors should not only provide the charging infrastructure but also offer additional services such as standardized accounting systems or the possibility to reserve a charging column.[99]

Technical progress. Technical solutions are key to overcome the challenges described. R&D efforts have to focus on the most promising technologies to ensure a short time-to-market and reduce R&D costs. Furthermore, a collaborative approach along the entire value network is a prerequisite for the development of technical solutions. No single player covers every step from cell materials to the EV, underscoring the need for collaboration. Numerous joint ventures and partnerships within the value network exist between OEMs, between suppliers and between OEMs and suppliers. However, those partnerships are difficult to manage and the future of several remains unclear.

Demand for Advanced Energy Storage Solutions Summary

- Advanced energy storage solutions for grid-scale applications are key enablers for a strong growth of intermittent power generation from renewable resources.
- For grid-scale storage, PSH accounts for the vast majority of energy storage worldwide. It is not clear which of the other available storage technologies is the most promising for a wide-scale application. Power-to-gas might offer significant opportunities in the future.
- Early stage of development, low efficiency and high costs are the key trials facing grid-scale storage solutions.
- A smart combination of production, transmission, storage and consumption is needed to base the energy system on renewables; an illustrative example is the Offshore Grid study within the Intelligent Energy Europe programme.
- Energy density for mobility-applications and high costs for lithium-ion batteries are still the most significant challenges.
- Regulatory and financial incentives will be key enablers for the problems confronting energy storage solutions in both the grid-scale and the mobility segments.

The Grid Itself Offers Solutions for Reliable Electricity Supply

In the developed world and countries with emerging infrastructures, large grids supply the bulk of electricity. In regions with less established infrastructure, the development of a large electrical grid might not be appropriate or plausible. For example, countries with emerging economies, weak regulatory environments, limited infrastructure and dispersed populations may be better off developing small solutions. Micro-grids, which mimic traditional energy grids on a smaller scale (for example, a region or neighbourhood), may be suitable for certain areas. Off-grid solutions, such as small wind and solar power plants, are also possible solutions and might be apt for countries with limited or no infrastructure.

Traditional electricity grid. This is a centralized solution that distributes electricity to consumers on a large scale. From grid-connected power-generating facilities, high voltage transmission lines typically transport electricity over hundreds of kilometres and direct current lines are able to transmit electricity over thousands of kilometres. While this system allows electricity-generating facilities to service relatively large areas, transmission losses are a considerable limitation. About 10-15% of the total US$/KWh cost paid by consumers is related to transmission.[100]

Two principal trials for the traditional electrical grid are ageing infrastructure and the integration of renewable energy sources. In many developed countries, the electrical grid is over 40 years old, which decreases transmission efficiency[101]. Transmission losses tend to be highest in developing economies, but developed countries with older grids face similar problems. Power interruptions are another important obstacle. In the US, the DOE estimates that power interruptions cost consumers up to US$ 80 billion per year, which amounts to approximately one-third of annual electricity costs.[102] Updating existing infrastructure and incorporating smart-grid technology that improves electricity management and grid efficiency could address this problem, but the extreme expense of the solutions is a potential roadblock to widespread application[103].

Renewable energy integration. Renewable energy sources pose many problems for electrical grid operators and technical advances will be required to integrate these sources. The main challenge is intermittency – renewables cannot be relied upon to provide electricity consistently. They also are hobbled by the limits and cost of electricity transmission. In contrast to traditional electrical plants, renewables often must be located in specific areas to capitalize on natural conditions, such as rivers, high solar irradiation, or high wind speeds. Such locations frequently are far from the demand for energy.

Several possible solutions exist but they will be expensive. The IEA estimates that grid integration from 2011 to 2035 will cost US$ 15-24 billion per year.[104] As mentioned earlier, one promising solution to intermittency is the development of grid-scale electricity storage to time-shift energy and match supply and demand.

Improving transmission range and minimizing losses will be important if distant demand centres seek access to renewable energy sources. Several companies are developing solutions – superconductive transmission and high-voltage, direct current (HVDC) lines are two examples. Norway, with its huge PHS capacity, will play an important role in the integration of renewable energies in Europe. Norway and Germany recently decided to build a new HVDC transmission line (NORD.LINK) with a capacity of 1,400 MW between the two countries. The installation will be completed in 2018 and will cost at least € 1.4 billion. The new line will offer the opportunity to store excessive wind energy produced in northern Germany in Norway's PHS facilities.

Public opinion often poses another trial for extending a power grid. For example, Germany currently is finding it difficult to install new capacities for integration of renewable energies. Although at a national level the public has accepted the idea and a political decision has been taken to develop renewables and cease nuclear power generation, the people at a regional level are yet to agree to build those new transmission lines. Compromises will be necessary to transform the energy landscape and avoid power interruptions.

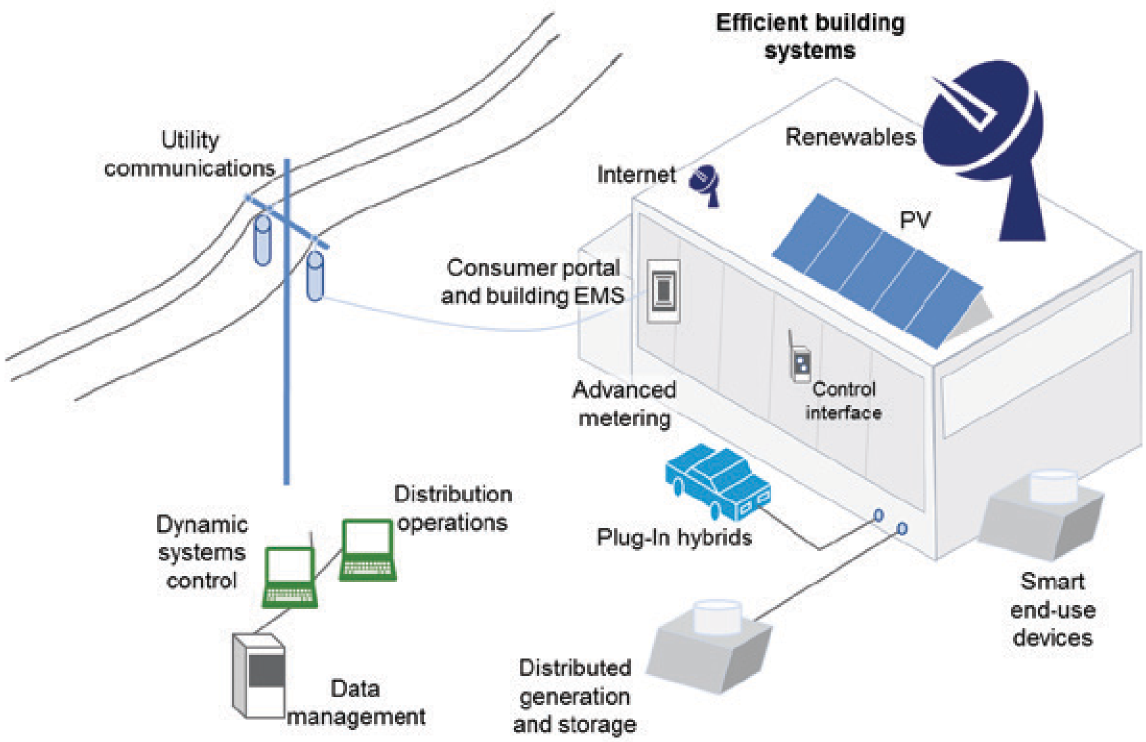
Smart grid. Smart-grid technology is a promising way to facilitate the integration of renewables and improve the overall operation of the electrical grid. Though smart grids may differ in complexity and capability, at the core they are digitally enabled electrical grids that use real-time supply and demand information to increase efficiency and reliability. Smart grids involve networks of computers and new technologies such as smart metres, dynamic pricing, smart thermostats and appliances, and consumer energy-use dashboards. Figure 20 depicts a hypothetical smart grid that connects a variety of supply and demand technologies.

These technologies allow smart grids to enhance reliability, time-shift usage to off-peak hours and reduce peak demand, lower aggregate electricity usage and actively manage electricity demand (or supply) of EVs and certain appliances.

One of the most exciting capabilities of a smart grid is an ability to better integrate renewable energy sources. For example, a smart grid's ability to monitor energy supply and demand in real time can help to address intermittency. It also enables bidirectional or net metering, which compensates electricity-producing households and companies for their contributions to the electrical grid. Even in the absence of renewable energy, smart grids offer numerous advantages for electricity producers and consumers. For example, smart grids have a self-healing capability and can detect possible loss in power quality and/or surge in load. They can also isolate sections of the grid automatically and prevent system-wide collapse of the kind that happened in August 2003 in the north-east and mid-west of the US and Ontario, Canada.

Figure 20: Map of a Hypothetical Smart Grid

Source: Smart Grid Demonstrations, Electric Power Research Institute (EPRI)



Micro-grids. Micro-grids are small electricity grids that operate independently of, or in conjunction with, traditional electricity grids. Pike Research estimates that micro-grids will account for 4.7 GW of electricity[105] and US$ 17.3 billion of global revenue by 2017, which would represent a CAGR of over 22%.[106]

Micro-grids have several advantages over their traditional counterparts. For a start, they can provide electricity in geographies where a traditional grid is neither viable nor cost-effective.[107] They also require less capital investment and, as a result, may be a better solution for poorer countries or regions.[108] Micro-grids can often incorporate distributed-energy and renewable energy sources at a lower cost than traditional grids, while reducing GHG emissions and maintaining power quality and reliability.[109, 110]

However, micro-grids have several disadvantages, including the typical drawback of grids of all sizes. For example, micro-grids can have interoperability issues with traditional grids; to address these challenges, both grid operators must work together to establish common standards. Additionally, micro-grids that connect to the traditional grid may be charged standby fees for non-emergency use.[111] These challenges affect micro-girds in developed countries, but are not relevant in emerging countries with true stand-alone micro-grids.

Off-grid. The term "off-grid" is used to describe a situation in which a village, company or household is not connected to any type of electrical grid. This includes a system developed for an individual household or individual user. Currently, the most pervasive example is the diesel generator, but other exciting new solutions have emerged that use distributed power, such as small solar and wind systems. For example, in India, where rural electrification is relatively low and homelessness and poverty extremely high, the country's Tata business group is developing a pre-fabricated low-cost house with a rooftop solar panel. Because these houses will not be connected to an electric grid, distributed solar power will provide most (if not all) of the home's electricity. Another example is Bergey Windpower, a US-based company that provides small wind-turbine solutions that can be used in villages. The systems cost between US$ 20,000 and 150,000 – often cheaper than extending the electrical grid (if one is available) and often cheaper to operate than a diesel generator.

Though these solutions target emerging markets, the developed world also can benefit from similar renewable solutions; these might not be technically off-grid, but are likely to be part of the energy solution in all markets.

Interconnectivity. Energy demand does not stop at national borders. The variety of energy sources requires interconnectivity of transmission and distribution systems. Every regional market has gradually interconnected energy across borders[112] to reap benefits such as lower costs, higher reliability and increased competitiveness.[113] For example, a boost in trade among the Baltic States has resulted in a combination of hydro- and thermal-based power supply across Europe, thus levelling prices across regions.[114] Interconnected countries should consider the opportunities of mixing energy sources to compensate for intermittency, but also require substantial reserve power as a safety net.[115]

To make interconnectivity successful, countries must be willing to purchase energy sourced outside their borders.[116] At a time of focus on energy security and independence, this could be challenging for countries with interconnected grids.[117] Identifying an investment mechanism for cross-border connections could be another problem. International financial institutions have a role in such a situation, establishing public-private partnerships that bring countries to agreement.[118] Overall, the advantages of interconnectivity for commerce and development far outweigh its disadvantages.

The Future Electricity Grid Summary

- Traditional electricity grids in many developed countries are ageing, resulting in transmission losses and power interruptions. Traditional grids also face a challenge of incorporating intermittent renewables with low capacity factors.
- Smart grids use real-time supply and demand information to increase the overall grid's efficiency and reliability, and can more effectively integrate renewables.
- Micro-grids require less capital investment than traditional grids and could be appropriate for geographies where traditional solutions are neither viable nor cost-effective.
- New products such as bio-generators, residential-scale wind turbines and solar-powered houses enable off-grid energy generation and consumption.

Increasing Efficiency in Energy Consumption Is an Important Lever to Transform the Energy Landscape

Two major levers exist to deal with growing energy demand, while reducing GHG emissions and enhancing energy security. One is the development of alternative energy sources such as unconventional natural gas reserves and renewable energies; the other is increasing the efficiency of energy use.

Remarkable efficiency improvements have been attained. As a result, energy efficiency resulted in fuel and energy cost-savings of US$ 180 billion in 2005; global energy intensity (final energy use per unit GDP) fell by 26% between 1990 and 2005.[119] Significant possibility for further efficiency gains remains. According to IEA assessments, application of the best available technologies in industry alone could cut energy use in the sector by almost one-third.[120] The agency estimates that the timely implementation of 25 policy recommendations it has proposed could save 7.6 gigatons of CO_2 per year by 2030.[121] Therefore, progress in the implementation of already identified energy efficiency measures could significantly increase the environmental and economic sustainability of the energy value network.

Governments, industry and civil society are increasingly aware of this potent way to transform the energy landscape. Currently, the use of energy varies by country. In general, developed countries use energy more efficiently than do their emerging counterparts. Europe and China are compared in the chapter, *The Future Energy Landscape: Europe and China*, later in this report.[122]

Figure 21: World Final Energy Consumption by Sector, 2010

Source: *World Energy Outlook 2012*, International Energy Agency [123]

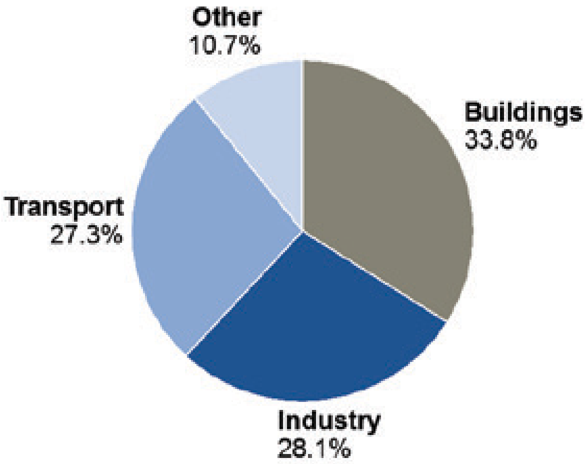
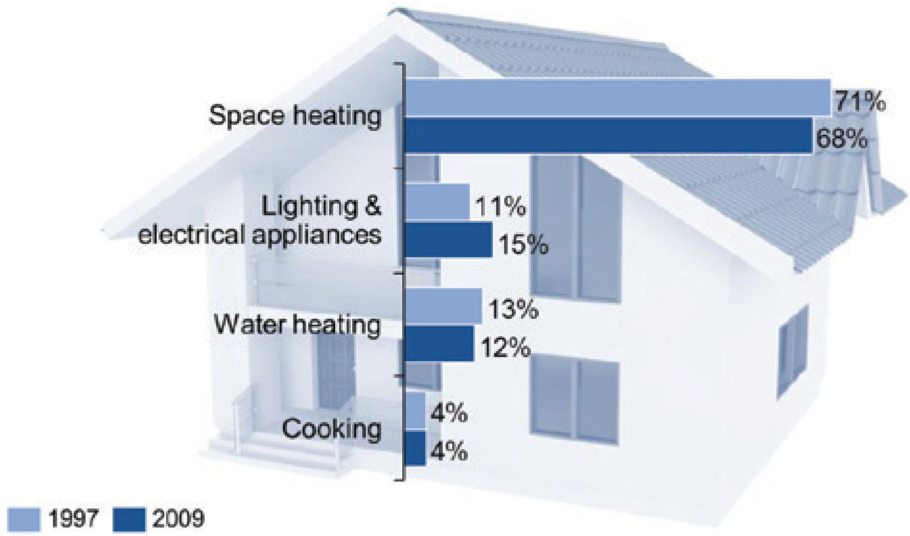


Figure 22: Household Energy Consumption in the EU27

Source: Energy efficiency trends for the households in the EU27, Odyssee



To address energy efficiency potential, a toolset for different sectors is required. Industry, transport and buildings are the three biggest energy consumers globally. Buildings consume about 33.8% of final energy, while industry consumes about 28.1% and transport about 27.3% (see Figure 21). Each sector has numerous possibilities to increase its energy efficiency and subsequently reduce demand.

Buildings. The buildings sector is the largest consumer, with high potential for enhancing its energy efficiency. Improvements could significantly reduce GHG emissions and ease demand. Heating is the main consumer of household energy; better insulation therefore is the single most important measure to improve efficiency. In Europe, this has led to heating registering a decline in share of total energy consumption (68% in 2009), while lighting and electrical applications showed a rise (15% in 2009; see Figure 22).[124] New technologies such as light-emitting diodes (LED) have the ability to considerably cut the amount of electricity used for lighting.

One trend is that while the residential buildings sector is improving energy efficiency, households are using more energy-consuming devices, largely offsetting the savings achieved[125]. In the EU's 27 member-countries (EU27), energy efficiency in the household sector grew by 24% between 1990 and 2009 (1.4% per year). Final energy consumption in the EU27 in the same period rose by about 8% (0.4% per year), while electricity consumption increased by an annual average of 1.7%.[126] This was due mainly to a greater number, and greater use, of household electrical devices in households, even though the energy efficiency of the devices improved. The average energy consumption of large electrical devices such as dryers, washing machines and freezers fell in the EU27 by about 7% between 2005 and 2010.[127]

An evolving concept is the "zero-emission building" or even "zero-emission community". The technology for zero-emission buildings largely exists, but requires the involvement of emerging industries such as energy storage and information technology (IT)-smart energy management, and the use of biomass and waste as energy sources. Moreover, a facility management is needed to link and administer the different technologies.

Zero-emission buildings could significantly cut total GHG emissions. Certain enablers can ensure a successful development of the concept:
- Community models that increase energy reliability. In the US, for example, severe weather conditions sometimes cut off households from the grids for days, and communities therefore want to be independent from large centralized grids
- Technological development
- Development of IT systems

However, several obstacles remain, including:
- Inconsistent regulation – for example, in the US almost every town has its own building code
- Out-dated education models – for example, for engineers and architects
- Costs – new investment models and market prices have to reflect the real costs of technology
- Remaining CO_2 emissions – use of waste or biomass to generate power still produces a certain amount of CO_2

Industry. In industry, energy efficiency is an important lever to reduce overall costs. In regions such as Europe with comparatively high prices for energy, companies recognize that energy efficiency is essential to stay competitive with companies in regions with low energy prices, such as China.

Energy-efficient improvements can be classified into three main segments:[128]
- **Investing in better equipment and technology.** Adaptation of best available technologies could cut global industrial energy use by about one-third.
- **Managing energy and optimizing operations**. Systems optimization, such as integrated system design and operation, can achieve additional savings of up to 20% in some cases.
- **Transforming production systems**. An integrated and holistic approach to manage resources and waste can further improve energy efficiency. Strategies include greater use of recycled materials and sharing of resources among industries.

More and more companies set specific efficiency targets – for example, in the framework of corporate sustainability initiatives – and implement comprehensive energy management systems to reduce costs and GHG emissions. Generally seen as vital for energy efficiency, energy management systems provide the transparency and accounting that can trigger technological solutions along the entire value chain of an industry.[129] Key technological potential in industry includes drivetrains, compressed air, cooling and venting equipment, as well as the more obvious energy demands for heating and lighting.

In other sectors, such as high energy-consuming industries, energy accounts for such a significant share of total production costs that energy-efficiency improvements have long been at the core of production optimization. For example, energy consumption for steel production globally has fallen from 0.51 tonne of oil equivalent (toe)/ton in 1990 to 0.40 toe/ton in 2010 (-1.2% per year).[130]

Increasing energy efficiency is driven by not only the industry itself, but also public agencies. For example, the US DOE is launching a voluntary programme that will provide industrial and commercial facilities the opportunity to earn a Superior Energy Performance certification, to allow and verify improvements in energy performance through application of the ISO 5001 energy management standard.[131] The DOE is working with industry experts and standard-formulating bodies to build a supporting structure for industry to increase energy efficiency.[132]

Transport. Transport can roughly be divided into two sub-sectors: freight and passenger. In the former category, trucks consume most of the energy in this sub-sector and are less energy-efficient than ships and rail in ton-kilometres, and therefore offer huge potential for energy-efficiency improvements.[133,134] Modal substitutions (e.g. diverting freight movements from road to rail) and advanced engine technologies therefore are critical factors in diminishing the energy intensity of freight.

In the passenger category, individual cars consumed more than 87% of the energy in this sub-sector, while buses, trains and ships together accounted for only about 3%, and airplanes for about 10%, according to 2005 figures.[135] Driving behaviour, reduction in weight of vehicles and volume of loads, and advanced engine technologies are the main levers to cut fuel consumption in passenger vehicles.

Using new lightweight materials in vehicles can significantly restrain fuel consumption. Since 2008 the average weight of a vehicle has dropped by 20%, translating into a similar reduction of GHG emissions per vehicle.[136] In 2020 the average car will weigh approximately 1.1 tons, containing 18% plastics (up from 14% in 2000), 7% rubber, 55% metals (down from 63% in 2000) and 20% other materials.[137]

In a passenger car, only 17-21% of energy from fuel is transformed into power to the wheels (see Figure 23).[138] More efficient engine technologies are therefore a major lever to lower a vehicle's fuel consumption. Electrical vehicles have the highest conversion rate of chemical energy to energy released from the powertrain, but the electricity needed for charging the batteries can emit large amounts of GHGs if produced in coal-fired facilities and transmitted over large distances. Such a scenario would essentially shift emissions from a tailpipe to a power plant, and move energy consumption from engine to turbine. Moreover, charging a battery is an inefficient process, and energy essentially is lost at a different point in the energy supply chain.

Energy-efficiency indicators can be a powerful tool to ensure the development, implementation and monitoring of energy-saving technologies and approaches. Many countries already have indicators in place, but these are distinct to each country and therefore often are not comparable. The IEA assists efforts to develop consistent global indicators.[139] More and better data are needed to draw a full picture of the current state of energy efficiency.

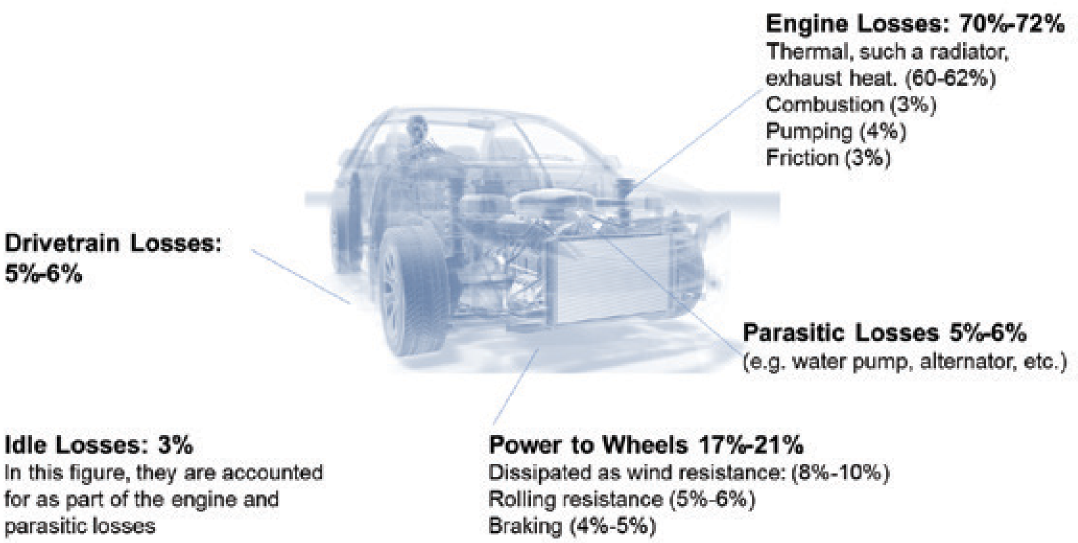
Energy prices that reflect the environmental impact of energy extraction could be a vital lever to further increase energy efficiency and curtail overall demand.

Energy Efficiency Summary

- The three largest energy-consuming sectors globally are buildings (33.8% of final world energy consumption), industry (28.1%), transport (27.3%).
- Improving energy efficiency is often termed a "sleeping giant" and a crucial lever to make the energy landscape sustainable.
- Companies recognize energy efficiency as an important criterion to stay competitive while governments increase legislative pressure and policy incentives to increase the adoption of energy efficient technologies.

Figure 23: Energy Losses in a Passenger Vehicle (Combined City/highway Driving Cycle)

Source: US Department of Energy, http://www.fueleconomy.gov/feg/atv.shtml, October 2012



The Future Energy Landscape: Europe and China

Europe Has Put Its Energy Landscape on a Decarbonization Path

Europe's energy consumption levels have remained relatively constant over the past two decades. Gross energy consumption had remained almost unchanged from 2003 to 2008, and showed a significant decrease in 2009, mainly due to the economic crisis.[140] Given the region's historically low population and economic growth (as measured by GDP), it is likely that energy demand will continue to exhibit a similarly flat trajectory, although some types of energy – for example, electricity – are still expected to climb[141].

Besides the relatively modest increase in energy demand and a developed energy infrastructure, Europe faces significant hurdles to making its energy landscape environmentally sustainable and securing its energy supply in the long term. Regarding energy supply, European countries have a paucity of non-renewable energy resources compared to other regions. According to Eurostat, a Luxembourg-based Directorate-General of the European Commission, Denmark is the only EU27 country that is a net exporter of energy. On average, the EU27 countries rely on international trade to satisfy 53% of their gross energy demand; the EU's five largest economies – Germany (60%), France (50%), United Kingdom (28%), Italy (84%) and Spain (77%) – are no exception.[142]

The EU clearly addresses the need for an energy setting that is environmentally and economically sustainable, as well as secure, and has put relevant policies in place. Under the "20-20-20" targets for 2020, the EU aims to:

- Reduce its GHG emissions by 20% from 1990 amounts
- Increase to 20% renewable energy's share relative to energy consumption
- Achieve an improvement of 20% in the EU's energy efficiency[143]

These three major policy objectives currently shape the EU's energy landscape. Other longstanding policy aims provide the (evolving) framework in which the objectives are being implemented:

- Full liberalization of energy markets – i.e. transition from (often) state-owned monopolistic supply structures to competitive, market-based energy provision[144]
- European energy market integration – i.e. easing barriers between national energy systems and markets, thereby facilitating pan-European trade in energy[145]

This chapter gives an overview of the status of the European energy market, and the key drivers of its transformation.

Liberalization and integration of the European energy market. The European Commission has a target to find a common energy policy for all member states and has announced that the next chapter in the integration process is to build a European Energy Community (EEC).[146] A fully integrated European gas and electricity market is planned for 2014.[147]

A key challenge for the EU will be to harmonize the 27 different national regulatory regimes and existing energy policies. Currently, a multitude of policies act in concert with many overlapping areas and effects. For example, while the ETS, the Renewable Energy Directive, and rulings aimed at the mobility and transport sectors have had an impact on energy efficiency in Europe, energy efficiency is directly targeted by several other directives, including the Energy Efficiency Directive (EED) and the Energy Performance of Buildings Directive.

Although liberalization of the energy market has progressed in recent years – consumers can switch suppliers, for example – further work is required to align national markets and grid-operation policies, and facilitate cross-country investment in infrastructure.[148] Moreover, the market concentration in electricity wholesale and natural gas wholesale is still high on a national basis.[149] The European Commission announced the third energy legislation package in 2007 to strengthen competition in the natural gas and electricity markets.[150] Another trial is the integration of renewables into the energy market, as they partly undermine the liberalized market mechanisms.[151]

Reduction of greenhouse gas emissions. Europe has set its energy sector towards "decarbonization" and is dedicated to becoming a low-carbon economy. The EU is, and most likely will remain, at the forefront of international climate policy and is committed to limiting global warming to a maximum of 2°C. It has a target to reduce GHG emissions by 20% in 2020 compared with 1990, but has offered to further cut its emissions to 30% in the same period if other major economies in the world undertake to reduce global emissions.[152]

A key EU mechanism is the ETS, the first such system put in place in 2005 by the European Parliament and the European Council. Its success has been very limited. Incentives for industry to curb GHG release are extremely low, at the current prices of below € 5/t, induced by the financial crisis in 2008. To reinforce the ETS, the EU decided to change the current system of giving emission allowances to companies in the third trading period (2013-2020).[153] EU-wide rules will apply across all European states and most emission allowances will no longer be allocated for free.

The national goals for non-ETS emissions are another tool to constrain GHG emissions – and one that complements the ETS.[154] A binding target to cut GHG emissions has been set in most sectors that are not included in the EU ETS, e.g. transport, agriculture or buildings.[155] The "Effort Sharing Decision" sets individual nation targets for 2020, compared to

2005. Luxembourg and Denmark at the bottom end have to lower their emission levels by 20%, while Bulgaria at the upper end is allowed to increase its emission level by 20% in the same period. The levels are based on the relative wealth of member states, each of which is responsible to meet this target.

Carbon capture and storage technologies are a third pillar of the package from the European Commission.[156,157] The CCS Directive establishes a legal policy framework to capture and store CO_2 in geological formations. However, CCS technologies are currently expensive and many issues remain unresolved, such as the long-term stability of CO_2 in subsurface cavities. In 1986 naturally sequestered CO_2 leaked from Lake Nyos in Cameroon and killed 1,700 people. To ensure public safety, a significant regulatory framework has to be created to guarantee that stored CO_2 cannot leak or induce subsurface sediment movements. Public perception of this technology is partly negative. Public resistance in Germany, for example, has led the government to announce that storage of CO_2 in underground caverns is unlikely to play a major part in decarbonization. Although pilot CCS plants have launched around the world, it remains to be seen if this technology can support the GHG emission reduction target.

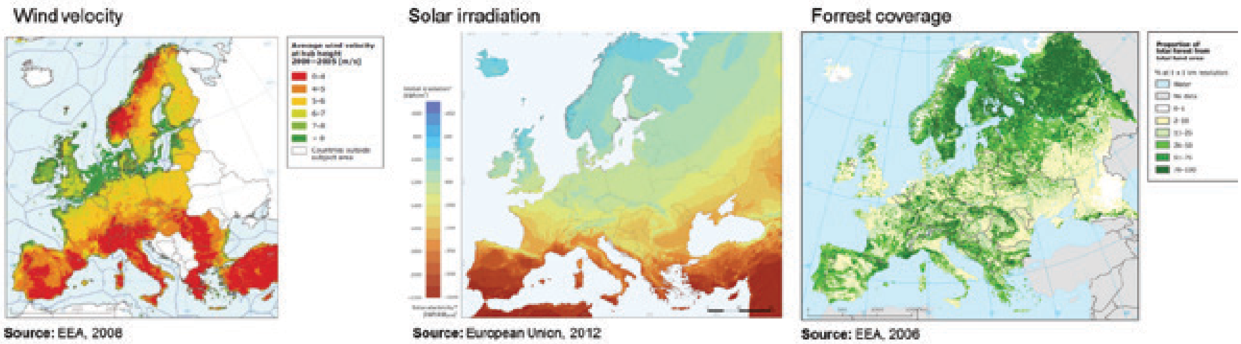
If implemented and controlled appropriately, all the tools described will support the target. GHG emissions have indeed been lowered in Europe, but a significant amount of this was – and is – due to the economic crisis. Strong efforts to reach the reduction goal need to continue.[158] Further advancements in the renewables sector and greater energy efficiency are other essential tools to achieve the target.

Increasing share of renewable energy sources. Renewable energy's share of primary energy consumption is continuously increasing; a target to achieve a 20% share by 2020 has been set. According to the European Commission, renewable energy's share of gross electricity generation can reach 36% by 2030.[159]

The development of renewables offers the possibility in Europe not only for energy security and a reduction in climate change, but also for economic growth. A report from the European Commission states that strong development of renewable energies could generate more than 3 million new jobs by 2030, and such an advance is a top target of the EU 2020 strategy for smart, sustainable and inclusive growth.[160] The political decision to foster renewable energy is therefore driven by not only environmental considerations, but also local economic needs and industrial and energy security policies.

Figure 24: Wind Velocity, Solar Irradiation and Forest Coverage in Europe

Source: US Department of Energy, http://www.fueleconomy.gov/feg/atv.shtml, October 2012



The development of renewable energy as a whole, as well as the mix of different renewable energy technologies, is determined more by political decisions and less by technical feasibility or environmental conditions (e.g. wind velocity, solar irradiation and forest coverage). Figure 24 shows that wind velocity is higher in northern parts of Europe than in the southern parts, and solar irradiation is more intense in the Mediterranean states than in the northern. However, even in regions with only average solar irradiation, the costs to produce energy with solar energy technologies are below final consumer prices. Moreover, new wind turbines can produce cost-competitive electricity with only medium wind velocity, and cheap biomass is often shipped from other regions to fuel biomass-based power plants, independent from the availability of domestic biomass.

The EU's member states have set binding national targets to raise the share of renewables in energy consumption in 2020.[161] But the targets vary by country, from 10% in Malta to 49% in Sweden. Biomass will have the largest share of all renewable energy sources in every member state except Cyprus, and will account for 12% of total energy contribution in the EU27 in 2020.[162,163]

Looking only at future gross electricity generation, renewable energy sources will reach 36% of total generation, according to national plans of the member states.[164] Figure 25 provides an overview by country of the shares of different renewable energy sources in electricity generation in 2030. Wind power will be the most important, providing 17% of total electricity; followed by hydropower, providing 9%; and biomass, providing 7%. In Austria, Denmark, Latvia, Portugal and Sweden, renewable energy sources will provide 60% or more of electricity in 2030. In addition, in 12 of the 27 member states, renewables will be the most important source for electricity generation.

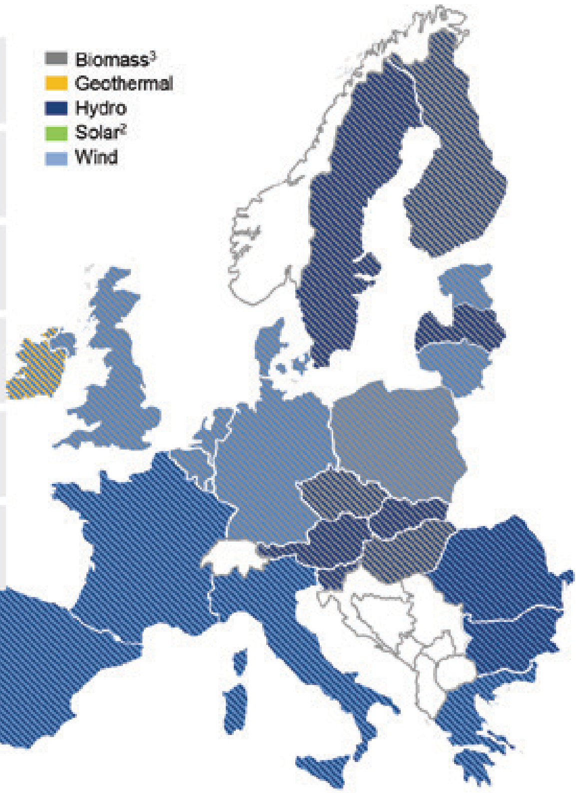
Overall, policies and consumer choices will drive and determine the future energy mix in Europe; environmental conditions will influence development in each country, but will be much less important. Europe can transform its energy landscape and can generate most of its energy using renewable sources. It will require political will to make this happen.

Europe could also benefit from the vast potential for solar power in North Africa. Concentrated solar power technologies have enormous potential in northern Africa, and electricity generated there could be transported to Europe using high-voltage direct-current transmission lines. This would be a large project needing major investments in power plants and transmission lines, but it holds the promise to significantly boost the percentage of renewables in Europe's energy mix. The non-profit DESERTEC Foundation explores those opportunities.[165] Such a project can only be successful with the right political support, and if different stakeholders take on the investments and the North African states sign a long-term agreement of mutual benefit.

Figure 25: EU27 Future Gross Electricity Generation, by Renewable Energy Source and Country, 2030166

Source: *EU Energy Trends to 2030, 2009 update*, European Commission

Austria (77%) Hydro (55%) Biomass² (13%) Wind (8%)	**Belgium (22%)** Wind (13%) Biomass (8%) Hydro (<1%)	**Bulgaria (17%)** Hydro (8%) Wind (5%) Biomass (4%)	**Cyprus (25%)** Wind (15%) Solar² (6%) Biomass (4%)
Czech Rep. (7%) Biomass (4%) Hydro (2%) Wind (1%)	**Denmark (62%)** Wind (42%) Biomass (20%) Solar (<1%)	**Estonia (28%)** Wind (20%) Biomass (9%) Hydro (<1%)	**Finland (41%)** Biomass (21%) Hydro (15%) Wind (6%)
France (27%) Wind (10%) Hydro (9%) Biomass (5%)	**Germany (45%)** Wind (31%) Biomass (6%) Solar (5%)	**Greece (34%)** Wind (20%) Hydro (6%) Solar (5%)	**Hungary (22%)** Biomass (13%) Hydro (5%) Geothermal (2%)
Ireland (38%) Wind (30%) Geothermal (4%) Biomass (2%)	**Italy (32%)** Wind (10%) Hydro (10%) Biomass (7%)	**Latvia (60%)** Hydro (33%) Biomass (15%) Wind (11%)	**Lithuania (14%)** Wind (5%) Biomass (5%) Hydro (3%)
Luxemburg (15%) Wind (6%) Biomass (6%) Solar (2%)	**Malta (22%)** Wind (13%) Solar (7%) Biomass (2%)	**Netherlands (33%)** Wind (23%) Biomass (10%) Geothermal (1%)	**Poland (10%)** Biomass (6%) Wind (2%) Hydro (1%)
Portugal (69%) Wind (21%) Hydro (19%) Biomass (17%)	**Romania (38%)** Hydro (30%) Wind (5%) Biomass (3%)	**Slovak Rep. (21%)** Hydro (10%) Biomass (7%) Wind (2%)	**Slovenia (31%)** Hydro (20%) Biomass (10%) Wind (2%)
Spain (48%) Wind (27 %) Hydro (8%) Solar (6%)	**Sweden (61%)** Hydro (39%) Biomass (12%) Wind (10%)	**UK (37%)** Wind 27% Biomass (7%) Geothermal (2%)	
EU-27 (36%) Wind (17%) Hydro (9%) Biomass (7%)			



1. According to the Reference Scenario of the 'EU Energy trends to 2030' report
2. Solar, tidal, etc.
3. Biomass & waste

Source: European Commission, EU Energy trends to 2030, 2010

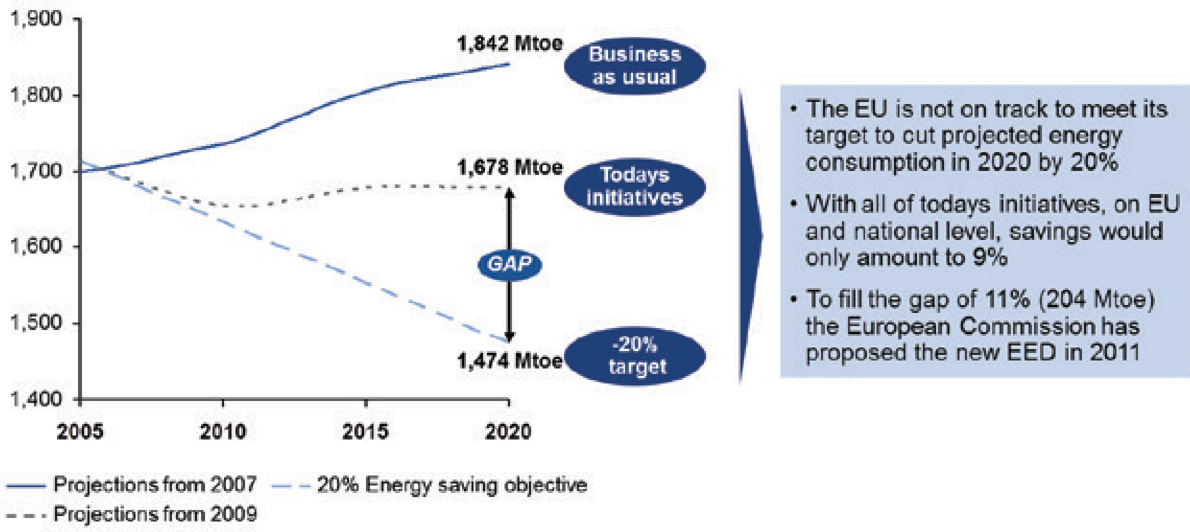
Improvement of energy efficiency. The EU currently is not on track to meet its target of cutting energy consumption by 20% by 2020. With all of today's initiatives, at the EU and national levels, reductions would amount to only 9%. To fill the gap of 11% (204 million tonnes of oil equivalent or Mtoe), the European Council endorsed the new EED on 4 October 2012. The directive sets legally binding measurements to enhance the efforts of EU member states to increase energy efficiency at all stages of the energy value network.[167] The directive requires member states to establish energy- efficiency schemes or policy measures that cover households, industries and transport.

According to the Energy Efficiency Plan 2011 of the European Commission, efficiency is a key component of European energy policy and therefore constitutes a cornerstone of overall EU 2020 strategy.[168] The 2011 plan highlights, for instance, the necessity to reduce final energy consumption in buildings, as this sector is responsible for about 40% of such consumption. To achieve this, adaptation of training for architects and engineers is suggested. Other targets are adaptation of national and European financing (e.g. intensification of energy taxation), savings for consumers and improved transport efficiency.

As mentioned earlier, energy efficiency is an important lever to reduce overall costs, which in turn is vital for European industry to compete in global markets against companies from countries such as China with low energy prices. Highly efficient production capacities therefore are critical. The European Commission proposes to create instruments that link the profits of utility companies to energy efficiency rather than to the volume of energy delivered, and instruments that allow financial value to be attributed to saving of energy.[169]

Figure 26: Gross European Union (EU) Primary Energy Consumption (in Mtoe)

Source: *A New Directive on Energy Efficiency* presentation, 2011, European Commission



Post 2020. Further integration of energy policies throughout the EU will remain a key challenge even after 2020. As described earlier, a multitude of policies needs to be implemented and harmonized to ensure sustainable energy supply in the medium to long term.

To achieve the 2050 target of reducing GHG emissions to 80-95% below 1990 levels, the European Commission has developed a roadmap for 2050 that lays out how to secure and decarbonize the energy system until 2050, and how to move from 2020 to 2050.[170], [171] The study shows that a fully decarbonized electricity sector, theoretically, is technically feasible and economically affordable, but can only be realized with significant political will at both the European and national levels.

The European Commission's *Energy Roadmap 2050* lists 10 conditions that must be met to achieve a new decarbonized energy system in Europe.[172] They include: a requirement to boost energy efficiency, continued development of renewable energy sources, and greater investment in R&D. The roadmap emphasizes that energy prices should reflect real costs, as this will make transformation of the energy landscape easier in the long run. Addressing regulatory and structural shortcomings, and establishing a fully integrated market are also mentioned. With those conditions in mind, Europe can transform the energy market into an environmentally, economically and socially sustainable energy landscape. To achieve this goal, a collaborative approach is needed, including among the different European nations, industry stakeholders and civil society.

European Energy Landscape Summary

- European energy policy is driven by the "20-20-20" targets for 2020 to secure energy supply and reduce the impact on the climate: reducing GHG emissions by 20%; increasing the share of renewable sources to 20%; achieving a 20% energy-efficiency improvement.
- Longstanding policy provides an evolving framework in which energy objectives are being implemented: full liberalization of energy markets, and European energy market integration.
- The EU ETS, targets for non-EU ETS emissions, national renewable energy targets, and CCS technologies are the main tools to cut GHG emissions and develop renewable energy sources.
- The EED and Energy Efficiency Plan 2011 set legally binding measurements and specific targets to enhance the efforts of EU member states to boost energy efficiency.
- The potential for various renewable energy sources differs by country, although Europe overall can meet most of its energy demand through renewable energy.
- Transformation of the energy landscape will enable a secure supply, mitigate climate change, and foster the growth of the European economy, with the possibility of an estimated 3 million new jobs until 2030.
- *Energy Roadmap 2050* outlines the way to achieve the goal of an 80-95% reduction of GHG emission by 2050.

Environmental and Economic Sustainability Are the Key Challenges for the Chinese Energy Landscape

China has shown remarkable development of its energy landscape in the past decade. It has established a grid system that covers almost 100% of households and provides reliable electricity supply even to remote regions. Having successfully overcome earlier hurdles, China now faces new ones: tremendous growth in energy demand (China will account for 35.5% of total global energy demand growth between 2012 and 2035), energy security concerns, climate change and environmental protection. To feed its impressive economic growth, China is extremely dependent on fossil-fuel imports. While China has been importing oil for more than 10 years, it now has to import gas and even coal. Energy-related topics, such as alternative and renewable energy sources, environment protection and alternative-fuel vehicles are at the top of Chinese legislators' agenda. Moreover, life-threatening air pollution in its major cities has encouraged China to invest heavily in low-emission energy. This combination offers China the opportunity to not only mitigate the challenges of energy harnessing but also foster the restructuring of its economy to become a leader in developing new energy-harnessing technologies. The question is: How will China transform its energy landscape into a sustainable one?

The following chapter gives an overview of past developments and highlights key targets in China's current five-year plan and the challenges to reach them.

Achievements. China has managed to evolve a reliable energy infrastructure, including a large centralized electricity grid, to which almost every household in the country is connected. Massive power outages, as happened in northern India in July 2012, are largely unknown in China. Indeed, the country was, for a long time, energy self-sufficient and able to provide reliable electricity despite a steady growth in demand. China in recent years has launched programmes to shut down the most inefficient plants and increase the energy efficiency of large production facilities.

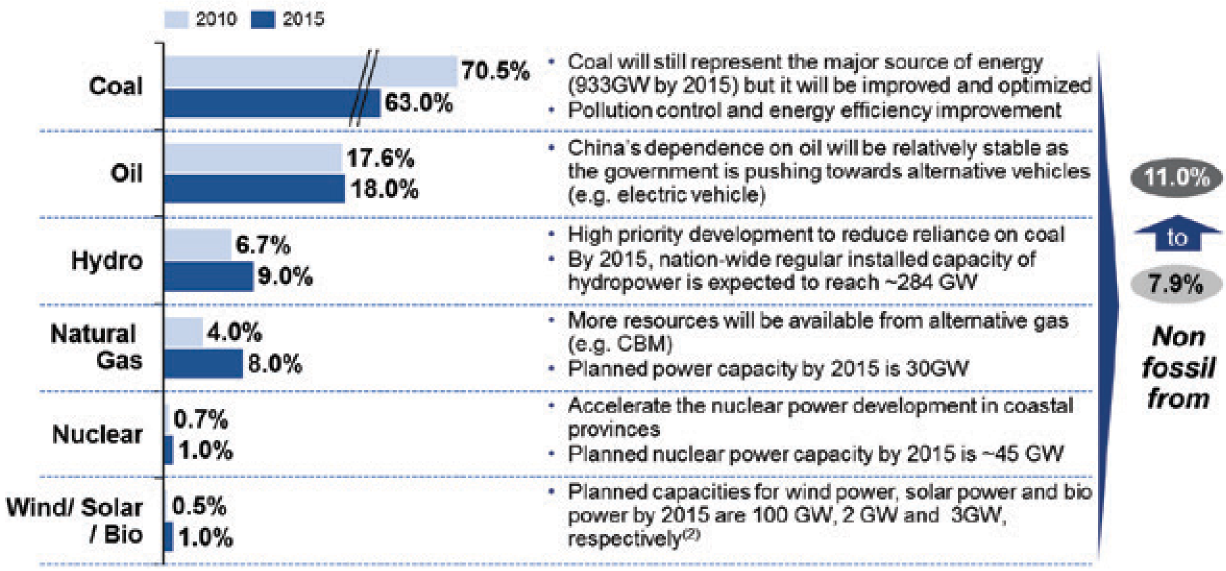
It also has balanced the regional mismatch of energy demand and supply. Most fossil-fuel reserves are located in the west and north-west, while the large cities and economic hubs are predominantly in the east and south. To mitigate this disparity China has built several ultra-high voltage (UHV) electricity transmission lines and is among the world's leaders in this technology.

Sustainability. Yet China needs to transform its energy landscape for the future. Most importantly, energy supply and demand must be made more sustainable. China's current 12th Five-Year Plan (2011-2015) aims to establish an environmentally friendly and resource-efficient society. Specifically, non-fossil fuel resources should increase their share to 11% of primary energy consumption (see Figure 27), energy consumption per unit of GDP should decrease by 16%, and CO_2 emissions per unit of GDP should decline by 17%. At the same time, the plan expects an annual GDP growth rate of 7%.

What has been done and what is still needed to meet these different targets? China faces low energy-efficiency per unit of GDP, which has a huge influence on environmental, economic and social sustainability. Currently in China, about 0.36 tonne of oil equivalent (toe) primary energy is needed to produce US$ 1,000 of GDP, while in Germany and France, only about 0.1 toe and in the US about 0.15 toe is needed.[173,174] This inefficiency is largely due to long-distance transmission

Figure 27: China's Estimated Energy Consumption (as a % of the Total), 2010 and 2015

Source: China Electricity Council; APCO; A.T. Kearney analysis



lines, lack of building insulation, and the structure of industry. China has a high amount of heavy industry consuming a lot of energy. Industry also is largely fragmented, missing out on the advantages of scale. The result is high inefficiencies, particularly among the thousands of small and mid-sized companies. Many companies are unwilling to make the initial investments for more efficient systems and energy-saving equipment.

To achieve the Five-Year Plan's targets, China must boost energy efficiency. The government has established an extended version of the former Top-1,000 Energy-Consuming Enterprises programme, which now covers 10,000 companies, to tackle the issues of inefficiency and high CO_2 emissions. The initiative, along with others such as the Small Plant Closure Programme, can create higher efficiency if implemented.

However, the most important enabler would be a pricing mechanism that reflects the real energy costs. Prices for electricity and refined oil are not based on the market but controlled by the National Development and Reform Commission (NDRC), a macroeconomic management agency under China's State Council. Costs for consumers are well below the real price, because the NDRC wants to keep energy at an affordable level, thereby preventing energy prices from pushing up the consumer price index and consequently possibly leading to social instability.

The NDRC implemented a first-tier electricity-pricing system for households in the first half of 2012, giving local authorities the right to decide thresholds of the first tier. This pricing mechanism was primarily established to control energy demand peaks and save energy, but not to reflect the real price for energy. Controlling energy demand peaks is necessary, as China's utility is not very flexible and has difficulties with fluctuating demand and supply. Instead of enhancing the electricity infrastructure's flexibility, which would cause tremendous investment costs, China tries to ease fluctuation in demand via pricing mechanisms. A market-driven price for energy, and consequently a significantly higher price, is unlikely to emerge in China in the near term. However, a rise in energy prices will occur in the medium term and will pose a tremendous trial for industry if it does not become more energy-efficient.

To enhance energy efficiency, cut CO_2 emissions and develop renewable energies, some provinces are implementing a tax on carbon emissions, but the current system is only a first step towards an effective carbon levy. China's industry is largely based on coal, which makes it difficult to implement an extensive carbon tax system, leading to higher energy costs without a major impact on economic growth. It seems unlikely that the Chinese government will push for a carbon tax, but instead will most probably promote GHG credit trading and emission quotas for unit products.

China's national power grid is in the hands of two state-owned enterprises: State Grid Corporation of China, which supplies electricity to most of northern and north-east China; and China Southern Power Grid Corporation, which supplies most of south-east China. This monopoly structure hampers competition. The government has tried to foster direct selling of electricity to consumers from independent power producers (IPPs), but faces resistance from the politically well connected utility companies.

As it tries to rebalance economic growth, the government is emphasizing emerging industries and power-related sectors. Power-generation equipment and electrical vehicles are two examples. In keeping with renewable energy priorities set down in the 12th Five-year Plan, further hydropower projects, onshore and offshore large wind-power bases and solar energy plants are scheduled.

So far, the domestic market for wind and solar energy is weak, and their development faces major hurdles. About 40% of installed wind-power capacity currently is not connected to the grid, and offshore wind energy has limited potential as China's deep shelf restricts possible locations for offshore wind parks. Moreover, renewable power plants (and suitable wind and sun conditions) often are situated in areas without large demand (e.g. solar power plants in Tibet, Inner Mongolia and Xinjiang). Long-distance transmission lines are needed, which often means low economic profitability of these resources.

On the global market, China is the largest producer of wind turbines and solar panels. But the success of its solar industry, especially in Europe and the US, means China now has excess production capacity of solar panels.

Meanwhile, Europe and the US have begun antitrust investigations against China's solar industry to protect their own, which have been hit hard by cheap Chinese competition. The loss of the EU market, which is vital to China's solar industry, would be the last straw. To protect its wind and solar industries, and fulfil its own emission targets, China therefore needs to develop the market at home.

Even after Japan's Fukushima accident, nuclear power is promoted in China, which continues to have ambitious nuclear plans. Mainland China has 14 nuclear power reactors, with more than 25 under construction and several more planned. The current and upcoming plants are expected to increase production capacity to 70-80 GW by 2020 from 11 GW today.[175] The most significant challenge is that the plants under construction face a huge shortage of skilled workers over the next several years. Other major trials include nuclear safety issues and an insufficient domestic uranium supply. However, China has already signed deals for uranium supply from Canada, for example, and is buying into Namibia's uranium mines.

China's electric-vehicles market is forecast to reach 1.15 million units in annual sales and total ownership of 5 million units by 2020. The Department of Science and Technology has launched an aggressive five-year plan to develop electric vehicles, which have been named one of seven key emerging industries. The government plans to invest RMB 115 billion (US$ 18.7 billion) in energy saving and new EV technologies between 2011 and 2020. However, the time frame for ramp-up may shift due to "growing pains" – for example, low customer acceptance because of inadequate infrastructure for charging, or safety concerns after an electric taxi burst into flames in Hangzhou in April 2011. It is also questionable whether developing an EV market will benefit the environment and the climate, because much of the electricity produced in China is by burning high GHG-emitting coal.

At the social level, people in China are becoming increasingly aware of environmental issues and progressively worried about the health effects of air pollution in their cities. The Olympics in 2008 were a trigger. The government's efforts to reduce the smog and chronic air pollution in Beijing, including by temporary closing many industrial facilities during the games, made people realize how clean the air could be if industrial emissions were cut. Overall, though, the budding awareness is not yet at a stage to drive changes in energy politics, as economic growth is still considered the country's first priority (to create jobs and wealth).

Unconventional fossil-fuel reserves. China has a huge hunger for energy to foster its economic growth. Energy security therefore is vital, as demand cannot be met by domestic sources and a reliable supply is essential for further economic development. For example, China is the world's biggest consumer of coal (49.4% of total global consumption in 2011[176]) and currently cannot supply enough coal from its sizeable domestic resources (13.3% of global reserves[177]). More than half of China's oil supply currently is imported, and though gas imports are smaller these also will climb in the future. Besides efforts to secure resources abroad and to develop non-fossil fuels, China has substantial plans to develop domestic coal and unconventional fossil-fuel reserves. It aims to increase natural gas' share of total energy consumption from 4% in 2010 to 8% in 2015.

Two types of unconventional gas reserves mainly can be found in China: shale gas and coal bed methane (CBM) or coal mine methane (CMM). According to the 12th Five-year Plan, a continued increase in shale gas-based exploration is expected. The government is realizing several policies aimed at encouraging its development:

- **Classify shale gas**. Shale gas was classified as a separate "mineral resource", breaking the exclusive rights for exploration of national oil companies.
- **Complete shale-gas assessment**. Plans exist to complete a nationwide assessment of shale gas by 2015 defining 30-50 shale-gas prospect areas.
- **Speed up exploration and development**. Plans exist to build 19 exploration and development bases in Sichuan province within the next four years.
- **Set incentives and market based pricing**. Plans exist to release favourable fiscal incentives to shale-gas producers and set a market-based pricing regime.
- **Build new infrastructure**. It is proposed to construct gas transmission pipelines in shale-gas exploration and development zones, and grant shale gas access to existing pipelines.

The government wants to develop CBM/CMM production to reach 22 billion cubic metres (m^3) in 2015. To encourage exploitation, China's national energy agency plans to double the subsidy for CBM production to RMB 0.4 per m^3 from RMB 0.2 per m^3.

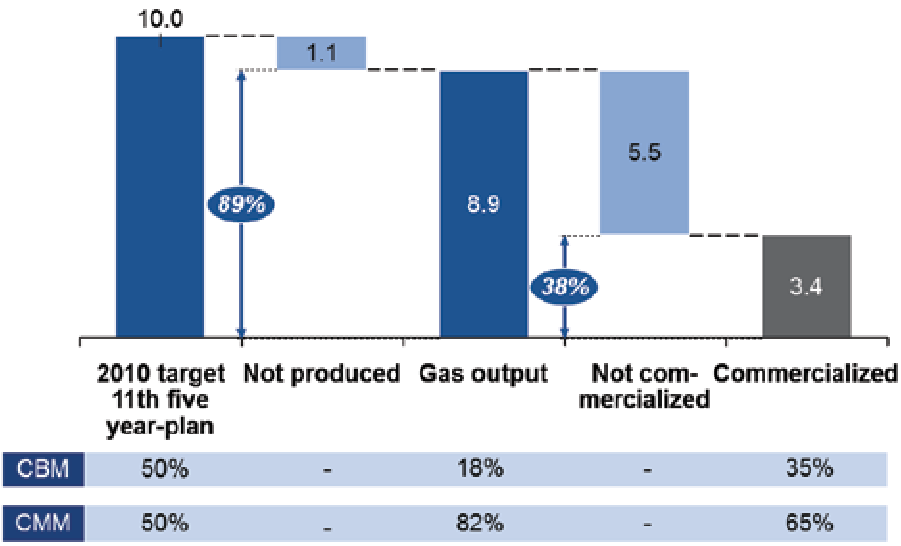
Experts believe the government's targets for unconventional natural gas might be too ambitious under current conditions, and require more time and effort to scale up. The shale-gas reserves are not well explored, and current volume estimates might not prove true.

Several major obstacles also need to be overcome to foster development of unconventional gas reserves. In the case of shale gas, these include:

- **Difficulty in exploitation, poor abundance and lack of technological expertise**. Geological formations in China containing shale gas differ from those in the US. Access to shale gas is relatively easy in the US, but in China the geology makes it more complicated to produce the gas. Chinese companies lack the technological expertise and the lessons learned from the US apply only partially in China. The hit rate is still low, when drilling for unconventional gas reserves; the capabilities for horizontal drilling are limited, and the abundance partly proves to be poor.
- **Pipeline infrastructure and access**. China's natural gas pipeline infrastructure is insufficient and the current construction rate is too slow. Furthermore, a few large companies, mainly China National Petroleum Corporation (CNPC), control the pipelines. CNPC has rejected other companies' requests to use its existing pipeline infrastructure.
- **Water scarcity**. Substantial water scarcity exists near shale gas-rich areas in China's north-west. Technologies currently are developed to reduce the amount of water needed to drill for the gas. GasFrac, a Canadian company, is experimenting with liquefied propane gas to substitute water; the gas evaporates underground and returns to the surface for re-use.[178]

Figure 28: CBM/CMM Production during the 11th Five-Year Plan

Source: CUBM 2011, Oxford Institute for Energy Studies, A.T. Kearney analysis



Plans to foster CBM/CMM production were announced several years ago, but a boost has not yet been seen. The previous Five-Year Plan had aimed to produce 10 billion m^3. Figure 28 illustrates that only 8.9 billion m^3 was reached, of which only 3.4 billion m^3, or 38%, were commercialized. The other 62% was either wasted or used differently, e.g. for electricity production via gensets in mines.

Several reasons prevent success. As with shale gas, an insufficient pipeline infrastructure hampers CBM/CMM production. But the biggest challenge is the monopolistic structure of the industry. China United Coalbed Methane (CUBM) was established in 1996 as a state vehicle to develop CBM/CMM. It has exclusive rights to explore and produce CBM/CMM in cooperation with international companies. Even companies producing coal from a certain mine do not have the licence to produce CMM from the same mine. This monopoly structure has led to inefficiency, partly because CUBM in 2003 became a joint venture between CNPC and China Coal, neither of which put CBM/CMM production high on their agendas.[179,180] China's government is addressing this issue and slowly curtailing CUBM's monopoly.

Chinese Energy Landscape Summary

- China has established a reliable energy infrastructure that enables its current economic growth.
- Despite large domestic resources, China has lost its energy independency, due to its remarkable economic growth and the subsequent increase in energy consumption. Energy security is therefore at the top of Chinese policy-making.
- The energy sector is centralized and monopolistic, and greatly affected by government regulations.
- Increasing energy efficiency will be vital for China to sustain economic growth and become environmentally and socially viable. Different instruments will be required to transform the energy landscape accordingly. These include: energy prices that reflect actual costs, a carbon tax system, and investments in infrastructure (e.g. replacing inefficient industrial facilities).
- Major efforts are under way to explore unconventional natural gas reserves, but significant obstacles could stymie the increase of natural gas' share of total consumption as planned.
- The government acknowledges the need to transform the energy landscape, and the 12th Five-Year Plan sets specific targets. However, change will take time and further efforts are urgently needed.
- The development of the energy landscape will also depend on future economic growth. Since this currently is difficult to forecast, estimates of advancements in energy are equally hard to make.

The European and Chinese Energy Landscapes Differ Significantly but Face Similar Challenges

The energy landscapes of Europe and China differ significantly. Both face different challenges, though also some common ones.

A major variation is in energy demand. China's growing economy will lead to a substantial surge in energy consumption in coming years, while Europe will show a modest increase. This means that Europe "only" has to maintain its existing infrastructure and transform it step by step. China, on the other hand, has to transform its energy landscape and invest heavily in necessary infrastructure to manage rising energy use.

Europe has the advantage of a mature energy infrastructure, while China's is still emerging, and is hobbled by very low energy efficiency, insufficient transportation structure, and a less-developed power set-up. The power infrastructure in Europe can cope with greater fluctuations in supply and demand than can its counterpart in China.

Another dissimilarity is the availability of domestic fossil-fuel reserves. Neither region is energy- independent and energy security is important for both. But unlike most countries in Europe, China holds noteworthy energy resources, including coal and shale gas, and could be largely energy independent. China is also aggressively securing reserves abroad, and buying African mines or Western know-how.

Both Europe and China face considerable challenges in energy efficiency, to not only reduce climate change but also remain competitive in global markets. In spite of having one of the most advanced energy landscapes worldwide – which is much more efficient than China's – Europe still needs to enhance its energy efficiency. One way would be to set up a pricing mechanism that reflects the real costs of energy. Neither region has such a tool. Europe has market mechanisms in place, but the actual movement of energy prices is highly dependent on political decisions (for example, Quotas, RES targets, Nuclear Exit, Grid Expansion). In China, regulators largely set prices.

The environmental impact of energy production without doubt is greater in China than it is in Europe, due to China's far less energy-efficient industry and the predominant use of coal in energy. Even so, Europe, as one of the world's largest energy-consuming regions, has to heighten its efforts to protect the environment and the climate. Both Europe and China already address this issue (for example, through policy frameworks), but further action is required.

In both regions, a key question is that of the political will. Further technological developments are needed, but existing technology already provides most tools. The energy sector is largely affected by governmental regulations, and lobbying from various groups makes it difficult to change the current status. Whether it is to increase the share of renewable energies, construct new transmission lines or foster distributed energy solutions, political will is crucial. The greatest challenge for both regions therefore is policy rather than technological breakthrough.

Developments in Energy Harnessing Offer Opportunities but Also Pose Challenges to Most Industries

Industry accounts for about one-third of the world's energy consumption, and although usage is overwhelmingly concentrated in basic and heavy industries, all companies should make energy management important.

The results of a 2011 survey of businesses and consumers on energy efficiency and use, demonstrated overwhelmingly the emphasis placed on energy management across a variety of industries.[181] According to the survey by Deloitte Touche Tohmatsu, one of the Big Four professional services firms, 90% of companies reported having electricity and energy management goals. Most commonly, companies sought to cut electricity usage or costs by 25% within two to three years; 24% of them expected future regulations for better energy management. In addition, 53% of companies reported reducing electricity use because it is "the right thing to do".

The following section provides an overview of specific industries and highlights the ways in which they interact with the Energy Harnessing value network, in terms of demand and supply. The industries are:

- **Chemicals**. This industry occupies a unique position in the Energy Harnessing value network as both an energy-intensive component of manufacturing and a supplier of supply-side, energy-efficient technologies. As a result, chemicals companies have a dual mandate to improve their own energy efficiency and develop the next generation of solutions to increase energy supply.
- **Electricity**. As generators, transmitters and distributors, electricity utilities are involved in nearly every facet of the Energy Harnessing value network. Consequently, it is imperative that the utilities collaborate with other stakeholders to develop and commercialize innovative energy solutions.
- **Renewable energy**. As suppliers of renewable energy technology, these companies will develop innovative solutions that help to satisfy a growing energy demand. These solutions also will help to mitigate the harmful environmental impact of most fossil fuel- and nuclear-based Energy Harnessing.
- **Automotive**. This industry is a manufacturing component that deserves particular attention because of its role in generating demand for transportation fuels. With a rising emphasis on fuel economy and emerging technologies (such as hybrid and electric vehicles), as well as surging demand in developing markets, the automotive industry is crucial to the shaping of future energy needs.
- **Construction**. This industry encompasses infrastructure as well as commercial and residential buildings, which represent a large percentage of aggregate energy use. By embracing innovative concepts in construction and design, the industry has an opportunity to slash aggregate energy consumption.

Chemicals

Resources and energy are critical inputs for the chemicals industry. Over the past few decades, the industry has greatly reduced its energy intensity. It also has been involved in creating several products to facilitate the expansion of energy supply. The industry was instrumental in developing fluids that enable deeper, safer drilling and hydraulic fracturing for shale-gas production. Because of their involvement on both the demand and supply sides of the energy equation, chemicals companies will continue to be fundamental to the future of Energy Harnessing.

Challenges

- **Access to feedstock.** Chemicals companies face uncertainty related to feedstock availability and prices, which will be driven by several factors: decoupling of oil and gas prices, energy security concerns, increased focus on carbon intensity and as-yet unclear commercially viable alternatives, such as biomass, coal-to-liquids and others.
- **Changing end-markets.** Changes in end-markets driven by the demand for energy-efficient and green products will require chemicals companies to develop new solutions.

Opportunities

- **Reducing costs.** This is possible through energy-efficient processes.
- **Access to feedstock from liquid-rich shale gas.** Production of liquid-rich shale gas in the US offers the opportunity for the domestic chemicals industry to grow significantly, due to low-cost feedstock (mainly ethane, propane, butane and condensate).
- **Increasing recycling.** Chemicals companies have the opportunity to introduce new processes to recycle raw materials or extract additional value from used articles
- **Introduction of renewable raw materials.** Chemicals companies can develop and use renewable raw materials to create green, sustainable products. Renewable materials can slash products' carbon intensity and promote environmental sustainability.
- **Development of new materials that increase energy efficiency.** New materials have the opportunity to promote energy efficiency. For example, structural foam has reduced automobile weight by an average of 36 lb (16.3 kg) and helped to increase fuel economy.[182] Future opportunities include: new catalysts for natural gas and hydrocarbon conversion, and conversion of ethanol to gasoline; new enzymes for cellulosic conversion; feedback and sensing to optimize the electrical grid; and new materials for batteries and solar PV cells.[183] The development of a catalogue on emerging technologies and materials for Energy Harnessing could help the industry to select the most promising for further development.

Electricity

As producers, transmitters and distributors of electricity, utilities play a major role in the Energy Harnessing value network. Depending on the regulation in a given locality, utilities' interests and actions can vary widely. In many instances, utilities have an incentive to sell as much electricity as possible (without harming the electrical grid), which might conflict with larger societal goals to cut energy use. However, such behaviour is far from universal and certain policies, such as decoupling, discourage it. Regulations to boost energy efficiency and use more renewable energy sources exist in many countries and will drive the industry's future development. Many utilities are already adjusting. For example, some incentivize customer investment in green construction, heating and lighting; construct EV-charging stations, or encourage efficiency during peak periods through time-of-use pricing.[184]

Challenges

- **Infrastructure development.** The integration of renewable energy sources often requires upgrading of existing infrastructure, from new offshore wind parks, new transmission lines to large storage solutions. Huge investments also are necessary to replace old infrastructure, such as unreliable transmission lines and inefficient gas- or coal-fired power plants. A cross-stakeholder approach is necessary to fund and realize those projects, as a single participant cannot cope with the outlay, especially in times of financial pressure.
- **Volatile raw material prices.** Volatile prices for fossil fuels, especially gas, are a major challenge for utility companies. They have to decide on large investments, such as new power plants that will last for up to 40 years, even though forecasting future prices for fossil fuels is difficult. For example, the current low price of natural gas in the US would make construction of new gas-fired power plants economically unfavourable. However, gas prices have always been highly volatile and

increases are expected, with many wildcards influencing the outcome.

– **Regulation.** Utilities are often highly regulated. The utility companies are able to influence policy to a certain degree but their actions are largely dictated by regulations. For example, many utilities would prefer to invest directly in renewable solutions, but regulation can restrict their ability to make certain decisions and take certain risks, which can discourage investment.[185]

Opportunities

– **Uniquely situated to provide solutions.** Utilities are uniquely situated to innovate for the energy value network. They generally have access to capital, understand customers' needs and are established members of their communities.[186] They are also well positioned to work with regulators and manufacturers to determine standards, pricing models and regulations for new technologies. They can provide the competence and investment necessary for the development of distributed energy generation.
– **Development of storage solutions**. Large-scale storage solutions are essential for renewable energy sources and utilities are in a unique position to test and deploy these technologies (once they are commercially viable).[187] Storage technologies also allow utilities to operate more efficiently.
– **Integration of smart grid technology.** Smart-grid technology has the potential to dramatically improve the efficiency of the electrical grid. In addition, such technology will facilitate the incorporation of intermittent renewables, such as solar and wind.

Renewable Energy

Renewable energy companies range from start-up ventures that focus on R&D of new concepts to large-scale producers of alternative-energy technologies, such as solar panels and wind turbines. Across the spectrum, these companies are developing the next generation of energy solutions to meet growing energy demand and reduce society's global carbon footprint.

Challenges

– **Competition with fossil fuels**. Except for hydropower and some wind projects, most renewable energy sources have not yet reached cost-parity with fossil fuel-based sources. Indeed, low-cost shale gas (with a lower carbon footprint than coal or oil) will provide significant competition for renewables for a long time. To become truly viable, renewables must reduce cost and operate independent of government subsidies and other financial incentives.
– **Access to capital**. Many renewable energy companies are small-growth and require financing to survive. Securing funds is often a problem due to the capital intensity of developing and scaling new technologies, the risk associated with renewable energy ventures, and an uncertain path to economic viability.
– **Lack of storage options and insufficient transmission lines restrict integration**. To allow for demand shifts and to balance the base load, renewable energies like solar and wind require large storage options to counteract intermittency. Renewable energies also often need to be transported over large distances (if produced in offshore wind parks, for example) and therefore require new transmission lines that can transport electricity with minimal losses.
– **Shifting regulatory and policy environments**. Renewables often rely upon government subsidies and other policies to make them competitive with other energy sources. When a country or region is in financial trouble, these policies are often modified or abandoned. This uncertainty makes potential investors wary of renewable energy companies, reducing the latter's access to capital and limiting the pursuit of innovative ideas.

Opportunities

– **Increasing distributed energy generation and grid parity.** These drive growth of renewable energy sources such as wind and solar.
– **Policy support fosters renewables in the market.** Incentives, such as subsidies and carbon pricing, bolster the economics of renewable energies and help them to reduce costs and compete against other energy sources.
– **Collaboration with industry members.** Renewable energy companies can partner with other industry members, such as manufacturers, power companies and utilities, to develop commercially viable renewable energy solutions.

Automotive

From 2012 through 2016, the automotive industry's revenue is projected to rise at an annual rate of 4.6%, driven largely by growth in emerging countries, especially in Asia-Pacific.[188] Several trends are likely to change the nature of consumer demand in the industry. The uncertainty around future oil prices, tighter regulations (such as emissions standards) in the developed world, and cost-consciousness in the emerging economies will greatly encourage car companies to create more fuel-efficient and environmentally friendly vehicles. These trends will create multiple opportunities: for example, the adoption of alternative fuels (including electricity), the use of lighter and more energy-efficient parts, the redesign of manufacturing processes, and improvements in the supply chain. These trends, along with general advances in manufacturing process, have the potential to slash worldwide reliance on transportation fuels and reshape global energy demand.

Challenges

– **Increasing regulation**. Stringent emission regulations, such as the US' Corporate Average Fuel Economy and mandatory European car fleet targets, force the industry to focus on improving fuel efficiency.

- **Cost of green technology**. Green technology, such as EVs, need to cut costs further to become economically viable.
- **Lack of required infrastructure for new technologies**. New technologies, such as EVs and alternative fuels, require additional infrastructure to facilitate mass adoption. EVs in particular need charging stations and connection to the electrical grid. Ways to enable the necessary investments need to be found.
- **Rising transportation fuel costs**. Rising fuel costs are boosting demand for more fuel-efficient vehicles and creating opportunities for alternative technologies such as EVs.

Opportunities

- **Cost reduction**. This can be enabled through energy-efficient processes.
- **Commercialization of fuel-efficient automobiles**. Automotive companies are focusing on developing lighter auto parts, such as lightweight plastics, to use instead of steel. Lighter vehicles would be more fuel-efficient. BMW's i3 model aims to be the first fully emissions-free vehicle, with a target to use 50% less energy and 70% less water than typical BMW Group assembly processes.[189]
- **Expansion of alternative fuels**. Companies are increasing their investments in new technologies to produce cars that run on flex fuels, as well as hybrid and electric vehicles. These cars will help to address emission standards and regulatory reforms that require improved efficiency. They may have the potential to reduce dependence on foreign oil (e.g. by using biofuels or electricity generated from natural gas-fired power plants or renewable energy sources).
- **Collaboration with non-traditional players**. Such collaboration will be important. Partnerships with battery manufacturers, electrical utilities and governments will help companies to foster innovation, as well as share the costs and risks associated with developing new technologies.

Construction

Between 2000 and 2010, energy consumed globally by buildings increased from 397 quadrillion Btu to 522 quadrillion Btu.[190] By 2030, the UN Environment Programme estimates that GHG emissions from buildings will reach up to 15.6 billion tons in 2030 from energy used to heat, ventilate, cool and light buildings – double the 8.6 billion tons produced in 2004.[191] Fortunately, the UN Programme reports that energy consumption in new and older buildings can be cut by 30-50% without significant investment.[192] Globally, these reductions could have an enormous impact. In Europe, lowering energy use in buildings by 30% would result in an 11% reduction in overall energy use; this would represent half of Europe's 20-20-20 targets – achieving an improvement of 20% in energy efficiency.

Challenges

- **Inadequate regulatory environment**. Some regions lack energy-efficiency regulations and others change their policies frequently, particularly during bad financial times, which deter investment in energy-efficient construction.
- **New sustainable building materials**. In many regions, construction companies use energy-intensive building materials. Developing sustainable materials to substitute the unsustainable ones can be expensive.

Opportunities

- **Cost reduction**. This can be enabled through energy efficient processes.
- **Innovations for reducing the energy footprint**. A number of technologies exist to improve the energy efficiency of buildings, including new forms of insulation, energy-efficient windows, heat pumps, high-efficiency gas boilers and building-integrated PVs.[193] These innovations can be applied to new construction and can be used to retrofit existing buildings.
- **Establishment of national and local building regulations**. Establishing policies in coordination with the energy and climate change policies of nations and localities will create a baseline for energy efficiency and set expectations. This should be accompanied with appropriate training and education, a focus on defining baseline performance measurements, as well as a mechanism to enforce compliance.

Strategic Relevance for Industries Summary

- Industry plays a dual role in the Energy Harnessing value network as a consumer and a developer of supply solutions.
- Across all industries, policy and regulation, an emphasis on cost reduction, and changing consumer preferences will drive efforts to improve the energy efficiency of processes and end- products. For example, the automotive industry will continue to cut energy consumption in the manufacturing process, even as it creates more fuel-efficient vehicles.
- From a supply perspective, renewable energy companies, in collaboration with industries such as chemicals, will develop the next generation of energy solutions.
- The unique position of utilities as producers, transmitters and distributors of electricity gives them an integral role in developing and integrating new energy solutions from a demand and supply perspective.

The Role of Collaborative Innovation in Energy Harnessing

Megatrends, changing consumption patterns and an increasingly complex, integrated global ecosystem require a new collaborate approach to innovation. Chemical companies and their non-chemical partners are being asked to cooperate across traditional value chains and to apply their knowledge, capabilities and expertise outside their usual areas of experience. New value networks, such as Energy Harnessing, offer significant potential for those players able to leverage approaches that are cross-industry and cross-value chain in order to develop advanced solutions to the energy conundrum.

Collaborative innovation. Collaborative innovation requires two or more players (e.g. industry, government, academia, research institutes, customers, regulators and/or non-profit organizations) to be partners in developing new products, processes, services or even business models that address an emerging consumer need. Collaborative innovation often includes partners from different regions and builds up into a network. (Figure 29 shows an example of a collaborative innovation network.) Compared to traditional approaches, collaborative innovation mobilizes maximum creativity to develop best solutions fast, and link idea creation and evaluation.

Collaborative innovation requires cooperation along the entire process of innovation management, from scouting/ idea generation, product/ service development and launch of new offerings to continuous improvement. Cooperation also can be restricted to certain steps in the innovation management process.

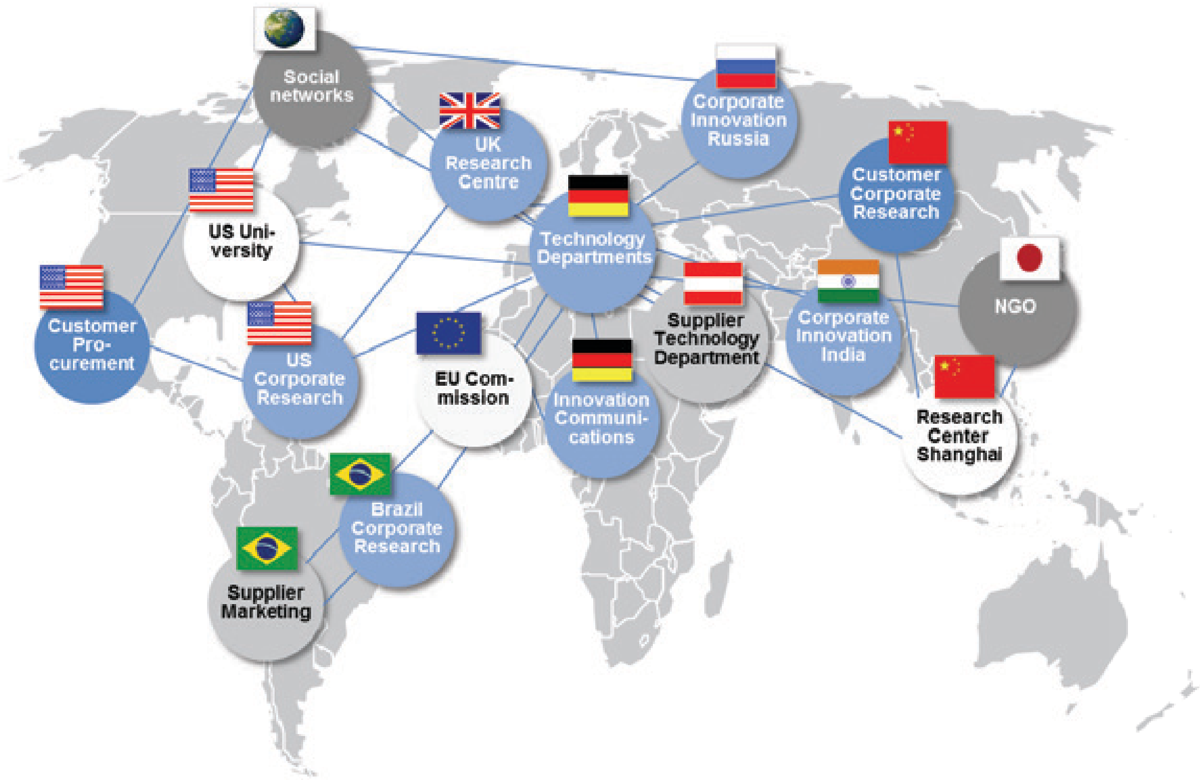
Collaborative innovation targets the best available and expected know-how, resources and competences, the sharing of risks (and costs) of innovation, and the securing of a competitive edge (through talent, resources or intellectual properties) in order to enhance the effectiveness of innovation and speed up the time-to-profit.

This requires an open innovation approach and mind-set, as well as the right collaboration and legal framework to protect the interests of all partners. Changing means of communication, e.g. the Internet and social media, provide opportunities and risks that need to be managed. Collaborative innovation takes advantage of out-of-the-box sources, such as online surveys, street interviews, university forum discussions and journalistic dialogues.

Personal relationships and meetings might become crucial to establishing a trusted partnership and building a collaborative platform. Exploiting the full potential of digital communication while continuing face-to-face interaction is, and will continue to be, a major challenge for collaborative innovation. Establishing the right structures for tomorrow must be started today.

Collaboration is essential for future growth in many industries, including chemicals. In Europe's chemicals companies alone, for example, collaboration could trigger additional sales of more than US$ 30 billion annually, according to a recent market survey of A.T. Kearney.[194] According to the Chemical Customer Connectivity Index (C3X), a regular market panel to assess short- to long-term trends at the interface between chemical players and their direct customer industries, 90% of the chemical manufacturers and 82% of their customers expect collaboration to intensify and become the most important value-lever in the next five years.[195]

Figure 29: Global Innovation Network: An Illustrative Example



Collaborative innovation in Energy Harnessing. In the Energy Harnessing value network, innovation is required to successfully transform the energy landscape, and meet the future challenges of sustainability and surging demand. The World Resources Institute characterizes the need for innovation in the energy sector as follows:[196]

- Many opportunities to innovate exist because technologies are nascent.
- Very large investments are required for innovations and can take a long time to pay off.
- New technologies cannot charge a premium because they integrate with the mature power or transportation-fuel sectors.
- New entrants are few, and large global players have a role.
- Knowledge is often tacit and comes from diverse sources such as scientific research, suppliers and customers.
- Innovators tend towards a geographic clustering, often near customers.

These factors create opportunities for industry to develop new solutions and leverage new technologies to achieve greater energy efficiency. However, companies contend with higher costs and risks of innovation, as well as relatively long time-to-profit. While chemicals players have kept innovation budgets almost at a comparable absolute level, innovation spend has gone down relative to revenues in recent years.

Internet of energy. In the future, more energy will be produced using distributed sources, greater energy efficiency will be needed, and the generation, transmission and distribution of power will be increasingly decoupled. This calls for comprehensive communication and interaction between the different energy stakeholders – utilities, industries and private households, among others.[197] The "Internet of energy" concept can provide solutions. New information and communication technologies (ICTs) offer an opportunity to boost communication between players to use energy more efficiently and better balance demand and supply.

Ongoing pilot projects include E-Energy, a funding programme of Germany's Federal Ministry of Economics and Technology and Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. The term "e-energy" stands for the digital networking and optimization of the energy supply system, from generation and distribution to consumption.[198] The project's goal is to strengthen the effectiveness of the existing supply infrastructure, develop the use of renewable energy sources, and reduce GHG emissions. To achieve success, all value-adding parts of the energy value network are covered and different stakeholders mutually develop solutions.[199]

Six model regions in Germany have been selected for research and for developing solutions for a future energy system based on ICT. Each region will focus on a different aspect.[200] For example, a consortium made up of EnBW, ABB, IBM Germany, SAP, Systemplan and the University of Karlsruhe is working together to develop a model house in MeRegio[201] that generates power using a photovoltaic or mini combined heat and power (CHP) system. The power generated is then either fed into the grid or used to charge the electrical vehicle parked in the garage. If needed, the car's battery can also feed power into the grid. ICT interlinks the house with a smart-grid platform and the consumer can view the process via an Internet portal.[202]

The model regions illustrate how a collaborative approach can work across industries and stakeholders in Energy Harnessing. However, sustainable cooperation (especially between companies without governmental support) is needed, as is the development of business models and ICT solutions.

Other examples. The ADELE project is another example of a partnership between different companies and research institutes. It was launched in 2010 by RWE Power, a German utility company; General Electric, a US conglomerate; Züblin, a German contractor in the field of building construction and civil engineering; and Germany's National Research Centre for Aeronautics and Space. The goal is to develop an adiabatic CAES plant for electricity supply, with a storage capacity of 1 GWh and electrical power of up to 200 MW. [203] In ADELE, companies across the entire value network are working together with a public-funded research institute to develop an efficient and suitable grid-scale energy technology.

Numerous other collaborations exist. It was recently announced that Tesla Motors of the US would develop an electrical powertrain for Daimler's B-Class electric drive vehicle, after both companies had worked together on the electrified Smart car. In a joint venture, Samsung and Bosch collaborated on lithium-ion batteries – two suppliers cooperating to develop new products. Joint ventures between OEMs and suppliers also exist, such as the partnership between A123 Systems, a US lithium-ion battery maker, and SAIC Motor, a Chinese state-owned automotive manufacturing company, to cultivate new solutions to tap China's market for hybrid and electric vehicles.

Many large companies have venture capital funds that invest in new

technologies. Intel Capital, managed by Intel Corporation, is one of the largest such funds in the world. Since 1991 it has invested US$ 10 billion in 1,200 high-tech companies, most of which were small businesses at the time.[204] Among them was Grid Net, a US-based smart-grid company. Together, the two companies have created a smart energy meter using Intel's processing chip and Grid Net's software. To launch the meter, they have joined a consortium (along with Trans Grid, IBM, EnergyAustralia and others) to support "Smart Grid, Smart City", a demonstration project in Australia to test the smart grid and smart meters across at least 30,000 households.[205]

As the examples show, collaborative innovation is gaining importance. However, more value network ventures and partnerships are needed.

Key success factors. To be successful, collaborative innovation requires aligned objectives and substantive commitment from all parties, as well as a willingness to equitably share risk and reward. Customer-supplier relationships provide benefits for both sides, but solving arduous problems necessitates deep levels of trust and commitment. Collaboration is most effective when the partners have similar corporate cultures that support innovation. A lack of real openness among different stakeholders, often due to potential intellectual property conflicts, can hinder development of new technologies.

Four elements are vital for positive collaborative innovation:

- **Trust among collaborators**. The various parties should trust one another and have a clear understanding of what each offers to, and seeks from, the collaboration.
- **Stable and contractually fixed legal framework**. An agreed-upon framework should define the roles of each of the collaborators as well as the common goal that unites them. This gives clarity to the development arrangement and goals. Each collaborator should bring a unique advantage in terms of networks, expertise, resources or customers.
- **Clarity around how the results of the collaboration will be used and divided**. Upfront negotiating of intellectual property rights, costs, targets and key functionalities allow partners to collaborate freely. Terms for use of the collaboration's benefits by each partner, within or outside a defined field, should be clarified.

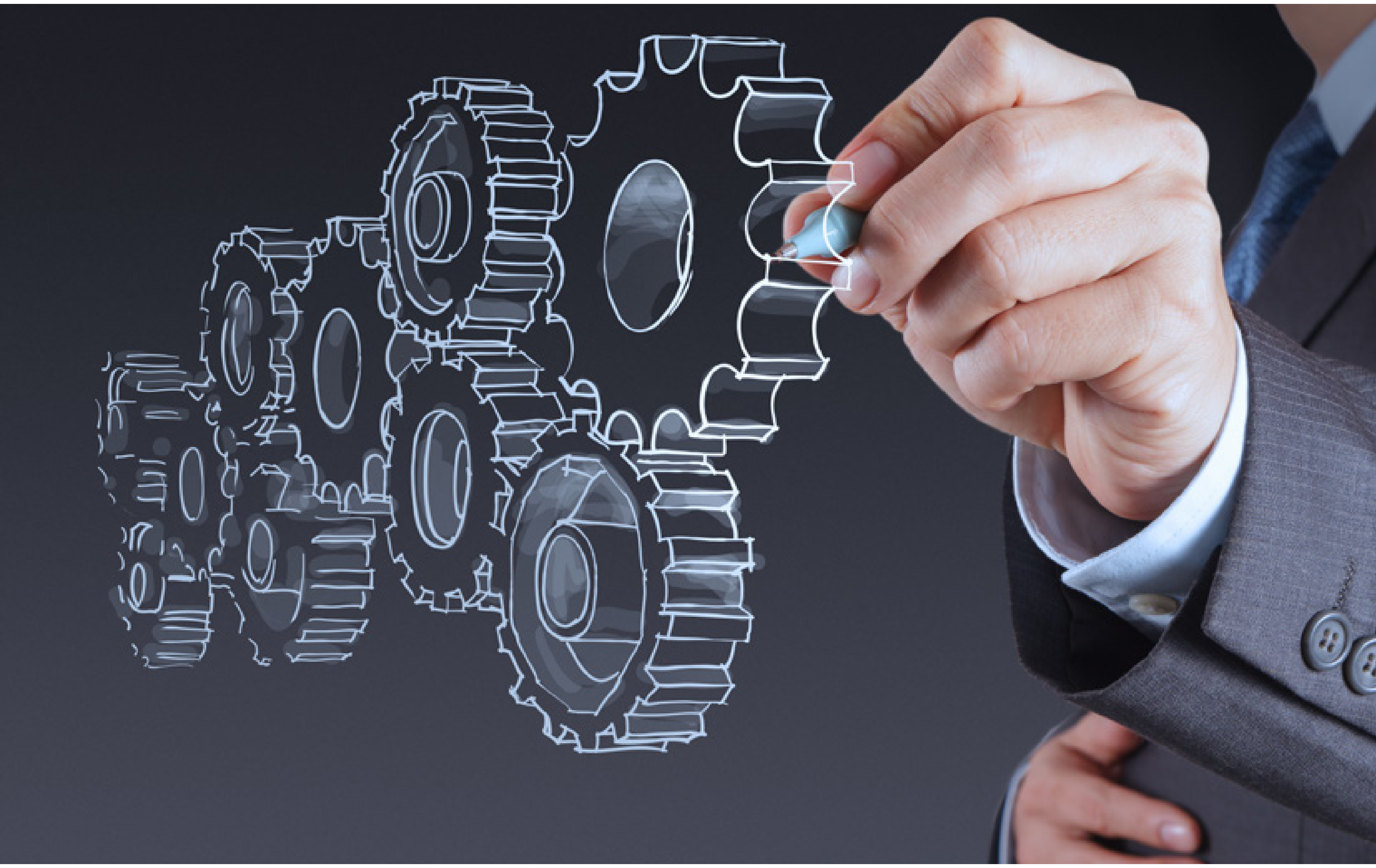
– **Clear structures, processes and resources**. It is critical to allow for creativity as part of the process. But once a concept is proved, the partners should have a well-defined, well-resourced plan for development and completion. Success requires a disciplined commitment to the plan and dedicated personnel who can carry out the project to conclusion, with enough flexibility to adapt to changing requirements of the value network.

All collaborators should be active participants, instead of mere reviewers of the results of a partner's efforts. Some relationships become formal business arrangements over time; others run their course and the collaborators part ways.

Time for action. Collaborative innovation is important throughout the entire Energy Harnessing value network. New technologies and solutions – hence collaborative innovation – are urgently needed in production of shale gas from difficult geographical formations, creation of more efficient solar panels, smart-grid applications, and advanced grid-scale and e-mobility energy storage solutions, among other areas. To innovate quickly in these fields will be important, for companies to stay ahead of the curve, for governments to ensure energy security, and for communities to protect the environment and climate.

The Role of Collaborative Innovation in Energy Harnessing Summary

- In the chemicals and industrial-products sectors, traditional innovation approaches usually are no longer suitable to mitigate the current and future challenges of Energy Harnessing.
- Collaborative innovation is an alternative solution in which two or more entities cooperate to research and develop products, and share costs, risks and rewards.
- Successful collaborative innovation requires trust among partners, a clear definition of the cooperative arrangement, goals, use and division of results, and focused processes and resources.



Conclusion

The future of Energy Harnessing is fundamental to global economic growth and sustainability. It will determine how societies live and will profoundly affect the world. Several megatrends, such as climate change, growing energy demand and limited resources, will urge people to adjust their energy landscapes and address future energy needs. Developing an energy background that is economically, socially and environmentally sustainable is essential. Renewables must dominate the global energy landscape because traditional sources such as coal, crude oil and natural gas are not only harmful to the environment but also are finite in the long term. Additional technological developments, new business models, financial capital and, most importantly, political will are crucial to make renewable energy a success story that subsequently transforms the energy landscape.

In the short term, the energy vista will change because of, for example, the discovery of abundant shale-gas reserves. The energy outlook and economic projections for the US already have fundamentally altered due to shale gas. The country is now positioned to become a major natural gas producer, reduce its dependence on foreign oil and develop a significant energy cost advantage over other nations. The United Kingdom, too, is determined to use shale gas to restart its economic engine. It remains to be seen what kind of shale-gas story other countries such as China, Mexico and South Africa will have. Natural gas without doubt will be vital for the shift from a high- to low-carbon energy landscape, and will be the “transition” fuel. Two main reasons behind this: first, flexible gas-fired power plants are the backup for intermittent renewables; and second, gas is the fossil fuel with the lowest emission intensity. Hence, gas could replace storage solutions until emerging technologies are fully feasible.

To satisfy the world’s hunger for energy, more innovative solutions are needed. The energy demand of the developed world will grow relatively slowly over the long term, but that of the emerging economies will surge. This extraordinary increase in demand will have profound implications for the energy landscape; meeting the demand will require a global effort. Part of the solution will come from growing supply, but fulfilling demand will be impossible without substantial gains in energy efficiency, not only in developing countries such as China but also in developed regions such as Europe.

In the coming decades, industries such as construction and manufacturing will provide the next generation of energy-efficient products for consumers. From increased fuel economy to solar-powered cell phone chargers, products will focus on improving energy efficiency at multiple levels from personal power to national grids.

Energy storage is one link between rising demand and supply of renewable energy. Verified storage techniques such as pumped hydro storage, cutting-edge battery and super-capacitors will be required to integrate renewable energy into the electrical grid, power buildings and houses, and fuel vehicles. Energy storage will solve several problems, ensuring the technical substitutability of renewable energy sources and enabling wide distributed generation.

In the absence of these advances, however, the short-term future of Energy Harnessing must be examined, given the current technological landscape. Because of the costs of transportation and/or transmission, Energy Harnessing will always be a global issue with regional or local solutions. Fundamentally, countries can be distinguished based on the state of their energy infrastructure (for example, developed, developing and limited) and their domestically available resources. Distributed solutions (e.g. solar panels on rooftops or distributed energy storage solutions) will be important for all countries to establish a sustainable new energy landscape. To balance supply and demand, stakeholders in each region will need to inventory available resources, develop sustainable energy sources and increase energy efficiency.

Despite the local nature of solutions, the importance of global cooperation must not be ignored. Technologies and best practices developed in one region can, and should, be leveraged in another. For example, solar-powered electronics created in the developed world can, and should, be applied in emerging countries with limited infrastructure. Collaboration, however, must be more regional – it should involve governments, industries, non-government organizations and academia across the value network. Only by working together, regionally and across industries, will solutions be developed to address current and future energy challenges.

The urgency to transform the world’s energy landscape – and develop solutions to mitigate the challenges along the way – cannot be overemphasized. Time is running out to prevent a climate change that will have a potentially tremendous impact on global society and the planet. It is time for action.

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