WORLD ECONOMIC FORUM

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White Paper

Game Changers in the Energy System

Emerging Themes Reshaping the Energy Landscape

In collaboration with McKinsey & Company

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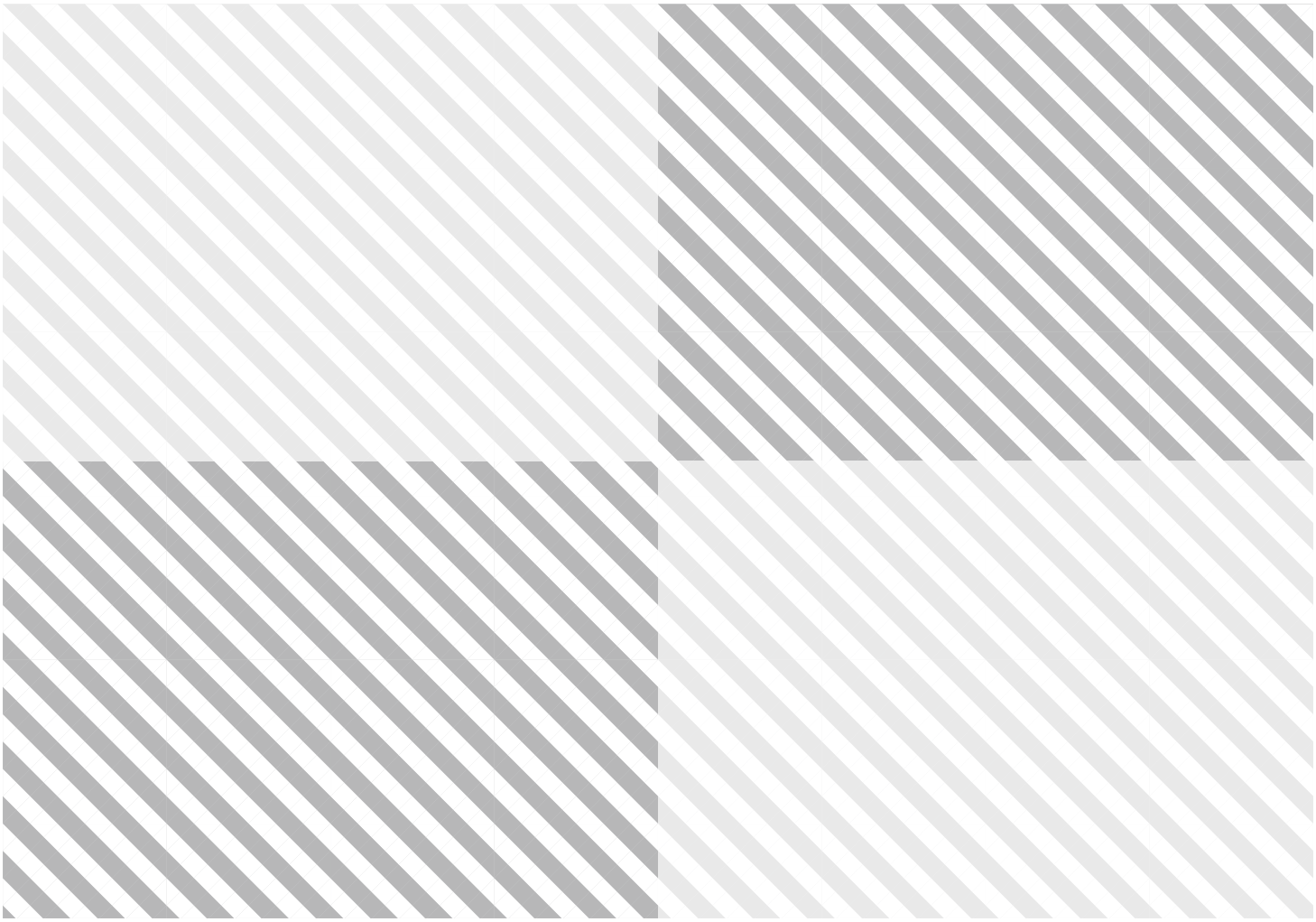

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Introduction

Project context

The global energy ecosystem is in the midst of a transformation at a scale and pace perhaps unseen in a century, buffeted by discontinuities in every direction. Deep trends in the global economy, including industrialization in emerging markets, changing demographics, rising nationalism, and innovations affecting cost and efficiency are overturning past assumptions about the demand for energy – and the supply of fuels and feedstocks that drive it. Technology disruptions have unlocked vast new sources of energy (e.g. renewables, shale gas, tight oil) while changing the contours of demand for that energy (e.g. advanced materials, light-weighting, electric vehicles). Geopolitical developments are changing production profiles across regions, sometimes at a rapid pace. The arena is being redrawn by government policy and international agreements, reflecting changing public priorities and increased public scrutiny.

Several challenges stem from the fact that the energy ecosystem is exactly that – a system – comprising an extraordinarily complex network of sectors and stakeholders across diverse segments of the global economy. Now that so many pieces of the ecosystem are in flux, it has become unusually difficult to anticipate what the future holds – and to know what actions are required today to thrive in the years ahead. Understanding the urgency and implications of these "game-changing" trends will be critical to businesses, governments and society as a whole. In many cases, responding to these game-changing trends will require fundamental shifts in how businesses are run, how policies are set, or how household decisions are made – and these changes will not always be easy or obvious.

Because of their ecosystem-wide ripple effects, identifying and understanding potential game changers requires a systemic dialogue across sectors and stakeholders, a task which the World Economic Forum is well positioned to undertake.

Objective and approach

The objective of this paper is to provide a structured perspective on potential game changers in the energy system, by anchoring these ideas to deep global trends and synthesizing diverse perspectives across industries, stakeholders and geographies into coherent, deep-rooted themes.

The Game Changers in the Energy System project adds to the existing body of knowledge on this topic through a different approach, which aims to build a system-wide perspective across multiple stakeholders and geographies; provide structure in order to get beyond buzzwords; surface the root causes behind potential disruptions; and identify implications of these potential disruptions for stakeholders in the energy system across business, government and society.

For the purpose of this undertaking, the energy ecosystem comprises a set of stakeholders that includes:

- **Energy companies** (e.g. oil and gas, electric utilities, renewables developers, service companies, technology and equipment providers)
- **Large energy users** (e.g. chemicals, advanced materials, metals and mining, automotive, manufacturing)
- **Financial sector** (e.g. commercial banks, private equity, institutional investors)
- **Policy-makers** (e.g. legislators, ministries of energy, environmental agencies, financial regulators)
- **International organizations** (e.g. International Energy Agency, United Nations Framework Convention on Climate Change)
- **Civil society stakeholders**

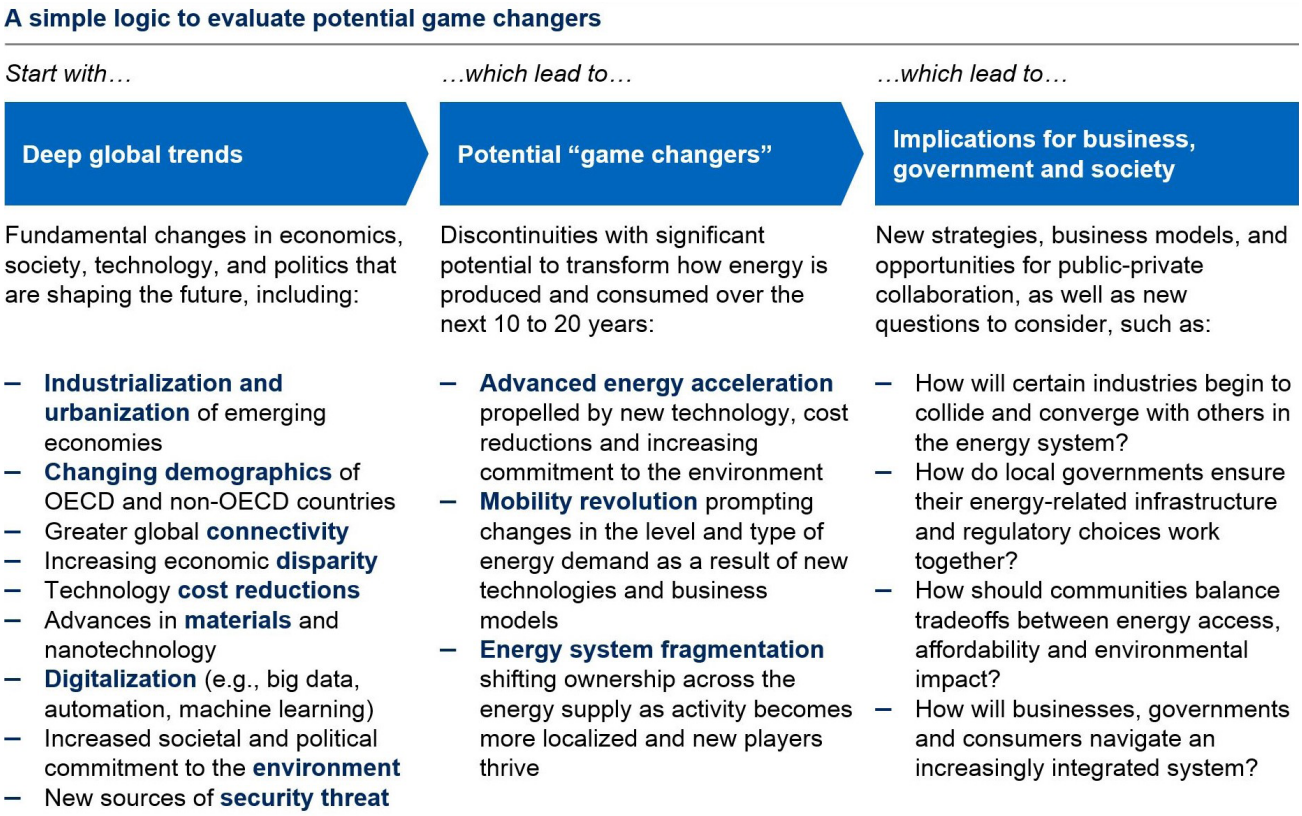
To better understand global trends across the energy ecosystem, the World Economic Forum conducted a series of expert interviews and multistakeholder roundtable discussions, supported by expertise and analysis from McKinsey & Company. In addition to seeking a breadth of industry expertise across the energy ecosystem, the project also gathered perspectives across geographies, with roundtable discussions held in London, Geneva, Dubai, Tianjin, New York, Houston, San Francisco and Washington DC.

The project defines a game changer as a discontinuity with the potential to have a step-change impact on a group of stakeholders (e.g. businesses, governments, consumers). For the purpose of this project, the scope is focused on potential game changers that could come to pass within the next 10 to 20 years.

A structured, disciplined logic is necessary when thinking about the emergence of game changers (Figure 1). The project began by identifying and understanding deep global trends, or fundamental changes in economics, society, technology and politics that are shaping the future of the energy ecosystem and the world. By anchoring to deep global trends, the truly important and deep-seated implications for the energy system can be crystallized – and interesting but ultimately ephemeral ideas, and the usual buzzwords, can be disregarded.

From the deep global trends emerge potential discontinuities, or game changers, capable of having a step-change impact on a group of stakeholders within the energy ecosystem. Whether these game changers come to pass at scale – in other words, achieve a breakthrough – depends on a set of factors that could accelerate or decelerate their impact in the next 10 to 20 years. Once these factors are understood, the implications for business, government and society must be considered, such as new strategies and business models, new priorities for governments, and changes in consumer preferences and behaviours.

Figure 1: Guiding framework for identifying and understanding the implications of potential game changers in the energy system.



Source: McKinsey & Company, World Economic Forum

Through multistakeholder discussions and research, three game-changing themes emerged as having the greatest potential to impact the energy system: advanced energy acceleration, mobility revolution, and energy system fragmentation. The sections that follow explore the momentum gathering behind these themes, the factors that could accelerate change in the next 10 to 20 years, and possible implications for businesses, governments and society.

Potential Game Changers

Advanced energy acceleration

The energy system sits on the cusp of a profound expansion of technologies. Already, hydraulic fracturing and directional drilling have unlocked shale, and advances in wind, solar, storage and smart grid technologies are changing the power industry. But this may only be the beginning: economic development requirements globally have increased demand for energy; increasing societal commitment to the environment has intensified demand for low-carbon energy; and technologies to meet that demand are becoming increasingly economical. Moreover, new technologies contributing to improvements in energy efficiency are decoupling energy consumption from economic growth.[1] An unprecedented diversity of energy technologies may be poised for a breakthrough.

Drivers of change

In recent years, private sector-led cost reductions have made renewable energy sources increasingly competitive. For example, the cost of solar panels has fallen by over 80% since 2005 as a result of technological innovations in manufacturing, leaner supply chains and improved economies of scale.[2] In many regions, solar and wind energy have become cost competitive without subsidies, with several new power purchase agreements (PPAs) falling below US$ 100 per megawatt-hour (MWh). In early 2016, a solar contract was awarded in Coahuila, Mexico at a price of approximately $40 per MWh – the lowest subsidy-free solar contract ever seen, according to Bloomberg New Energy Finance.[3] Given this momentum, a recent study projects that by 2025, between 2,000 and 3,000 GW of solar capacity will be economical – representing almost half the world's total electric power capacity today.[4]

Solar and wind are not the only power generation technologies coming into focus – next-generation energy technologies such as fuel cells, small modular nuclear fission reactors and even nuclear fusion are also receiving increased attention from university laboratories and start-ups. For example, in early 2016, the US House of Representatives approved a bill enabling the private sector to partner with national laboratories to study nuclear reactor technology.[5] Shortly thereafter, the US Department of Energy awarded research grants to a nuclear start-up and a gas and electric utility company to further develop advanced nuclear reactor designs.[6]

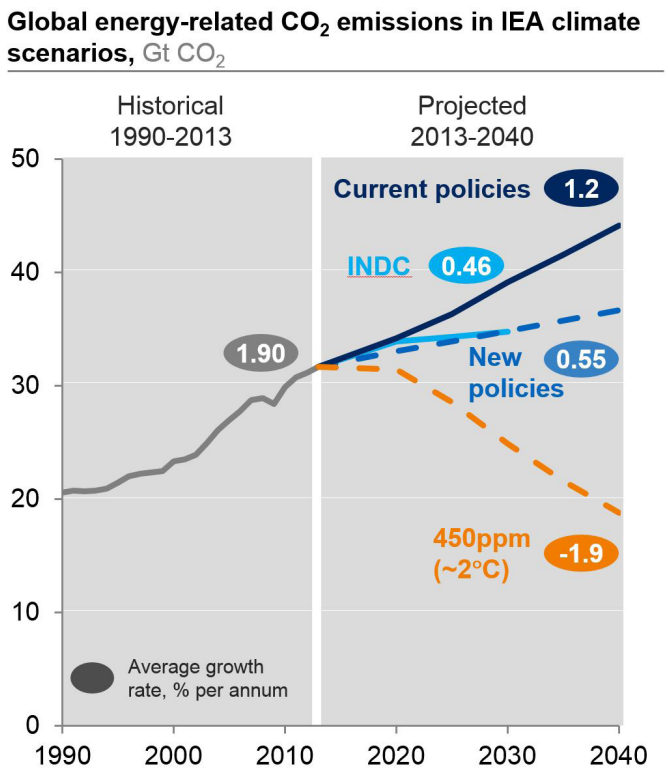
In parallel, social and political commitment to environmental protection and emissions reduction has grown meaningfully in some areas of the world as public concern over climate change continues to rise. According to a 2015 Eurobarometer survey, 91% of Europeans see climate change as a serious problem, up from 64% in 2009.[7] Similarly, a Gallup poll from March 2016 indicates that US concern about global warming is at an eight-year high (64% of Americans are worried).[8] In developing countries, where most of the world's population resides, climate change awareness lags behind. A study published in 2015 found that more than 65% of adults in developing countries have never heard of climate change.[9] The study also found that of those respondents who were aware of climate change, most people in developing countries perceived it to be a much greater threat than did people in developed countries.[10]

Growing public concern has propelled policy-makers towards action. At the local level, policy commitment has become widespread through a variety of support schemes to spur investment in renewable energy (e.g. subsidies, feed-in tariffs, emissions and efficiency requirements). The United Nations Framework Convention on Climate Change (UNFCCC) has reinforced climate change action as a global priority by aligning 195 countries towards a shared objective to limit global warming by reducing their greenhouse gas emissions. Roundtable participants viewed the Paris Agreement as a major milestone. The plans submitted in 2015 by each country – the nationally determined contributions (NDCs) – set targets for emissions reductions by 2030, relying primarily on increasing the share of (near) zero-carbon sources (e.g. renewable energy, nuclear, or fossil fuels with carbon capture, utilization and storage).

To meet the planned targets in the NDCs, the worldwide increase in power generation from renewable energy sources will exceed twice that from fossil fuels by 2030, growing the share of renewables in the power supply mix from 20% today to roughly one-third in 2030.[11] However, some studies suggest that meeting the NDC emissions targets will not be enough to achieve the well-below 2°C objective of COP21; by 2030, emissions will need to be about 30% lower than the targets set by the current NDCs (Figure 2).[12] The first five-year update for the NDC plans, due in 2018, may begin to close the gap. Although recent events such as Brexit and the US election have intensified the uncertainty around continued global commitment to climate change efforts, it is not yet obvious what the implications will be.

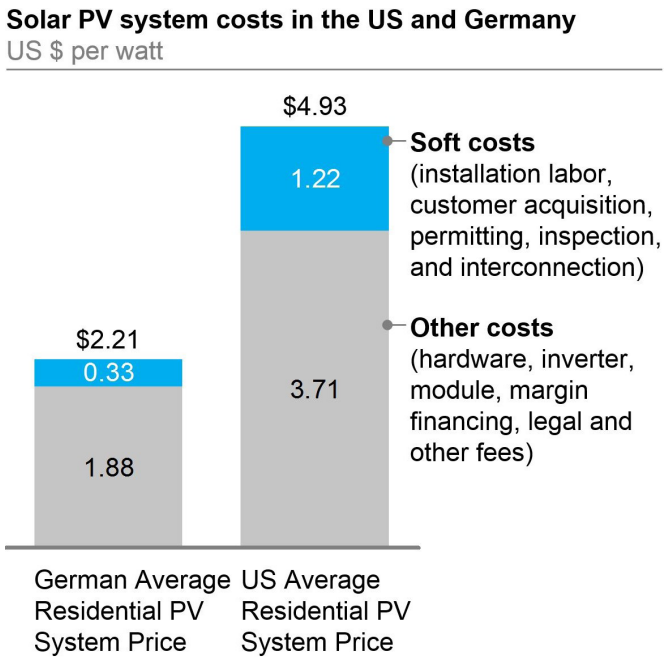
Despite growing momentum towards low-carbon energy sources and technologies, a large-scale shift in the energy mix has yet to break through. Renewable energy sources are growing, yet still account for only 10% of global primary energy consumption.[13] Addressing emissions from fossil energy sources will also be critical to achieving a low-carbon energy mix. In the next two decades, total primary energy demand from rapidly developing nations like China and India cannot be met by renewable energy sources alone. China has announced a target of 20% of primary energy demand to be met by non-fossil fuel energy sources by 2030.[14] India has pledged to source 40% of its electricity from renewable and other low-carbon sources by 2030.[15] Even upon meeting ambitious national targets, China and India will likely continue to see fossil energy sources account for a majority of the energy mix. If these and other countries aspire to a low-carbon energy mix while still meeting economic development goals, there will be a need for not only rapid deployment of existing renewable energy technologies, but also economic solutions to improve the emissions profile of fossil energy sources.

Figure 2: Current NDC plans will make progress towards the well-below 2ºC objective.



Source: Ecofys

Figure 3: Costs of solar PV in the US and Germany.



Source: Rocky Mountain Institute

Unlocking a breakthrough

The next wave of cost reductions and further technological breakthroughs could accelerate the advancement and deployment of a wide menu of low-carbon energy technologies in the next 10 to 20 years.

Cost reductions in system design and construction could enable another step-change in the competitiveness of renewable energy generation. To date, much of the private sector cost reductions have occurred along the manufacturing supply chain. Equipment costs account for approximately one-third of the total price tag for US residential solar systems.[16] The remaining two-thirds are "soft costs," such as permits, installation and maintenance. Solar companies could reduce installation and maintenance costs by simplifying system design by developing standards or using prefabricated components. This "design for constructability" approach may require firms to collaborate closely with their engineering, procurement and construction (EPC) counterparts to develop standardized components.[17]

Policy-makers may also play a role in reducing soft costs by streamlining the permitting process as Germany has done by minimizing requirements and creating national standards. A recent study estimated that average soft costs for residential photovoltaic systems in Germany were approximately one-fourth those of similar systems in the US (Figure 3).[18]

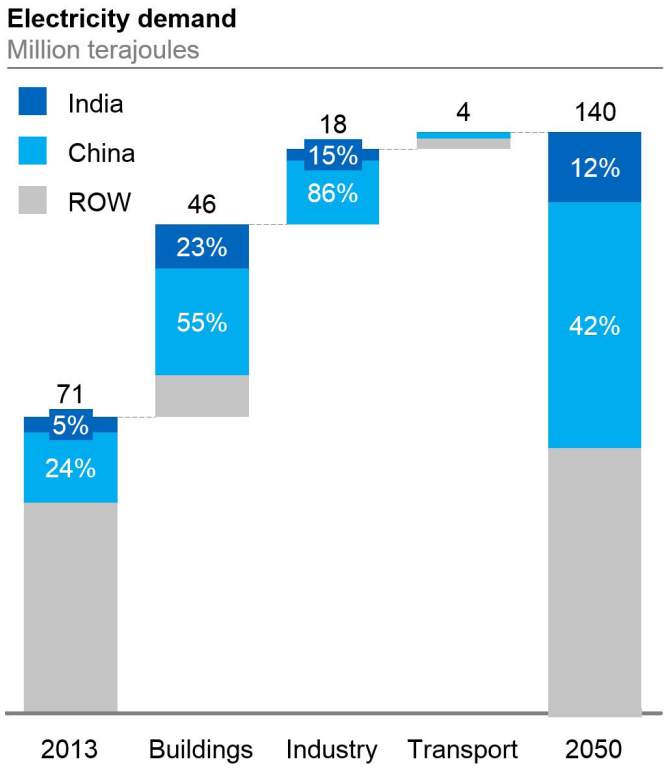
Moreover, affordable, efficient storage could unlock a breakthrough by mitigating the intermittency challenge of renewable energy generation. Lithium-ion technologies, which have progressed the furthest of battery technologies, accounted for 96% of new energy storage deployments in 2015.[19] Lithium-ion batteries can fulfil a wide range of applications, from utility-scale energy storage to residential systems. Many experts agree that a breakthrough in storage would be a key enabler of the energy transition. Several participants in the roundtable discussions voiced scepticism, as for years a breakthrough has appeared to be "just around the corner"; others, however, suggested that new power purchase agreements that bundle battery storage projects could signal that we are nearing a tipping point for scalable financing of storage.

Supportive policies could accelerate the growth of the storage market. In most markets, however, policies fail to optimize deployment of energy storage due to misalignment of incentives to smooth power output, variability and inconsistent application of tariffs, and limited availability of customer and battery performance data.[20] To address the data gap, several roundtable participants suggested that policies creating greater transparency and integration of grid and storage data could enable companies to better identify opportunities to deploy storage technologies.

Further electrification of infrastructure would accelerate the shift to a low-carbon energy mix by enabling a greater proportion of total energy demand to be met by electric power generation from low-carbon energy sources such as solar and wind. Electricity demand is expected to grow at more than twice the rate of other final energy sources (e.g. liquid fuels), accounting for a quarter of global energy demand by 2050.[21] Overwhelmingly, this growth is driven by building and industry electrification in China and India (Figure 4).[22] Electrification presents a significant opportunity for

renewables; however, there are limits as to how much of the current economy can be electrified. Certain energy users, such as the aviation industry, will continue to rely on high-energy density liquid hydrocarbon fuels for the foreseeable future.

Figure 4: Electricity demand growth to 2050 is driven by building and industry electrification in China and India.



Source: McKinsey & Company

Commercially viable emissions reduction solutions – for example, carbon capture, utilization and storage (CCUS) – could enable fossil energy sources to remain a component of the future low-carbon energy mix compatible with climate objectives (e.g. well-below 2°C objective of the Paris Agreement). If the world is committed to driving towards a low-carbon energy mix, fossil energy players will face increasing pressure to exit the fossil energy business or reduce their emissions. In the next two decades, energy companies may be more likely to increase their investment in potential solutions for emissions abatement in response to business, social and political pressure. Government policies or economic incentives, such as a carbon tax, can be effective levers to encourage (or require) more companies to invest in and deploy these technologies. For example, a task force co-chaired by the US Environmental Protection Agency and the Department of Energy in 2010 recommended strengthening federal coordination to achieve widespread deployment of CCUS, adding that a carbon price would be a "critical" enabler.[23]

Potential implications for the energy system

Accelerated maturation and deployment of advanced energy technologies would test the ability of both the energy system and society to absorb change. It could do so in at least three ways.

First, advanced energy acceleration could drive a convergence in the energy system. More companies that today identify as "oil and gas companies" or "power developers" or "technology manufacturers" may increasingly integrate business models as "energy companies". Multiple forces underlie this convergence. Electrification of transport and heating would create a bridge between the oil and gas and electric power sectors, over which both new collaborators and new competitors will cross. Moreover, new technology companies, especially in the power space, are looking for patient capital, which has proven not to fit with the Silicon Valley venture model. In contrast, oil and gas companies have the capital and longer time horizons, and are looking for opportunities to diversify in the face of uncertainty over liquids demand for transport and over broader climate policy. Convergence within the energy system could upend old expectations about competitive advantage, and would require regulatory harmonization across oil and gas and power, which to date have been treated separately.

Second, advanced energy acceleration would "let a hundred flowers bloom" at once. Successive US administrations have adopted an "all of the above" policy on energy technologies, and emerging economies like China and India have predicated their economic development plans on a full menu of fossil, nuclear and renewable energy sources – partly because no one energy source can supply the full magnitude of need without also compromising other priorities like affordability or public health and environment. However, an economy based on so many technologies is unprecedented. The industrial revolution economy was built around steam engines powered by water, wood, or coal. The modern 20th-century economy added oil and gas, augmented by nuclear fission. In contrast, the 21st-century economy could depend, at least initially, on a range of nearly 15 to 20 different technologies (e.g. oil, gas, NGLs, coal, gas, wind, solar, hydro, geothermal, tidal, wave, nuclear fusion, nuclear fission, fuel cells, etc.), not ring-fenced by distinctions of transport, power and other end uses. This could create great uncertainty over allocation of research and investment dollars, as well as complexity in ensuring reliability of supply. Over time, the base of technologies may need to be consolidated.

Third, advanced energy acceleration may transform energy diplomacy. In today's world, energy security derives from access to resources (e.g. physical control or reliable access to coal, crude oil, or uranium), as well as the supporting energy supply chain and infrastructure.[24] In tomorrow's world, energy security may instead come from access to technology. A country may no longer need to enter into expensive agreements with other nations to secure fuel imports, if it can transform its indigenous natural resources into enough power to serve its population's needs. There will be a wider range of technology options to do so; however, countries must be able to access them, either through open markets or by enticing energy companies to make the technology preferentially available and affordable.

Mobility revolution

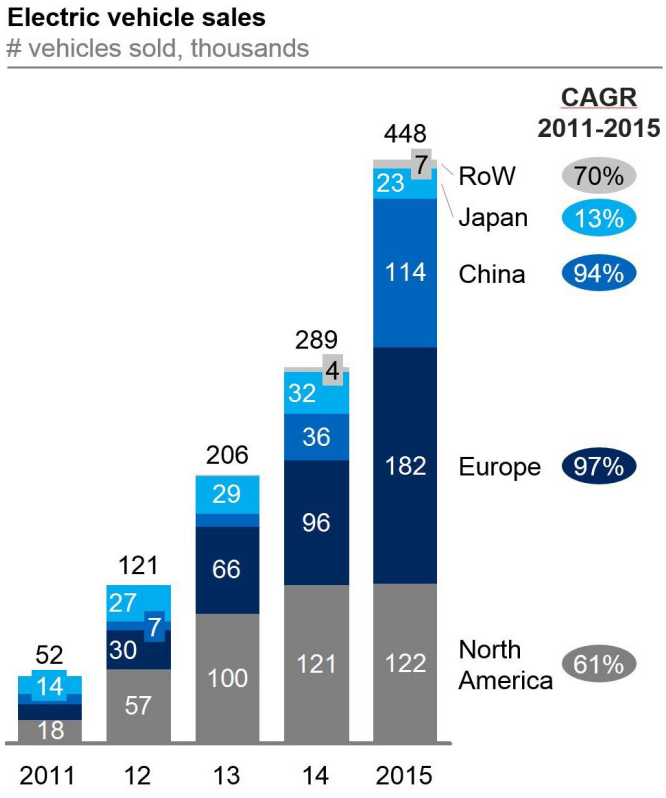
New technologies, new business models, changing consumer preferences and the emergence of cities as the critical hubs of economic activity in the 21st century may come together to change how consumers move around and interact with one another. If adopted at scale and in concert, these forces may create a mobility revolution – transforming how people move, who owns assets, how assets are used, and where money is made. In turn, they could rewire the arteries of commerce and society within leading cities around the world.

Drivers of change

New technologies and business models are poised to dramatically change the face of mobility, and at a faster pace than ever before.

Fuelled by falling battery costs, generous purchase subsidies, fuel economy and emissions regulations, growing commitments from car companies, and rising interest from consumers, global sales of electric vehicles (EVs) have risen quickly over the past five years (Figure 5).[25]

Figure 5: Electric vehicle sales have risen rapidly in recent years.



Source: McKinsey & Company

A recent study on the future of mobility projects that private EVs could become competitive with comparable internal combustion (ICE) vehicles by the mid-2020s on a total cost of ownership basis.[26] An increasing number of EV models are becoming available to consumers, in part enabled by the fact that the average price of lithium-ion battery packs used in EVs fell 65% between 2010 and 2015.[27]

Electrification of transport could have a significant impact on liquids demand. According to a recent forecast, if EVs account for the majority of new car sales by 2035, liquids demand could be reduced by 3 million barrels per day below forecast levels. [28]

In addition, the sharing economy is sprouting many new mobility services and product concepts that have the potential to profoundly change both private and public transit. Shared mobility services are increasing convenience, improving the customer experience and even lowering the cost of mobility. Didi Chuxing, a Chinese ride-hailing company operating in over 400 cities in China, has over 300 million users and provides more than 11 million rides each day in China alone.[29] Uber, by contrast, serves 40 million monthly active riders, spread across more than 500 cities in over 60 countries worldwide.[30] Ride-hailing services are more than just taxi services – they are capturing market share from other modes of transport, such as public transportation. Investment in ride-hailing companies rose from $200 million in 2011 to over $11 billion in 2015. Countries with large numbers of urban commuters, such as China, are experiencing particularly high growth.

Autonomous driving technologies – from automatic assisted breaking to self-driving cars– are also advancing rapidly. A number of car manufacturers expect to launch their first self-driving car models in 2020-2021.[31] Around the world, a handful of cities have launched pilot programmes to test autonomous transportation services – such as driverless buses in Dubai and Lyon, driverless taxis in Singapore, and self-driving Uber cars in Pittsburgh.[32]

Beyond technological advances, another key factor contributing to the acceleration of new mobility models is the rise of cities. As a result of urbanization and population growth, the average density of metropolitan areas is expected to increase by at least 30% between 2015 and 2030 – potentially doubling demand for transportation in these areas.[33] Furthermore, increasing prosperity in emerging economies could result in increasing demand for cars as more people move into the consuming class. As a result, mobility systems are likely to become strained – private car ownership could become less attractive, and consumers may demand different mobility options altogether.

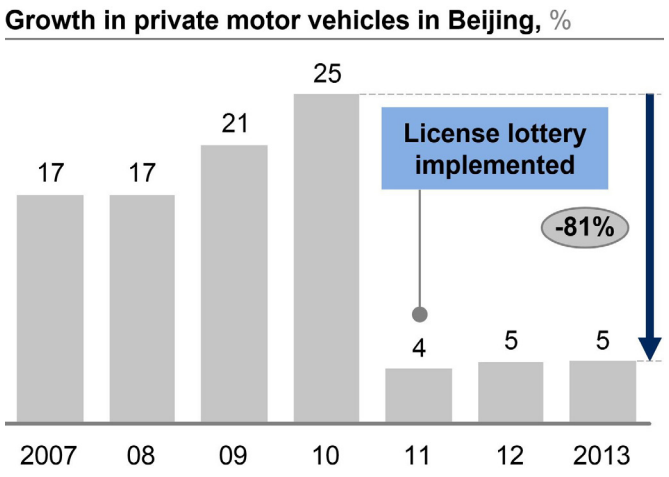
Unlocking a breakthrough

In parallel with continuing advances in mobility technologies, supporting policy efforts could accelerate the mobility revolution and its impact on energy demand.

In the next 10 to 20 years, policies and regulations will be among the biggest drivers that impact mobility and alter the natural course of car ownership and car usage rates. Such policy efforts could accelerate in the coming years, especially in high-density cities where traffic congestion and air pollution are growing concerns. Several cities are proactively focused on shifting consumers away from single occupancy vehicles towards more sustainable modes of transportation such as public transit, biking and shared transportation options. A wide range of policy strategies can be deployed to achieve this. Cities are experimenting with policy levers such as making parking more expensive

or restricted, creating car-free zones in the city centre, implementing congestion charges, and even outright restrictions on car ownership as seen in China. For example, larger cities in China have begun to restrict the number of license plates granted. In Beijing, the introduction of a license plate lottery effectively put the brakes on the growth of China's auto industry (Figure 6).[34]

Figure 6: Beijing's license plate lottery slowed vehicle ownership growth from 25% per year to 5%.



Source: McKinsey & Company

Cities could also play an enabling role in supporting infrastructure buildout required to underpin future mobility systems. Currently, users of shared mobility services use public transport 40% more often than those who do not.[35] As transit becomes increasingly multimodal, with public transit also benefitting from electrification and automation, cities can further enable and accelerate this shift by connecting the fragmented pieces of the mobility network into an integrated whole. The city of Auckland in New Zealand integrates data from business transactions, sensor data and social media feeds with multiple physical security, traffic management control and monitoring functions to manage its transport system on a day-to-day basis.[36] This data management solution was developed in collaboration between Auckland Transport and several private sector partner organizations, providing an example of the role that public-private collaboration can play in helping cities to develop new mobility models. Vietnam provides a similar example, where Da Nang's traffic control centre implemented tools to predict and prevent congestion as part of IBM's Smart Cities Challenge.[37] The real-time traffic data is shared with passengers through video screens at bus stations or via mobile apps.[38]

Several other cities are experimenting with different models to promote seamless, multimodal transit:

- Kansas City partnered with Bridj and Ford in a one-year pilot enabling residents to use an app to reserve seats on one of 10 vans driven by KCATA-employed drivers.[39]
- Pinellas Park, Florida discontinued its two least popular bus lines and now shares the cost of Uber rides for anyone traveling those two routes; commuters received a 50% discount for rides, with a maximum subsidy of $3 per ride to help riders connect to the transit system.[40]
- Summit, New Jersey recently began a pilot programme to subsidize Uber rides rather than build more commuter park-and-ride lots; the programme would save taxpayers an estimated $5 million over 20 years.[41]
- Volkswagen launched Moia, a mobility services company headquartered in Berlin, in December 2016.[42] In addition to ride-hailing services, Moia will begin offering an app-based ride-pooling service using electric vans in 2017.[43]

Not all pilots have been successful. Kutsuplus, a ride-sharing service operated by the Helsinki Regional Transport Authority allowing citizens to hail one of several mini-buses using an app, was shut down after running for more than two years.[44] To achieve sufficient scale required significant public funding that the Transport Authority budget, which was already subsidizing Kutsuplus rides, could not support. City officials ultimately terminated the project in December 2015. However, the pilot successfully met its goal of assessing technological feasibility and user acceptance, as the Kutsuplus system ultimately had 21,000 registered users.

While technological innovation and supportive policies can advance individual mobility trends – specifically, electrification, shared mobility and automation – what is more significant is their combined impact and potential to reinforce and magnify one another. One study estimates that, combined with an increase in vehicle utilization as a result of car sharing, fully autonomous vehicles could reduce the cost of personal mobility by 30-60% relative to private car ownership.[45] Moreover, a mobility revolution could significantly impact liquids demand. A recent study, which estimates that EVs will represent 27% of new vehicle sales in 2035, indicates that the impact of shared and autonomous vehicles could reduce global light vehicles liquids demand by 2 million barrels per day below its business-as-usual scenario.[46] If the decline in the costs of these new technologies were to accelerate, further increasing the penetration of electric, shared and autonomous vehicles by 2035, liquids demand could be reduced by an additional 4 million barrels per day (Figure 7).[47]

In several of the roundtable discussions, it was pointed out that developing countries may follow a different path with regard to a mobility revolution or advanced energy acceleration. These countries will likely need to build new infrastructure to support these potential game changers, providing critical energy and mobility access to the large population entering the consumer class. Leap-frogging to innovative shared mobility models or distributed generation technologies may overcome the lack of existing infrastructure, as mobile phone technology has done in emerging economies.

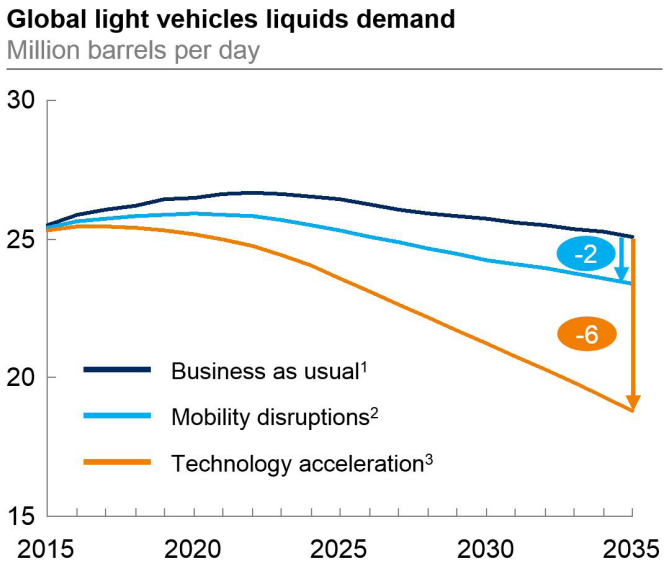
Potential implications for the energy system

A mobility revolution is "revolutionary" precisely because it affects the social geography of a population and how it interacts. As a result, it could result in multiple deep changes.

First, a mobility revolution portends a shift towards a unified "power system". What were once disparate, disconnected segments of the energy system – liquids-fuelled transport, gas-heated buildings, electricity-powered lighting, diesel-

based backup generation – could converge around the electron. Electricity from power plants or rooftops will power homes and charge batteries, which will supply or slot into cars, which will act not only as modes of transport but as portable batteries themselves. Such a power system will change how individuals manage their energy and make transportation decisions, how governments regulate electricity, and how manufacturers design their products.

Figure 7: A shift in the global fleet towards electric, shared and autonomous vehicles could reduce liquids demand by 2 to 6 million barrels per day.



1 Assumes current regulatory and technology developments result in EVs representing 27% of new vehicle sales in 2035
2 Includes the impact of shared and autonomous vehicles
3 Assumes an acceleration in the decline of technology costs resulting in greater penetration of electric, shared and autonomous vehicles by 2035

Source: McKinsey & Company

Second, utilities and automotive companies – not just OEMs, but the whole supply ecosystem – will develop new competencies. Utilities will need to understand a wider range of end uses (e.g. transportation patterns, which differ by time, region and season) and become more dynamic in managing fluctuating electricity supply and demand on the grid. Automotive companies must understand both the technologies and the regulations that govern the electron – a wholly new endeavour for them, far more complex than merely designing and manufacturing electric vehicles. In both cases, this may require a significant change-out in organizational capabilities and backgrounds.

Third, cities will develop new channels for revenue generation. On one hand, cities are becoming the locus of economic activity and decision-making, more so than national or state institutions – this potentially makes city-level revenues more important to support city-level public goods.[48] On the other hand, new business models around electrified transport, shared transportation and automation – and infrastructure investments to lock those choices in – will upend traditional sources of revenue. Old modes of public transit, with fares that filled city coffers, will be supplanted by new ones. Those new transportation offerings may be privately owned and operated. Defining an efficient revenue regime towards new modes of mobility, without hampering them, will be an important part of the future.

Fourth, the electrification of transport will change the route to monetization – and therefore the priorities – of energy companies that focus on liquids. The weight of liquids consumption will shift from transport to chemicals, which are likely to see growth globally and will sustain demand for liquids as a feedstock. As the chemicals market grows in importance, oil companies may restructure themselves to win those markets – for example, consolidating acreage that supports naphtha or natural gas liquids production, re-organizing and re-skilling to better match the needs of chemicals customers, and forming new partnerships or joint ventures to gain competitive edge in chemicals markets.

Energy system fragmentation

The energy system is poised to shift from an era of concentrated power and ownership to one of decentralization, fragmentation and intensified competition. For the past half century, energy markets have been dominated by large players, often national champions, whose scale has been a deep source of advantage. In the future, however, the driving force behind energy market outcomes could be an unpredictable interplay of a far greater variety of smaller and more agile participants, including residential and industrial energy “prosumers” and financial players, competing across increasingly localized arenas.

Drivers of change

Energy system fragmentation is characterized by two increasingly visible features of the energy system: less ability to shape market outcomes and a shift in competitive advantage from scale to agility in an increasingly volatile market environment.

First, although there are advantages to having scale, it is becoming more difficult for large players to shape and manage market outcomes. In oil and gas, for example, the role of OPEC may be changing as member countries compete not only with international oil companies and other large majors, but also with a long tail of decentralized onshore producers making uncoordinated decisions about production (in 2005, there were 26 oil and gas companies publicly traded in North America with over $1 billion in revenue; in 2015 there were 43).[49] In electric power, utilities face disruptors in the form of new and more varied generation sources, distributed generation and new technologies that add complexity throughout the grid. An increasing number of individuals, businesses and cities may own energy assets such as behind-the-meter solar power generation and storage and community microgrids. Both residential and industrial energy “prosumers” – consumers of electricity who also produce it and sell it back to the grid – will likely become an increasing contributor of renewable energy generation to the system. Not only will distributed prosumers form a growing share of the energy mix, but they will also add complexity to the energy system (e.g. additional data, bi-directional energy flows).

The trend towards more numerous, smaller players is partly due to technology. Advances in hydraulic fracturing and directional drilling unlocked the sizeable shale resource dispersed across North America (and potentially other parts of the world). Advances in solar technology and storage have enabled distributed generation, and a wide range of grid and behind-the-meter technologies have enabled power consumers to act increasingly as power market participants.

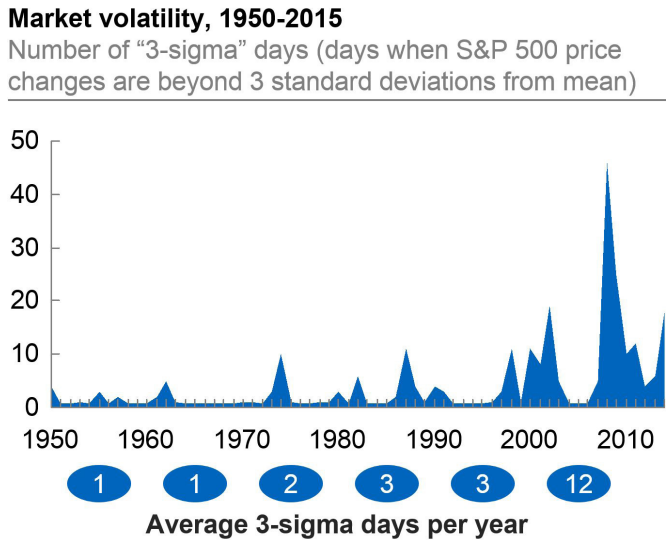
The trend towards more players is underwritten by a proliferation of new sources of capital. Traditionally, the majority of energy market capital has come from either public markets or government support. However, the investor profile is shifting due to increased interest from private investors, such as pension funds and private equity firms. Over the past five years, private equity firms have raised more than $200 billion for energy-focused investments, more than doubling from $26 billion raised in 2011 to $57 billion in 2015.[50] This influx of private equity capital makes it possible for small and medium players to remain capitalized even through tough market conditions and supports the emergence of new business models by matching new ideas with capital hungry for returns.

In parallel, governments have less ability to underwrite their state-linked energy companies (e.g. national oil companies, state-run utilities) or provide preferential economic treatment (e.g. subsidized electricity). The worldwide economic slowdown has dampened governments' abilities to maintain subsidies. In Kuwait, for example, subsidy reductions represent the majority of a 20.7% spending cut in the 2015-16 budget as the government tries to lower the cost of energy subsidies by nearly 35% from $19 billion in 2014-2015.[51] In Saudi Arabia, residential customers received electricity rate increases for the first time in 2016, and water prices rose by more than 400% for the average household.[52] Constraints will only tighten as ageing populations put greater pressure on government budgets. The budgets of NOCs are further burdened by other societal responsibilities. They are sometimes asked to fund and directly support social infrastructure (e.g. schools, hospitals) and regional development (e.g. roads, airports, telecommunications).[53] The burden of these responsibilities may increase as cities grow and government budgets become strained.

Second, the basis of competitive advantage is increasingly shifting from scale to agility – to have the ability to adapt quickly to changing conditions. To be sure, economies of scale still matter; however, the "minimum efficient scale" is smaller than it used to be. For example, as cryogenic technology for liquefaction of natural gas has developed and matured, a growing number of small-scale LNG facilities are being constructed around the world.[54] These facilities provide transportation fuel (e.g. compressed natural gas) and serve end users in remote areas not connected to the main pipeline infrastructure, providing greater agility in the gas distribution network. Particularly in the case of transport fuelling stations, and in regions with vast distances between commercial centres such as Australia, parts of the US and developing areas in Africa and Asia, multiple smaller LNG plants located closer to end users makes more economic sense than fewer plants with larger capacities.

Agility has become more important partly because world markets, and therefore the end-use markets for energy, have become more volatile (Figure 8).[55] In the face of greater uncertainty, it can be risky and, over time, value destroying to bet billions of dollars on assets that must live productively for 30 years. In contrast, agility – small initial footprints, investments in real optionality to monitor markets for a couple years before deciding how best to grow, the capability to rapidly adjust – is a better fit for a highly volatile world.

Figure 8: Market volatility has increased over the past several years.



Source: McKinsey & Company

In addition, agility becomes critical when competitiveness in the energy system increasingly depends on local differentiation. In oil and gas, neither country strategy nor even regional strategy is enough – basin strategy is what counts. It is not surprising that oilfield services companies organize their offerings at a basin-by-basin level, with tailored options in the dozens. In power, strategies are becoming nodal, with differentiated approaches at the level of sub-stations, nodes and even feeders.

Unlocking a breakthrough

Energy system fragmentation is already in motion. Whether it proceeds fitfully or accelerates forward depends on three factors: organization, digitalization, and technological and regulatory enablers.

First, energy companies – especially incumbents – must fundamentally reorganize to be agile. This is true across structure, process and people. Today's energy organizations reflect the logic of a large-scale world: tall hierarchies, organizational alignment against large geographies or rigid functions, greater focus on process excellence than dynamic action. Future energy organizations must support agility, combining dynamic capabilities (e.g. fluid teams, loose hierarchies, rapid prototyping, instant feedback) with a stable backbone of core processes and cultural norms.[56] Capital allocation processes must be revised to

accommodate smaller investments at faster cycles – subject to more flexible criteria than the "big capex" model allows – with continual monitoring of market conditions in order to decide which "options" to take. These organizations must be composed of people who are trained to solve problems, not just run processes, and who are comfortable changing course quickly. An important consideration highlighted in the roundtable discussions was the need to adapt the existing talent base to an increasingly volatile world, ensuring flexibility of the workforce and building the right skill sets and mindsets. Changing the culture and mindsets of large organizations, however, will not be easy, and building a flexible workforce will likely require ongoing retraining.

Second, energy companies must deeply integrate digital tools to make agility practicable. Currently, many energy companies talk about going "digital", but have yet to embed digital tools into their core work processes – a shift that has fundamentally changed other industries such as retail and financial services. Localized competition, however, demands extensive use of digital tools to make the business manageable. For example, power companies devising node-by-node strategies need node-by-node information as an input, as well as the ability to manage multiple services, remotely and onsite, differentiated to each node, simultaneously. Similarly, oil and gas companies will need to use increasingly granular, diverse, and sophisticated data to understand the subsurface of where they play, and service companies will need to tailor their equipment and service offerings to match basin-by-basin needs. With current systems, this would be unwieldy at best; for many companies, impossible. With emerging digital technologies, this becomes manageable. Technologies range from advanced analytics to virtualization and automation to blockchain applications that could make coordination seamless and instantaneous across multiple value-chain actors.

Third, regulatory and technological enablers will be important in laying the groundwork for all industry participants. Energy system fragmentation puts stress on existing systems and rules. For example, the proliferation of onshore oil and gas producers in North America is testing the limits of existing regulatory structures around drilling, permitting, water disposal, and public health and safety. Similarly, the expansion of distributed power generation has created debates about net metering policies and how to equitably pay for the grid. Moreover, managing distributed resources will require investments and upgrades to the grid, including new technologies to manage flows and ensure reliability.

Potential implications for the energy system

Energy system fragmentation will have profound effects for companies and policy-makers alike. First, it makes strategy development for companies and policy development for regulators more difficult because it increases the complexity of the present and shortens the horizon of the future. With so many players interacting with each other, in different ways at different localities, value will be dispersed across a fractured chain of activities and risks may be hidden in the interstices. In turn, the future will be more difficult to predict as fewer investors make multi-decade capital commitments; the norm will be smaller, shorter investments in which energy companies engage real options – choosing forks in the road – every few years. Coherent competitive strategies or public policies will require threading together an extraordinarily tangled, detailed web of inputs and probabilities. Collaboration across all stakeholder groups will be essential to tackle many of these topics effectively.

Second, energy system fragmentation may generate more partnerships. Partnerships are already a way of life in oil and gas, where companies split the cost and risk of large capital assets such as deepwater and LNG facilities. A natural assumption would be that smaller, less concentrated, more optional assets would lessen the need for partnerships by lowering cost and risk; however, the need may actually increase. More fragmentation may demand more coordination to get things done. Electric power provides a good example – utilities would need to coordinate with a wide range of fossil and renewable power generators, some of which are distributed generators selling surplus power onto the grid, and in turn coordinate with a more varied set of technology providers for the grid as well as behind-the-metre (e.g. energy efficiency and demand management technologies adopted by electricity consumers). Similarly, each oil and gas basin may represent a unique constellation of leading acreage holders, equipment suppliers, service companies, capital partners and other stakeholders, thereby driving partnerships to the basin level and away from the global level. In these new partnerships, risks may be distributed differently, and new actors may become the key players.

Third, energy system fragmentation could change how governments pursue energy security. Today, governments can be directive. Since the 1970s, OPEC has been able to shape oil prices due to the large share of supply under its control. Several OPEC member countries as well as Russia, China, Malaysia, Brazil and others have large oil companies that are either state-owned or state-backed and are often used as instruments of state policy. Across Europe and Asia, electricity is provided by large utilities closely aligned with governments. In a more fragmented system, however, governments may have substantially less control over outcomes. They must learn how to be shapers, using policy to nudge behaviours or empower national companies to compete in a more open market, and become more comfortable using market mechanisms instead of government deals to secure energy supply.

Fourth, energy system fragmentation could lead to the formation of several localized energy systems surrounding dispersed poles of economic activity. As economic activity becomes centred around mid-tier cities around the world, fragmentation allows for these smaller energy systems to be tailored to local needs. Therefore, local communities may have much more say over the composition of their energy mix, how it is provided to them and what policies will guide their energy system.

Finally, if energy system fragmentation accelerates, there is a risk that large-scale players will struggle to keep pace if they do not adjust quickly. However, smaller players that are already agile may eventually have to contend with large-scale incumbents with much deeper pockets after they adjust to the new landscape.

Conclusion

The potential game changers in the energy system, if they come to pass, will sow significant changes in business models, regulatory requirements, private and public funding, and national economic and security policy. Business and policy leaders should consider their answers to a set of forward-looking questions ahead of the change. Communities and individual households should also consider the impact of their choices as new technologies and business models empower consumers to become more active participants in the energy system.

The questions that will truly define business decisions, policy prescriptions and household choices necessarily vary sector by sector, issue by issue. It is worth considering a few overarching questions that hold true in general.

Questions for incumbent businesses

- **Where will certain industries begin to collide and converge with others in the energy system?** As dividing lines within the energy system start to dissolve – for example, as electrons become the shared unit of lighting, heating and transport – energy companies need to anticipate competitive effects on their traditional markets.
- **How do businesses build real optionality into their strategies to navigate a highly uncertain future?** The degree of change, uncertainty around technologies and policies, and increasing number of moving parts in the energy system makes the future ever harder to read. As a rule, strategies built on real options will become crucial versus the typical practice of making large bets.
- **How do businesses harness core competencies to pivot into new or changing sectors?** Today's core competencies will be important as a springboard to lead tomorrow's sectors – incumbents should think creatively about how they can be applied. Even more importantly, companies should consider what core competencies will truly differentiate them if these game changers come to pass.
- **How radically do businesses need to reorganize or revamp their organizational capabilities?** Agility, flexibility and fast decision-making could become crucial, especially as value pools and competition become increasingly localized. Moreover, as sectors within the energy system rub against each other and converge, new capabilities beyond the "stovepipe" of a given industry will be needed; incremental organizational change may not be enough.
- **How can businesses use M&A or R&D dollars to gain a foothold in new, unfamiliar, but potentially breakthrough sectors?** Investment allocation must become more strategic, and less opportunistic, as incumbents plot a course to participate in the energy growth vectors of the future. Corporate investments in disruptive companies, creative deployment of research dollars not only internally but with universities and start-ups, and other steps could be important – but they represent new territory for many large energy leaders today.

Questions for new entrants

- **How do new entrants tap into new sources of capital to ensure their businesses reach "escape velocity"?** Established Silicon Valley venture models and their "fail fast" approach have not succeeded in energy, given different time cycles, capital outlays and requirements to scale. Other sources of capital, using structures tailored for the needs of energy companies, will be critical. Much of this capital may come from other parts of the energy system itself.
- **How do new entrants find a competitive foothold in an increasingly integrated system?** The trends behind the potential game changers suggest convergence across the energy system. In response, we are already seeing increased integration within sectors (e.g. oil and gas equipment and services companies) and tentative integration across sectors (e.g. European oil and gas companies taking major stakes in electric power). New entrants will face highly scaled, diversified incumbents, even more so than today. They must either find niches to survive independently or find ways to join hands with an integrated player.
- **How do new entrants achieve "localization at scale"?** Competition could become increasingly local – locally focused, locally tailored. The wide reach and deep pockets of large incumbents may give them an advantage in "localizing", despite their typically heavy organizations – they have the scale and resources to tailor offerings to multiple markets at once. Smaller, newer companies will need to find alternative methods – potentially through digital technology – to grow across several markets while maintaining local differentiation.

Questions for political, policy and regulatory institutions

- **At a city or regional level, how do governments ensure energy-related infrastructure and regulatory choices work together?** The coming years could see a vast amount of infrastructure spending, not least as both leading and emerging global cities lay the foundations for their future success. Local choices about which transportation technologies and business models to support, through investment and regulation, will set the contours for energy use for much of the world. The more those choices interplay with each other – for example, electrified public transport with automation – the greater their impact.

– **How do governments anticipate technology and business trends in making infrastructure choices?** The infrastructure decision made over the coming years could potentially lock-in energy patterns for decades. Yet we face an uncertain time, when dozens of energy technologies and new business models are in contention and flux. It is unclear which will emerge as leaders. Policy-makers need to find ways to anticipate the trends, or create optionality to wait and see.

– **At a country level, how do governments ensure energy security?** Access to resources will continue to be important, which means geography will matter as well. Nonetheless, as new energy sources proliferate, the basis of energy security will come not only from resource access but also – maybe even more importantly – from technology access. Governments must decide how to use trade and investment policy to create that access.

– **How should government funding be managed and prioritized to unlock the most energy potential?** There exists a large menu of opportunities within the energy system that could enable game changers, but may require government support – at the same time that many governments will find public treasuries under growing strain from competing demands, such as aging populations. Governments will need to prioritize ruthlessly where they deploy funds into the energy system – to those areas likely to have a multiplier effect.

– **How can required government revenues be sustained as the energy system changes?** A large proportion of government receipts, at all levels of government, comes from taxes, royalties and other payments from the energy system. If these game changers come to pass, value pools will shift dynamically around the energy system. Wells that once were a rich source of public funds, to support important public purposes, may dry up. Governments will need to watch changes in the energy system closely, and adjust their revenue models with a commensurate dynamism.

Questions for communities and households

– **How should communities balance the trade-offs between energy access, affordability and environmental impact?** Energy system fragmentation, new technologies and a growing number of transportation options increasingly empower communities to decide what their local energy system should look like. With that power comes the need to decide upon local priorities. More affluent communities may be willing to pay more to adopt new energy technologies that are better for the environment, while cheap fossil fuel energy may be more desirable in low-income or developing areas, and communities without grid access may prioritize distributed generation.

– **How do individuals become "energy literate" as energy decisions overlap with basic household choices?** Energy is becoming increasingly integrated into consumer-oriented products and services, and beginning to overlap with household choices such as what car to buy, or how to regulate home heating and cooling. As energy decisions weave more into the fabric of daily life, individual consumers will need to develop energy literacy to understand and choose among a growing set of options as part of their household planning and decision-making.

The energy system is likely to undergo great change in the coming years; this is widely appreciated, almost a commonplace view. However, the streams of change are rarely brought together into a coherent whole. Those streams come together in three themes – advanced energy acceleration, mobility revolution and energy system fragmentation – that could grow in speed and force into a torrent. The future is not far off, and participants in the energy system must begin integrating these potential game changers into their thinking, their planning, their investments – not in some unforeseen distance, but today.

Contributors

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World Economic Forum

Roberto Bocca, Head of Energy Industries
Pedro G. Gómez Pensado, Head of Oil & Gas Industry
Bandar Alkhamies, Manager, Knowledge Management and Integration

McKinsey & Company

Thomas Seitz, Senior Partner
Nikhil Patel, Partner
Kassia Yanosek, Associate Partner
Ann Hewitt, Project Manager seconded to the Forum

Endnotes

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World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744

contact@weforum.org
www.weforum.org