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Rapporteur’s Summary

Marika Nell, PhD Student in Environmental Engineering
Cornell University Graduate School

The views expressed here are not the author’s, rather the rapporteur’s effort to reflect the discussion.

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The Aspen Institute’s Congressional Program convened a conference in Oslo, Norway from August 9-15, 2017, to consider the topic of Energy for America: Opportunities, Challenges and Solutions. Twenty-one members of Congress engaged with a dozen American and European scholars on a number of policy issues pertinent to U.S. energy needs. Both the Norwegian Minister of the Environment and Foreign Minister addressed the conference, as well as two high-level officers of major international oil companies.

The conference began with discussions on Norway’s unique energy situation. While more than 95% of the country’s energy supply is met using clean energy technology primarily from hydropower, a majority state-owned oil company has the largest sovereign wealth fund in the world, funded by revenues from offshore energy production. As the week progressed, members were able to discuss a broad variety of topics including the trends in energy and technology, the role of research and development, and the international framework for energy policy.

How a Major Oil Company Positions Itself in a World of Uncertainty

Statoil is an international player in the oil and gas industry, producing 2 million barrels of oil equivalent per day. Although 67% of Statoil shares are owned by the State of Norway, over half of the company’s production comes from sources outside of Norway. As a company, Statoil has a vested interest in U.S. policy, with 270,000 barrels of oil equivalent produced in the U.S. from the Eagleford, Bakken, and Marcellus shales and offshore production in the Gulf of Mexico.

Statoil currently operates under the assumption that peak global demand for oil will occur in the 2030s. With this in mind, it positions its business to include a “cost-competitive renewable business and carbon-competitive non-renewable business.” Currently 64% of oil is consumed by the transportation sector. While this will likely change with the adoption of electric vehicle technology, heavy duty vehicles and heating will still require oil and even maintaining current levels of production is an enormous challenge. Statoil examines projects with a time horizon of 30-50 years and assigns a price of $50 per ton of carbon dioxide in its economic modelling to encourage implementation of projects with lower emissions. Statoil’s rate of generation of emissions is at 10 kilograms (kg) of carbon dioxide (CO_2) per barrel, much less than the industry average of 17 kg of CO_2 per barrel.

Despite its footing in the oil and gas industry, Statoil is committed to expanding into the renewable energy sector. In some respects, development of renewable energy sources is a key tool in overcoming the greatest threat to its business model: the volatility of oil prices. Company policy requires that 25% of Statoil's research and development (R&D) will be spent on new energy solutions by 2025 and it is leveraging knowledge of offshore technology to implement offshore wind power. It currently operates a carbon capture facility in Norway and recognizes the potential for energy storage such as batteries to play an increasing role in the future of the grid. Statoil will have 80% of its capital invested in fossil fuels in 2030, but this will still be in accordance with the international Paris climate agreement, and it intends to be among the lowest in emissions. Norway runs on 98-100% green energy, so the biggest reduction in greenhouse gas emissions comes from switching to electric vehicles, which is incentivized through tax abatement by the Norwegian government.

Regarding energy policy, one industry representative noted that it is easier for companies to operate with one federal regulation instead of a patchwork of state regulations. Although some regulations passed by the Norwegian government were met with resistance, these regulations have ultimately inspired innovation to reduce carbon emissions. For example, when Statoil was required to reduce flaring on offshore rigs for the sake of methane emissions reduction, this spurred technology development and improved operations. Due to expanding pipeline networks for export and the implementation of reinjection to improve production, this encouraged the company to extract more oil and reduce downtime on those rigs.

Infrastructure development is necessary for both natural gas production and renewable development. With natural gas, this may take the form of pipelines and for renewables, this may be transmission lines. From a security perspective, one scholar noted that the volatility in oil producing regions of the world will only increase as climate change impacts these areas. If the Western countries reduce their dependence on Middle East oil, it will intensify the conditions in the Middle East and could exacerbate immigration problems that already exist in Europe. Both physical and cyber security of company assets takes on increasing importance.

Trends in Energy and Technology

In this session, conferees discussed the broader trends pertaining to energy and technology including the status and prospects for oil, natural gas, coal, nuclear, energy efficiency and renewable energy technologies. One scholar contended that, when it comes to energy technology, the world is entering a strategic inflection point due to 3 “Ds”: diversification, digitization, and decarbonization.

With respect to diversification, there are many energy options available to consumers in modern times. In recent years, the century long run of traditional thermal power plants as a dominant source of energy has been disrupted by the unconventional shale gas revolution. This revolution allows the U.S. to keep and foster a regional approach to energy, which is advantageous when compared to the rest of the world. The application of hydraulic fracturing in this context is relatively new and, while it is already an example of government-funded research resulting in a revolutionary and disruptive technology, more R&D is required to further reduce costs. If implemented in a manner that was careful to limit fugitive methane emissions, the use of natural gas could reduce greenhouse gas emissions when compared to other fossil fuels. Meanwhile, renewable energy sources such as solar and wind and energy efficient technology such as LED light bulbs have also become more cost effective. However, these improvements have come after decades of R&D, highlighting the need for similar funding for technologies that are in earlier stages of development. For example, long-haul transportation (such as planes and trucks) must have liquid fuel, which currently makes this portion of the transportation sector dependent on oil. With more R&D, this oil could be replaced with biofuels. As one scholar pointed out, the U.S. needs to create a competition of ideas across the spectrum of energy technologies. Having a portfolio of options is necessary so that the whole portfolio succeeds even if individual projects might fail.

With respect to digitization, automation has increased efficiency and decreased costs across many industries. With respect to energy, this has resulted in an unprecedented level of automation in oil and gas extraction. Advances such as semi-automatic trucks have also been heralded as efficient, but it is necessary to be careful of the impact of job loss associated with these new technologies and programs must be in place to help transitions into different workforce solutions. The increased level of digitization also warrants increased awareness of cybersecurity.

Regarding decarbonization, the tipping point where clean energy will become economically feasible on a wider scale is approaching. According to one scholar, reaching this point is certain, and the only questions remaining are how quickly it will happen and what role the U.S. will play in its arrival. Thus far, the energy sector has consistently underestimated the growth in solar power because it is not accustomed to rapid development of technology. However, renewable energy and energy efficiency technologies—such as solar panels and batteries—can transform rapidly and the cost is driven down as production increases, in accordance with Wright's Law, which states that the rate of progress is dependent on the volume of a technology produced rather than the length of time since its inception. This is in stark contrast to energy production of the past because commodity prices are volatile, exhibiting no direction or trend. Thus, the price of coal today is roughly the same as it was in 1900 and it has not delivered long term price declines to consumers.

However, the question remains—when will clean energy match fossil fuels in economic feasibility? According to one scholar, the cheapest energy supply in the U.S. is natural gas, but solar and renewables are projected to start surpassing natural gas for new projects in the early 2020s and existing projects in the late 2020s. In the transportation sector, decreasing battery prices should help make electric vehicles cheaper than combustion vehicles by the mid-2020s. However, many scholars contended that to achieve this and in order to make the U.S. a leader with respect to energy technology, robust R&D is necessary.

Across all relatively new technologies, R&D creates the option space for the future; without it, competitors and other countries are able to hold the U.S. hostage. In order to stimulate this R&D, a vigorous private sector and smart public policy is required. Many participants expressed concern that China is now investing much more in R&D as well as manufacturing. While China does not have the R&D infrastructure that the U.S. has today, it certainly will in the future and could eventually outpace the U.S. An argument was made that it is critical that the U.S. government be willing to take on high-risk research because this research has the potential to develop disruptive technologies, but due to the level of risk, this approach is antithetical to what industry practices.

A suggestion was put forth for removing tax breaks and subsidies received by oil and gas companies in order to level the playing field with clean energy, while others called for the elimination of all energy subsidies—both explicit and implicit. In the future, savings from these diverted subsidies could be utilized to invest in clean energy R&D and to help transition coal industry workers to new industries.

International Framework for Energy Policy

The international framework for energy has changed dramatically in the last decade. The power of the Organization of the Petroleum Exporting Countries (OPEC) has been diminished by the upsurge in U.S. oil and gas extraction brought about by the widespread implementation of horizontal drilling coupled with hydraulic fracturing—technologies that have allowed the U.S. to become a major energy exporter. This dramatic change now casts the U.S. and Russia as two of the world's key energy players. The amount of natural gas production now taking place in the U.S. has decreased the price of natural gas considerably, shifting the U.S. from being a potential importer to now being an exporter of liquid natural gas (LNG). This change in the international energy picture also has significant foreign policy implications, by lessening U.S. dependence on Middle East oil and giving European countries, Japan and South Korea an alternative to Russian natural gas. In the geopolitical energy competition, there are three dominant forces: U.S. LNG, Russian pipelines, and solar panels from China, which have driven down the price of solar globally. In order to maintain the U.S. position as a key player, investment in renewable energy sources is necessary so that U.S. energy sources can compete with China.

The Paris climate agreement has also contributed significantly to changes in the international energy framework. With pledges from 152 countries, policies in pursuit of sustainable development goals are now the common guideposts in most countries. In many cases, striving for long term reductions in greenhouse gas emissions has worked hand in hand with economic development and has not put businesses at a competitive disadvantage. In Germany, for example, 400,000 jobs have been created in the renewable sector with at least two thirds of these expected to be long term due to maintenance and growth.

With this changed energy equation, questions were raised regarding government subsidies and treatment of each technology. It was argued that tax treatments offered to companies engaged in fossil fuel extraction should also be made available to those pursuing renewable energy. Currently, solar and wind companies are largely structured to incur more expenses, destabilizing the industries. Instead, it was proposed that these companies should qualify for master limited partnership status, like oil and gas companies, so that they could provide stable cash flows and attract institutional investors such as pension funds.

As digitization revolutionizes the energy sector and sources of power shift, the impact of these dramatic changes on rural communities and workers must be considered. It is important to work with rural communities, as one scholar suggested, to develop new visions for their future. Training programs are needed to adapt the workforce to new technologies and the expansion of broadband into these communities would allow them to participate in the digital economy. As traditional industries such as coal mining decline, there is space for growth of digital industries and the renewable energy industry in these same communities and they should have the opportunity to be participants in the change. As one conferee noted, four Republican governors have expanded rural development for renewables. While it did not create immediate jobs, it does augment income and it can create jobs in the long term if the demand for installation continues. For example, farmers in Wyoming can increase their income by as much as 50% by allowing 5% of their land to be used for the installation of a wind turbine.

Developing Effective and Efficient Energy Policies

The energy sector is inherently a technology-driven business, so the progress of technology creates the options and links it to Wright's law as discussed above. Energy projects typically represent massive capital investments with long time frames. For a conventional power plant, that may be 40 years while a building is meant to last for 100 years.

Today, the U.S. needs to perform a multi-objective optimization to find solutions that enhance the reliability, affordability, security and cleanliness of the energy sector. In order to do this, it was argued that policy must be driven toward explicit and specific goals without being set on a specific technology type. This approach allows the free market to drive down the technology's price, prompting researchers to finding new solutions. In order to keep policies from having only short-term impacts, it is important to set standards to encourage continuous improvement. For example, in California, a cost-based analysis is performed and economically feasible technologies are added to the building code every three years. Instead of plateauing like a set technology standard might, this approach continuously strengthened standards and now new houses in California use 75% less energy than they did at the beginning of the regulation.

Due to the capital-intensive nature of energy projects, it is economically efficient to reduce the risk of a project because risk influences the cost of capital. If regulations can reduce the risks for industry through measures such as pre-zoning land to streamline the permitting process or encouraging power purchase agreements, governments can cut the capital required for a project by 50% and encourage project construction within their municipalities.

Every technological advancement today came about from significant public-private partnership (whether formal or implicit). U.S. research universities are unparalleled in the world, and those universities, along with the government-supported national laboratories, provide a wealth of resources for research and for prototype development for smaller companies. In order to effectively harness this potential, one participant observed that a whole ecosystem must be built to encourage private-public-academic collaboration.

For many policy makers, the question of energy policy is inextricably entwined with morality while others believe that purely economic arguments should be made. Those guided by moral reasons largely cited bequest values, values of preserving the environment for the next generation, which are not accounted for in the free market. Several conferees noted that it would be more productive not to debate morals or science but the policy because this does not require upfront agreement in other areas. From economic and security perspectives, overhauling the energy sector makes financial sense. With these interests in mind, funding for more R&D and adding tax incentives to get the private sector to utilize new energy technologies are necessary steps for maintaining the U.S. position as a leader of innovation.

Several participants noted the need to change eminent domain laws to ensure that critical interstate energy infrastructure can be built. This would make it more difficult for single property owners to delay the transfer of interstate fuel or power. These members and several scholars raised concerns about the ability of states to impede the development of infrastructure such as natural gas through pipelines using state permitting processes.

Making the Future Grid More Reliable, Cleaner and Affordable

This session focused on lessons learned in the operations of California's power grid. California was chosen as an example because it has aggressive environmental and energy standards, resulting in 30% of its electrical load being supplied from renewables. One scholar noted that California alone has solar/renewable sources that equal as Nevada's entire electric load. This widespread implementation of renewable energy has led to two phenomena: higher ramps and over-generation. Higher ramps describe the trend where the running of appliances in the evening generates additional load just as generation from solar is winding down. This discrepancy needs to be corrected quickly and can be accommodated with natural gas plants. In over-generation, renewables such as solar generate more power than is being used. This can result in negative pricing and provides cheap, plentiful clean power. Due to these challenges and others, it is critical to harness policy to thoughtfully integrate renewables into the grid. There is a need to manage demand to encourage consumers to run appliances during times of plentiful power. This would minimize the need to burn natural gas when renewable energy cannot meet the demand and can be encouraged through pricing.

Another necessity, according to one scholar, is the regionalization of the markets for the benefit of all customers. Currently, there are 38 balancing authorities in the west, which leads to too many tolls and impedes the sharing of power. In contrast, the Midwest is covered by one. The ability to build transmission lines across jurisdictions is also key to this effort, but it is hindered by bureaucratic processes of various federal government agencies. One scholar noted that there also needs to be a change in how people pay for power. It is currently volumetric, but with the advent of "prosumers" (customers who also produce power), the system should be altered so that everyone tied to the grid pays for the necessary infrastructure.

Scholars discussed the merits of other renewable energy sources and battery storage as an alternative to natural gas for overcoming the ramping challenge. Natural gas plants are advantageous due to their flexibility and ability to ramp quickly. Geothermal is historically more expensive than wind and solar and less flexible than natural gas, although it is becoming more flexible due to technological improvements. Bioenergy plants could utilize waste from forests and are flexible, but are typically more expensive than natural gas as well. Finally, battery users could store electricity during periods of negative pricing and sell it back to the grid during ramps.

The grid, by and large, is the most economical way of sharing resources and storing energy at this point in time. Regionalization would only strengthen this network by allowing under-utilized plants to provide power to a broader array of users. Even with negative pricing in play, clear pricing signals encourage quick reaction from users, especially those using storage, and the response restores positive pricing. Meanwhile, "smart" home technology (which can be remotely controlled to reduce energy use when homes are unoccupied), including thermostats and appliances, can be used to capitalize on this pricing and optimize energy use, enabling a more efficient grid. According to one scholar, improved energy storage combined with "the internet of things" can serve as a disruptive technology for the power industry and may ultimately reduce the need for large power plants and lines, resulting in a phase out similar to landlines after the advent of cellphones. Multiple scholars emphasized that developing these technologies is critical to ensuring efficient grids of the future.

Security concerns were also addressed. As the grid becomes more digitized, it becomes more efficient but also carries with it a greater risk of cyberattacks. According to a grid operator, the systems are probed by hackers. In order to prevent a breach, they perform phishing tests every month and punish employees who fail.

Finally, one scholar purported that the keys to an efficient grid would be clearing the way for more transmission lines and implementing efficient practices such as pre-cooling skyscrapers by 3-4 degrees when anticipating surges in power use due to air condition or heating water during the day when excess renewable energy is available. Moreover, utilizing a mix of renewable energy sources including west-facing and south-facing solar and many kinds of wind, stitched together, would make power supplies more predictable and smooth overall. With the implementation of regionalization, efficient practices and renewable energy, there may not be a need for as many natural gas plants to be constructed and the existing ones could be used optimally. Several noted the need to reform the federal permitting process.

Transforming Vehicles and the Energy Needs of Transportation

For a long time, one scholar noted, the transportation industry has focused on incrementally improving the internal combustion engine, but there is a demand for more efficiency now as well as new technologies such as electric and autonomous vehicles. Vehicle emissions standards are key in promoting these changes. Most of the world's motor vehicle emissions standards emanate from California, and then flow to the rest of the U.S. and then Europe and the world because California adopts technology-forcing regulations. This has been seen in the past with the advent of the catalytic converter. Today’s societies must ask themselves how the same rapid advances can be achieved through policy solutions.

The conferees also discussed “Dieselgate,” which has highlighted deficiencies in European emissions requirements. Although the defeat mechanisms were illegal by U.S. standards, nearly all diesel cars sold in Europe over the past several years have had software that would constitute an illegal defeat device in the U.S. Despite this loophole in emission standards, one scholar noted that air quality in all German cities would typically meet U.S. air quality standards, except for a few instances were nitrogen oxide (NO_x) levels were too high. In the newest diesel and gasoline cars, there is not an issue of pollution except for carbon emissions. Particulates are no longer an issue due to trap-particulate filters and NO_x is removed by selective catalytic reduction technology. However, everything older than a few years is making a contribution to environmental pollution and each of these vehicles is used for at least ten years. To solve this problem, the German government and auto industry will be offering incentives for consumers to purchase newer vehicles and take older vehicles off the road.

An industry representative discussed targeted expansion of electric vehicles, stating that at least one major automaker will have 25% of the fleet of new cars sold worldwide in 2025 as electric vehicles, with a goal of 50% by 2030. In general, the auto industry faces challenges in marketing electric vehicles due to cost, range and lack of infrastructure for charging. Cheaper batteries with higher capacities are necessary for overcoming these challenges.

Autonomous technology holds great promise with respect to reducing accident rates and improving efficiency of transportations systems, but poses regulatory challenges. Technology entrepreneur Elon Musk has speculated that almost all cars sold in 10 years will have autonomous features. Most traffic deaths today are caused by human error, resulting in significant loss of life and over $10 billion in annual damage to public highways. While autonomous technology can remove this element of human error, concerns were raised about ethical quandaries. According to an industry representative, the notion that the "algorithm decides who lives and dies" is unfounded because accident data suggests that the dilemma of an unavoidable sacrifice does not exist. These vehicles will always be programmed to follow traffic laws and avoid the pitfalls of human drivers such as distracted driving and delayed reaction times. Even semi-autonomous features such as automated emergency braking can result in 70% fewer rear-end accidents even at low speeds.

However, while autonomous technology could utilize more efficient traffic routing, one scholar noted that the environmental impacts are less certain. Autonomous technology could result in more cars being on the road, much like the increase in vehicle miles traveled that was observed due to the emergence of Uber, Zipcar and similar companies. It is necessary to integrate this technology with existing public transport to reduce emissions and lessen congestion.

Questions were raised about the use of both autonomous and electric vehicles in rural areas. With respect to autonomous vehicles, maps of rural roads may not be as detailed and connections to servers may not be reliable. Scholars pointed out that rural residents have the most to gain from autonomous technology because they are forced to drive longer distances and that the technology can compensate for poor maps and connectivity. Military development has resulted in algorithms capable of detecting and mapping dirt roads. With respect to connectivity, autonomous vehicles would be able to function even without being connected to a server at all times.

Conversely, concerns were also raised about implementing these technologies in urban areas. Urban areas would benefit from the reduction in emissions prompted by electric vehicles and the reduction in congestion due to autonomous vehicles. One scholar noted that re-directing ten percent of vehicles prior to the formation of a traffic jam will prevent the bottleneck entirely. But, once it is formed, a traffic jam cannot be stopped. The issue of security and the possibility of weaponizing of autonomous cars was also raised. In order to avoid this, scholars noted that cybersecurity initiatives and maintaining up-to-date software would be imperative.

As the U.S. transitions to autonomous and electric vehicle technologies, it is important to consider secondary impacts. For example, revenues from speeding tickets may decrease if autonomous technologies only allow vehicles to travel at the speed limit or below, requiring the exploration of other sources of revenue. Moreover, there are 1.7 million truck drivers and 1.8 million taxi and bus drivers in a population of 328 million. Programs will be necessary to help those drivers whose employment will be rendered irrelevant with the advent of these technologies. It was suggested that these programs could take the form of community colleges offering courses targeted at training truck drivers to install charging stations for electric vehicles, as one example.

A representative of the automotive industry stated that industries need clear and predictable regulations that are technology neutral. In this age of rapid technological developments, new and better ideas that cannot be anticipated develop quickly and, thus, technology-specific regulations could quickly become outdated. Standardization of regulations is also critical to maintaining lower costs because it allows manufacturers to have a more streamlined, efficient design process.

Currently, the U.S. has the farthest-reaching fuel economy and greenhouse gas emission standards—but they expire in 2025. The U.S. Department of Transportation (DOT) regulates fuel economy and is restricted to setting five year standards while the U.S. Environmental Protection Agency (EPA) regulates greenhouse gases and has set standards through 2025. These timelines prevent a harmonized program, and one scholar speculated that this may result in weaker federal standards from the time period 2022-2025 due to the roll back of DOT standards in 2021. It is possible that California would continue to move forward with stringent standards, creating a schism between California and federal standards. In setting any emissions standards, one scholar stated, there should not be predictability that allows for defeat devices. After “Dieselgate,” the EPA and DOT implemented a new real-world emissions test that cannot be gamed and this prevents the dilution of emissions standards.

As the discussion concluded, several scholars emphasized that a multi-pronged approach is necessary for supporting electric vehicles. This will require a suite of policies including tax abatements, such as the one put in place in Norway for the purchase of electric vehicles. In addition, critical charging infrastructure must be developed and other incentives, such as access to high occupancy vehicle lanes or free parking can be used to further incentivize the purchase of electric vehicles. The electric vehicle market in the U.S. is largely reliant on the California emission mandate and the federal tax credit. For electric vehicles to become widespread, these incentives and new ones must be maintained and implemented to engage the public and limit risk to manufacturers.

How a Major Oil Company Positions Itself in a World of Low Oil Prices, Changing Technology, and Public Policy Demands

Lars Christian Bacher

Executive Vice-President, Statoil

At Statoil, we acknowledge and accept that our business operates under considerable uncertainty—changing oil prices, new technologies and geopolitical dynamics provide new business opportunities and risks. In order to position itself, Statoil must make certain assumptions about the future. Statoil's framework for this—'Energy Perspectives'—envisages three main scenarios: *Reform, Renewal and Rivalry*, as outlined below.

Context and Uncertainties

The future is uncertain, both short and long term. When trying to illustrate how global energy markets possibly might develop over the next 33 years, to 2050, it is important to realize that forecasting all the factors ultimately determining the outcome is impossible. This is one reason why this article contains illustrations of possible developments and scenarios that rest on different assumptions for key drivers. This gives us a chance of being vaguely right and avoid being precisely wrong.

The three scenarios, stories of the future, that we have established –*Reform, Renewal and Rivalry*—are described in more detail in the next section. Both in assumptions and outcomes the scenarios are very different. However, we find signposts for all of them in recent developments. And many other possibilities also exist.

There is currently a lot of focus on energy transition in political and economic discussions. This is driven partly by the significant changes in market conditions experienced over the last few years, partly by the significant step forward in global climate policy discussions, and partly by rapid technological developments holding the potential for significant change.

At the same time, it should be remembered that the global energy system is huge, complex, attached to capital equipment with long lifetimes, and affected by deeply rooted consumer behavior patterns. Moreover, it is growing, as the global population and economy are growing. Large changes in something this big will inevitably take time.

Below is a list of the general factors that together will determine the features of the global energy market by 2050. In the rest of the article, different assumptions are made on some of these to arrive at conclusions on energy demand and the energy mix in thethree scenarios. Other assumptions would have given other results. Black swans, known and unknown unknowns, will ensure that the actual outcome will be different from these scenarios, but hopefully somewhere within the range of outcomes that these scenarios define.

Economic Growth

Population growth, development of labor force characteristics, investments in productive capital and our ability to combine labor and capital productively together determine economic development. These factors are in turn affected by factors such as education, gender (in)equality, income distribution, technology transfers and economic policy in different countries. In these scenarios, the average annual economic growth between 2014 and 2050 varies between 1.9 and 2.7%, respectively. One factor that makes it difficult to forecast long-term economic growth is the aging of the workforce in many countries. Another is digitalization, a phenomenon carrying the potential for higher productivity development as well as for mass unemployment and income inequality.

Energy Intensity

Technology, market signals, energy policy and consumer behavior interact to determine how much energy goes into the production of a given amount of goods and services. Energy intensities vary across sectors and countries and over time. Consumer choices sometimes reduce or even wipe out the demand reduction following from an energy efficiency improvement. The three scenarios aim to take such rebound effects into account. The energy intensity of the global economy nevertheless declines by between 1.1 and 2.8% per year on average. This is higher than the 0.9% per year average for the period 1990-2014, reflecting policy push and technological progress. The improvement in the Renewal scenario is key to delivering on the 2° Centigrade (3.6 degrees Fahrenheit) target of limiting the expected rise in average temperature, but an enormous challenge.

Technological Development on the Supply and Demand Side

Technology and subsidies have combined to sharply reduce the costs of new renewable electricity over the last decade. Battery costs have also come down, paving the way for rapid growth in electricity storage, although significant increases in the use of critical minerals may limit the potential. The oil and gas price collapse, producer responses and technology breakthroughs have driven significant cost reductions also in the petroleum industry, some of which are structural and lasting. Standards and technology have reduced the energy intensities of all end-use sectors. Digitalization could allow for further cost reductions both on the supply and demand side. Ultimately, varying potential and success will affect the competitiveness and popularity of different fuels.

Energy and Climate Policies

There is a lot of focus on policy targets. Targets are important, but do not deliver results. Energy and climate policy measures are what matters. Subsidies, taxes, quotas, standards, and requirements lead to outcomes different from those that would prevail in unregulated markets. In many cases, there is a need to improve markets to reduce negative external effects such as pollution and greenhouse gas emissions. A special challenge is the need for coordinated, international measures to address global problems that cannot be solved locally. The future development of energy and climate policies is very uncertain, partly because concerns for energy efficiency and climate change must compete with other valid concerns in many countries.

Geopolitics and Regional Conflicts

Solving our common challenges requires cooperation, effective exchange of technology, good ideas and low-cost, low energy solutions, and trust. Geopolitical developments and regional conflicts might continue to hamper, rather than foster, such factors. In some dimensions, political developments the last year have reduced the likelihood of globally efficient solutions to common challenges. The future development in this area is crucial.

Black Swans

An important reminder is that we possibly will be surprised by events, developments and solutions that we do not know about and/or that have a low probability of occurring, but could have a large impact if and when they take place. One of the useful aspects of working with very different scenarios is that they could implicitly cater for some of these factors. To what extent this is the case for *Reform, Renewal and Rivalry* remains to be seen.

The Three Scenarios

This section provides a brief description of the three scenarios that form the basis of Statoil’s Energy Perspectives 2017. Energy Perspectives, which has been published annually since 2011, started featuring scenarios in 2014 as a response to the considerable uncertainty associated with long-term development in global energy markets. The three scenarios are all technically possible, and span a wide outcome range, but are not provided with specific probabilities indicating their likelihood of materializing. Each scenario is constructed from a distinct set of assumptions regarding the possible future development of the world economy and global energy markets. Further descriptions of the economic and energy-market specific implications of each scenario are presented in the following sections.

The Reform Scenario: Market Forces Coexist with Climate Policies

Last year's Reform scenario built on the national pledges by nations around the world in the framework of the Paris Agreement from COP21 (short for Conference of Parties, representing the 21 nations gathered in Paris in 2015 for the global climate agreement). In this year's Reform scenario, the pledges still form the backbone of fundamental transformations in the energy industry, but it is assumed that only those changes that can be accomplished through market-optimal, non-subsidized investments are sustained. However, mandatory standards and regulations coexist with market forces in the scenario, both play a role in shaping consumers' decisions, and both contribute to innovation and technology developments. As technologies that meet demand for low-carbon energy become increasingly economical, market intervention becomes progressively less relevant than commercial drive. Therefore, only some tightening of emission targets and policies takes place during the late 2020s and beyond.

The geopolitical framework in the Reform scenario is characterised by national policymaking, reflecting national and private economic self-interest tempered by, but not subservient to, international policy-making. Regional geopolitical tensions play out without bringing major permanent disruptions: the U.S. global leadership is called into question; local and regional conflicts continue to affect the Middle East; and Europe remains engrossed in domestic challenges precipitated by Brexit and resurgent fear of an European Union breakup. The global roles of China and Russia are moderated by their respective and different internal challenges associated with demographic, economic, environmental and political development. Policy coherence is, to an extent, side-tracked by terrorist attacks and transnational challenges, such as migration. However, international institutions and order remain largely intact. In the Reform scenario, research and development (R&D) and technology development are not hampered by geopolitical developments; as they are driven largely by commercial and national interests.

Economic growth in the Reform scenario is shaped strongly by demographic developments: increasing global population—with a decelerating growth rate out in time, and aging, particularly in the U.S., Europe and Japan. Productivity improvement, especially in the emerging economies, continues to unleash their catch-up potential. Global Gross Domestic Production growth in the Reform scenario is foreseen to slow relative to the average for the last 25 years, and to be significantly lower than in the five years prior to the 2008 crisis.

Global warming and extreme weather events dent economic activity somewhat from the mid-2030s, with an augmented impact during the 2040s.

Lower prices of fossil fuels and varying degrees of commitment to the tightening of climate contribution targets translate into higher oil and gas demand early in the forecast period. The EU emissions trading system (EU ETS) and other national and regional carbon pricing schemes function, but prices remain mostly unlinked and below the levels needed to stimulate a large-scale roll-out of Carbon Capture and Storage (CCS). The relative lack of progress in CCS undermines its role as a major climate risk mitigation tool.

In the Reform scenario energy systems become significantly more efficient than they are today. Average annual improvement in energy intensity is 1.9%, more than double the improvement seen in the last 25 years. This is achieved through a combination of measures, including fuel efficiency standards for vehicles, as well as advances in technologies relevant to buildings, industry, power and the entire range of energy sub-sectors. The changes in the energy mix are primarily a result of a gradual, but important shift from carbon fuels to green energy technologies, notably in the electricity sector, and a technology shift for light duty vehicles that enables significant electrification of the global car fleet, once electric cars become cost competitive. Regulatory incentives and subsidies that have helped wind and solar energy and electric vehicles gain traction in global energy markets are gradually phased out and leave space for profitable clean energy technologies.

Continued growth in global GDP in the Reform scenario outweighs the effects of a strong decline in energy intensity, so that projected energy demand continues to grow, albeit moderately. Fuel switching is too slow to stabilize and reduce energy-related CO2 emissions significantly during the forecast period. Therefore, Reform is not a sustainable scenario in the long run, leaving a wide gap when compared to the ambitions of the Paris agreement.

The Renewal Scenario: A Pathway to Energy Sustainability

The Renewal scenario focuses on developments that combine to deliver an energy-related CO2 trajectory that is consistent with a 50% probability of limiting global warming to a 2° Centrigrade rise in average global temperature. This year, Statoil has proceeded from a target of limiting cumulative global energy sector CO2 emissions to slightly below the level by 2040 in IEA’s 450 scenario (the 450 scenario sets out an energy pathway to limit the global increase in temperature to 2°C by limiting concentration of greenhouse gases in the atmosphere to around 450 parts per million of $CO_{2)}$, and then with the development extended to 2050.

The Renewal scenario plays out in a benign geopolitical environment where cooperation, not competition, drives policy. National policy agendas are shaped by a realization that the global warming threat calls for radical action, and that the severity of the required policies calls for a joint, coordinated response. The decision made in Paris to reconvene at five year intervals and tighten CO2 emission reduction commitments with the 2 degree Centrigrade target in mind, is carried out. International institutions, legal frameworks and trade agreements remain in place, although with greater influence from emerging economies such as China, Brazil and India. Economic and energy diversification, with plans for moving beyond coal and oil dependence, makes real progress and boosts energy efficiency across developed and emerging economies. Investments and technology transfers rapidly generate greater buy-in for greener forms of energy.

The global economic growth performance in the Renewal scenario, at first, is slightly below the Reform scenario, since reallocation of investments towards the green economy are initially driven by the need to reduce global CO2 emissions and fulfill agreed targets, and not by an expectation of the highest short-term economic return. However, later in the outlook period, economic growth surges as green investments yield higher return. The reduction of CO2 emissions in this scenario is sufficient to prevent an escalation of negative climate change impacts, hence, global GDP is expected to log an annual average growth slightly above the Reform scenario over the outlook period.

Lower demand for fossil fuels and carbon-conscious-producer attitudes leave the most expensive and CO2 intensive assets in the ground. Fossil fuel subsidies to end users are phased out faster in Renewal than in Reform, and carbon prices in interlinked carbon markets are notably higher than in Reform. High carbon prices also incentivize the development and deployment of large-scale CCS. This enables continued use of fossil fuels—though at reduced levels—in sectors that do not have satisfactory options.

Renewal is characterised by a stable policy and regulatory framework effectively mobilizing investment in clean energy and efficient energy systems. A more consistent emphasis on green technology development and deployment ensures faster energy efficiency improvements, a deeper decarbonization of power generation and a radical electrification of key transport segments. The key climate policy tools in action are partly market based, partly interventionist, and partly oriented towards R&D. Key results include declining costs of renewable technologies and car batteries, widespread availability of charging points for electric vehicles (EVs), technical maturity and affordability of large-scale electricity storage, smart grids, a substantial strengthening of transmission networks and refurbishing of a significant amount of homes and public building stocks.

The unprecedented pace of decline in energy intensity in the Renewal scenario, three times as high as the last 25 years, negates the impact of economic growth on global energy demand which is 6% below its 2014 level by 2050, despite the global economy being 2.6 times larger. Accelerated fuel switching on top of this revolutionary decline in energy use stabilizes and drastically reduces energy-related CO2 emissions.

The Rivalry Scenario: A Multipolar World

The Rivalry scenario portrays a multipolar world where populist, nationalist, inward looking and short-term priorities direct policy making, where climate scepticism runs high and where disorder, conflict and power struggle apply at the expense of cooperation and trust. In the Reform scenario, self-interest is kept in check by a realization on the part of leaders that key issues do require restraint and cooperation. In Rivalry, there are fewer concerns for the common good beyond the interests of the family, the tribe or the nation.

The issues and tensions defining the Rivalry scenario are fluent by nature and affect different regions in different ways in different time periods. Rivalry consequently seeks to portray a world characterized by progress and setbacks and by regions making progress and regions falling behind, rather than a world struggling uniformly and continuously throughout the entire outlook period.

The geopolitical scene in the Rivalry scenario is turbulent. Economic inequality within and between states erodes social and international cohesion. Conventional politics and principles are overrun by xenophobia and protectionism. Geopolitical rivalries remain elevated as state failures in exposed areas are not managed by established world powers, such as the U.S., and as emerging powers such as China and India do not fill the governance gap. Traditional institutions fail to mitigate the world’s problems due to lack of support and funding. Physical walls and border controls spell the end of benign globalization as it existed after the Cold War. Leaders rail against international institutions, trade agreements and economic blocs.

Challenging geopolitics hamper international trade and the deployment of new technology. Political and economic resources are channelled to less productive purposes. This leads to economic stress. Eventually there will also be negative environmental consequences of climate changes that unfold in this scenario. Therefore, global economic growth in Rivalry is curbed to a level well below that in Reform and Renewal.

Long periods of underinvestment in new production capacity and higher demand for fossil fuels allow the development of higher cost assets, leading to higher energy prices and to volatility related to unrest in producing countries. Carbon pricing falls off policy agendas. Although existing schemes linger on, prices are never linked and never reach levels where they have material impact on fuel switching and investments. In this scenario, there is no economic incentive to support R&D in CCS technologies, so no projects beyond those existing or currently under implementation are considered.

Policy and regulatory attention to local environmental problems is sustained, but concerns for global issues are not. Global climate ambitions are nominally still in place, but are in practice ignored. A preoccupation with security of energy supply and periods of high prices spur interest in energy efficiency and indigenous new renewable energy, but above all a will to take advantage of domestic fossil fuel resources. Regions well-endowed with coal, oil or gas continue to rely on these fuels regardless of their climate implications. The electrification of the global car fleet is much slower in Rivalry than in Renewal and Reform.

As projected and energy-related CO2 emissions by 2050 are higher in Rivalry than in Reform, despite substantially lower GDP, this scenario is clearly unsustainable also from a climate perspective.

Strategic Implications

It is not a given in which way the world will move. That is why Statoil and others prepare scenarios for these developments, and consider strategies that are robust in several possible future scenarios. A robust approach is to keep producing oil and gas as cost- and energy- and climate-efficiently as possible, because there will be a demand for oil and gas for many decades ahead, and it will be greater than the volumes we can produce from existing fields. Another robust strategy for Statoil, irrespective of scenarios, is to develop profitable renewable energy projects and low-carbon solutions in areas where we have a competitive edge and there is a demand. A low carbon footprint from operations will increasingly be a competitive advantage, and as a part of Statoil’s strategy, the climate roadmap sets a clear ambition in being a leading company in carbon-efficient oil and gas production. Moreover, Statoil has a strategic ambition to allocate 15-20% of its annual investments towards these new energy solutions in 2030.

The Tipping Point:
How America Can Lead the Transition to a Prosperous Clean Energy Economy

Eric D. Beinhocker

Executive Director, Institute for New Economic Thinking, University of Oxford

The world is approaching a historic tipping point. Rapid advances in price and performance are bringing clean energy technologies ever closer to the point where they beat fossil fuel technologies on the merits; where they are quite simply cheaper and better. Solar and wind are already beating coal in a number of situations and locations. Once this tipping point is broadly reached, the full might of markets will come to bear and drive a wave of transformation that will replace the fossil fuel economy with a clean energy economy. Betting on coal at this point in history is about as smart as betting on typewriters in 1976—the year Apple released its first personal computer.

This paper will argue that it is almost inevitable that the U.S. and the world will reach this tipping point, but that it is not happening fast enough. Progress needs to be accelerated in the U.S. for three reasons: First, the sooner the tipping point is reached, the lower the risks of damaging climate change. Second, in the race to build and deploy clean energy technologies there are significant first-mover advantages; the next ten years will likely determine which nations lead and which nations follow. Third and finally, for those who believe that government intervention in the economy should be limited, the faster America reaches this tipping point, the faster it can scale back intervention in its energy markets. A relatively brief but forceful policy push over the next ten years can drive the U.S. rapidly to the tipping point where clean energy technologies win on the merits and free market forces take over. Citizens will then enjoy the benefits of cleaner, cheaper, more secure energy, and the job creating economic growth that will come from this transformation, for decades to come.

This paper will briefly discuss: (1) why clean energy technology has advanced so rapidly and why the tipping point is almost inevitable; (2) why the U.S. needs to actively accelerate its progress to this point; and (3) how smart policies can ensure U.S. leadership in the energy economy of the future.

1. Technologies Beat Commodities: Why Clean Energy Technologies Will Win

Many energy analysts have been surprised by the rapid growth in clean energy technologies such as solar, wind, and batteries. For example, the International Energy Agency (IEA) has consistently underestimated renewable capacity additions (*figure 1*).[1] This is because few foresaw that the levelized cost of wind energy would drop 50% since 2009, and the median price of U.S. installed residential solar would more than halve between 2007 and 2015.[2] Battery costs have also dropped 58% from 2007-2015, and the cost of LED lights dropped 80 percent from 2010-2015. [3] Many people have also been surprised by rapid performance increases. The efficiency of wind turbines, for example, has doubled from 2000-2017.[4] Likewise, as the cost of electric vehicles (EVs) has come down, their power and range has gone up. EVs a decade ago were limited to a range of around 100 miles, while the latest models today can achieve 335 miles.[5] And consumers have been delighted to learn that EVs accelerate faster, are quieter, and more readily integrate advanced digital technologies than fossil fueled cars.[6]

But to people who study technology, this acceleration of progress is not that surprising. In fact, it is quite predictable. Professor J. Doyne Farmer, an American physicist at the Institute for New Economic Thinking at the University of Oxford, and his colleagues, have looked at the progress rates of a large number of goods in the economy over long periods of time.[7] Farmer and his team have shown that one can divide those goods into two broad categories: commodities and technologies. Commodities are goods that are dug out of the ground or grown—for example coal, oil, gas, copper, and wheat. Technologies on the other hand are goods that are designed and embed human knowledge—for example transistors, aircraft, gene sequencing machines, solar panels, wind turbines, and batteries.

In analyzing their data, Farmer and his team observed a striking pattern (*figure 2*). The prices of commodities are quite volatile, but there is no long-term trend—they follow what statisticians call a random walk. For example, coal prices rise and fall with changes in the economy, technology, regulation, trade, and other factors. But despite major changes in mining technology and declines in transport costs, in inflation adjusted terms the price of delivered coal is about the same today as it was in the 1890s (*figure 3*).[8] This is not to say there hasn't been technology progress—coal mining today is a sophisticated, highly-automated, business. But, nonetheless, after an initial period of price declines from 1820 to 1900 when fossil fuels were first introduced, the real prices of coal, oil, and gas have fluctuated a lot, but not trended downward.[9] The reason is that technology innovation in commodities tends to result in supply-demand cycles rather than long-term price decreases.[10] The cycles work like this: current sources of supply begin to dry up, prices rise, companies invest in research and development (R&D), innovations then allow them to tap new sources of supply, prices come down, eventually the new sources begin to dry up, and the cycle starts over. For example, oil has gone from on-shore, to off-shore, deep off-shore, the arctic, horizontal drilling, tight oil, and tar sands, with prices cycling, but no long-term trend.

Technologies on the other hand exhibit fundamental, long-term downward price trends (*figure 4*) as well as improvements in performance. The best-known example is Moore's Law which predicts that the number of transistors in a computer chip will double every 2 years. We have seen Moore's Law revolutionize the world and it is still going. Farmer and his team found that it is not just semiconductors that follow Moore's Law, but a wide variety of technologies, from communications cables to gene sequencing. In fact, Farmer and his team found that most technologies follow a function similar to Moore's Law known as Wright's Law, named after Theodore Wright, an American engineer who discovered it in 1936 while working on the production of B-29 bombers. Under Wright's Law the rate of progress is dependent on the cumulative production volume of the technology rather than on time as in Moore's Law. Wright observed that as the cumulative volume of B-29 bombers produced increased, their cost dropped rapidly. Wright's Law curves are also known as experience or learning curves because it is believed that the price and performance improvements are a function of the knowledge accumulated from experience working with the technology.

Farmer and others have shown that key clean energy technologies such as solar, wind, batteries, and LED lights, are firmly established on Wright's Law curves. The recent rapid progress in solar prices, for example, can be attributed to major increases in cumulative production volumes, largely due to increased global solar demand driven by policies such as Germany's feed-in-tariffs[*] and China's major expansion of solar capacity. In short, the more solar, wind, batteries, and other clean energy technologies produced, the cheaper and better they have become, and will continue to become—something that is not true of fossil fuel commodities (*figure 5*).

This accelerating progress on renewable prices and performance does not take-away the challenges of integrating large-scale renewables into the grid. However, grid technologies are improving as well and utilities around the world are increasingly gaining experience with managing high levels of renewables. For example, on June 7th this year, the UK ran on over 50% renewable power for the day, and during the same month the entire region of Qinghai, China, with a population of five million, ran on 100% renewables for a week.

Some clean energy technologies, however, are not declining in price. Nuclear has seen its costs rise over time and coal-based carbon capture and storage (CCS) has yet to see significant cost declines. Safety and other regulations are certainly part of the story. But it may also be due to the fact that each nuclear or CCS plant is so large, expensive, and unique, that it is difficult for the experience curve effect to kick in.

2. Accelerating the Clean Energy Tipping Point

Work by Bloomberg New Energy Finance and others shows that based on these experience curves, solar and wind are on track to reach two tipping points (*figure 6*).[11] The first is when unsubsidized new-build solar and wind beat new-build coal and gas. This first tipping point has already been reached in Germany, is expected to be reached in China by 2019-2021, and in the U.S. by 2022-2023. The second tipping point is when unsubsidized new-build solar and wind beat *existing* fossil plants. This is when large scale replacement of the energy infrastructure will begin. This is expected in the late 2020s to early 2030s across the developed countries and China, depending on national policies.

While this is encouraging, progress needs to be accelerated in the U.S. for three reasons: (A) to minimize climate damage, (B) to maximize U.S. technological and industrial leadership, and (C) to limit government involvement in energy markets.

A. Minimizing Climate Change

Scientists estimate that in order to avoid the most dangerous and irreversible effects of climate change, global emissions of carbon and other greenhouse gases must drop to net-zero by around 2050.[12] By that point humankind will likely have used up its remaining "carbon budget" and any positive emissions beyond mid-century will cause global temperatures to rise above 2ºC degrees (3.6ºF) creating significant risks including extreme weather events, rising sea levels, more unreliable food supplies, droughts, flooding, species extinction, and other negative effects on planetary ecosystems and human society.[13]

While 2050 may sound comfortably far off, it isn't. Energy-using infrastructure has a long-lifetime: 30-60 years for power plants, 10-30 years for transport, and decades or even centuries for buildings. So, the infrastructure the U.S. is building and planning today will determine its emissions mid-century. Researchers at Oxford have calculated that the power generation infrastructure on the ground today already has enough "baked-in" future emissions to exceed the world's carbon budget and lead to warming over 2ºC.[14] This means that the world needs to get to tipping point 1—when

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[*] A feed-in-tariff is a payment made by a utility (usually with government support) to a non-utility producer of low-carbon energy (e.g. a household or business with solar panels or wind turbines) to sell the power they produce but do not use themselves to the grid. The tariffs are designed to incentivize renewable energy adoption.

clean energy technologies are cheaper than new-build fossil—now. But the U.S. and other countries also need to accelerate progress to tipping point 2—when clean energy begins broadly substituting for existing fossil infrastructure – as soon as possible, but no later than a decade from now. If not, by 2030 the world may be locked into a path to temperatures higher than 2ºC with irreversible negative consequences that may be highly costly or impossible for humankind to adapt to.

B. Maximizing U.S. Technological Leadership

The second reason the U.S. should accelerate its clean energy progress is to maximize its chances of playing a leadership role in these technologies in the future. The U.S. has pioneered many key clean energy technologies (the first solar cells were developed by the U.S. space program) and numerous U.S. companies currently play leading roles in the industry. However, a consequence of Wright's Law is that knowledge and experience tend to build where production and demand are located, and it is a cumulative, accelerating process. This means that there are significant early-mover advantages, and catch-up may be difficult or impossible.

Thus, the countries that move aggressively to build a clean energy economy today will build the industrial ecosystems of talent, assets, infrastructure, and knowledge to dominate those businesses tomorrow. For example, China State Grid, which serves 1.1 billion customers, is investing $12 billion in R&D for smart grid technologies and is building the world's largest electric vehicle charging infrastructure.[15] Overall, China invested $103 billion in domestic renewable energy in 2015 versus $44 billion by the U.S.[16] If the U.S. steps back from clean energy leadership, there is a risk that America will be locked-out of this growing market, unable to catch-up, and dependent on imports for clean energy products and services from China, Japan, South Korea, Germany and other countries. It would also be a loss for American workers as we rapidly approach the tipping point where more jobs depend on the clean energy economy than on the fossil fuel economy.[17]

C. Limiting Government Intervention in Energy Markets

U.S. federal and state government has a long history of involvement in energy markets. Some of this is necessary and justified, for example state regulation of utility monopolies, safety and environmental standards, and government investments in energy R&D. However, the U.S. also provides large taxpayer funded subsidies and tax breaks to the energy industry—for example from fiscal years 2002-2008 the fossil fuel industry received subsidies and tax breaks of approximately $72 billion and the renewable energy industry received $29 billion.[18] Scaling back or eliminating these subsidies and tax breaks may be desirable both to reduce government spending as well as to limit government intervention in the energy market.

Somewhat counter-intuitively, the fastest way to achieve this may be to have a strong near-term policy push on clean energy technologies to accelerate them down the Wright's Law curve and get them over the tipping point to beating fossil fuels in unsubsidized free market competition.[19] At that point subsidies and tax incentives would no longer be needed for either the fossil or clean energy industries. The market could then decide which energy technologies are most efficient in which applications and locations. As with any major technology transition, some dislocation in labor markets is inevitable as jobs are created in one sector and lost in another. Some of the subsidies saved could thus be re-deployed to help workers in fossil fuel based industries make the transition. Once we have tipped to a clean energy economy, it may also be possible to unwind a number of government regulations. For example, the shift away from large monopolistic utilities to a more de-centralized system based on renewables may provide opportunities to substitute markets for regulation. In contrast, by continuing to provide major subsidies to fossil fuels and less (and inconsistent) support to clean energy, the U.S. is delaying the tipping point, requiring a longer period of government intervention and regulation, and harming U.S. competitiveness.

3. Smart Policies: Make Clean Energy Cheap

One of the primary goals of energy policy should therefore be to drive the cost of clean energy downward and its performance upward to reach the tipping point as quickly as possible. This strategy can be thought of as "make clean energy cheap." This is in contrast to the traditional approach which has been to "make fossil energy expensive" through regulation and putting a price on carbon emissions (i.e. cap-and-trade or a carbon tax). While there are strong economic arguments for carbon prices, they have been politically difficult as there are concerns about the near-term costs on consumers, many policymakers are skeptical of increasing taxes or regulation, and not surprisingly the fossil fuel industry strongly resists this. While policymakers should continue to look for avenues to create a price on carbon, they should also examine strategies for "making clean energy cheap."

The first lever is to significantly boost clean energy R&D. The U.S. government has a strong and successful track record in "mission driven innovation"—using public investments and the power of government to mobilize massive R&D on nationally important missions.[20] From Cold War military investments, to the space program, the fight against AIDS, missions to crack the human genome, and recent efforts to fight terrorism, U.S government agencies such the Defense Advanced Research Projects Agency (DARPA), National Aeronautics and Space Administration (NASA), National Institutes of Health (NIH), and Department of Energy (DOE), have played a critical role in driving progress in a wide range of technologies with massive positive spillover effects for the U.S. and the world.

Despite the urgency and opportunity of building a clean energy economy, the U.S. government invests relatively little on renewable technology R&D, just $1 billion in 2016. Research suggests that this should be increased to around $5 billion in order to have a meaningful impact on clean energy progress.[21] The private sector also has a role to play, for example in 2015 a group of 20 entrepreneurs and investors led by Bill Gates pledged $2 billion to the Breakthrough Energy Coalition to fund clean energy development.

The second lever the government has is to pursue policies that boost clean energy demand. This creates markets, drives up production volumes, pushes technologies down the Wright's Law curve, lowers prices, and increases performance. Much of the recent progress in clean energy technologies has been attributable to demand creation policies in Europe and China. There are a variety of policy tools that would have the impact of helping create large and stable markets for clean energy technologies in the U.S., including: carbon prices, public infrastructure investment (e.g. smart grid), feed-in tariffs, capacity auctions[†], removing fossil subsidies while boosting clean energy support, performance standards, regulatory reform, and government purchasing (e.g. energy, buildings, vehicles).[22] None of these policies is a silver bullet and each has pros and cons, but a smartly crafted package of such policies, implemented consistently and at scale over the next decade, would significantly boost U.S. clean energy demand, drive prices down further, and accelerate the U.S. to the tipping point.

[†] Many utilities and governments hold auctions where private sector companies bid to provide electricity generating capacity at the lowest cost for a given set of requirements. As clean energy costs have declined, clean energy sources have become increasingly successful in these auctions.

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Just as Moore's Law revolutionized the information world, Wright's Law is revolutionizing the energy world. Clean energy technologies are riding the Wright's Law curve and will out-innovate and out-compete fossil fuel commodities in the coming decades, and will replace fossil fuels as surely as personal computers replaced typewriters. The U.S. faces a choice: It can resist this transition but not stop it, spend taxpayer money on a declining industry, jeopardize its future competitiveness, and increase risks from the climate. Or it can, in America's proud tradition as the most dynamic, innovative, and forward-looking country in the world, choose to lead.

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Endnotes:

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Navigating the Turbulence of the Global Energy System

Arun Majumdar
Jay Precourt Professor & Co-Director, Precourt Institute for Energy
Stanford University

The legendary Intel Chief Executive Officer, Andy Grove, described in his famous book, "*Only the Paranoid Survive*," the notion of a strategic inflection point, when the fundamentals of a business, an industry, a nation or the world change. Past data and strategies are, then, no guarantee for future success. The potential for disruption is both an enormous challenge as well as a massive opportunity (see Fig. 1). The process of shedding past paradigms while recognizing and adopting the new fundamentals can seem unsettling, chaotic and turbulent at times. But it is through a process of experimenting with new ideas, gaining new insights and charting new courses that organizations can pivot to new strategies and pathways. The trajectories of these pathways may seem close at first, but the chosen path can lead to enormous differences in future success (see Fig. 1).

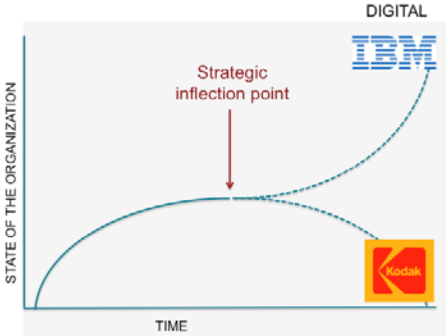

Fig. 1 According to Andy Grove, a strategic inflection point occurs when the fundamentals of a business, industry or a nation change and the past data and strategies are no recipes for future success. There is need to experiment and innovate. The trajectories of different organizations may seem close at that time, but the decisions on the path forward can lead to enormous successes or failures.

While this may have been true for the digital industry, it is now directly relevant to the largest industry in the world, which is in the early days of a dramatic transformation. We are talking about energy, the lifeblood of the global economy, and a worldwide market of ~$10 trillion per year that keeps our lights, medical devices and computers running, our homes cool or warm, our cars moving and provides millions of jobs. What occurs in the next two decades and what decisions are made by businesses, organizations, states, nations and regions will reshape the prosperity, security, the environment, trade and the geopolitics of the world.

After more than a hundred years of historic success, the fundamentals of the energy industry are rapidly changing because of three "Ds", namely: (i) *Diversification*, to offer more choices to consumers and provide energy security; (ii) *Digitization*, to automate, increase efficiency and lower costs; and (iii) *Decarbonization*, to reduce greenhouse gas emissions. Before one takes deep dives into the three "Ds", it is important to understand the grand energy challenges ahead. The world faces three of them, namely:

a) How can one continue the exponential economic growth while decarbonizing the economy cost-effectively?
b) How can the energy system be made resilient, adaptable and secure against various threats – climate, cyber...?
c) How can one provide access to affordable modern energy to every human being in the world, noting that there are about 1.2 billion people who don't have access to modern energy and another 1 billion people who have marginal access?

Every organization, be it a business, a state, a country, or a region, will need to address at least one or two of these challenges, and some will have to address all three. The paramount question can be summarized as: *What pathways or approaches should one adopt to address the future challenges while navigating, leveraging and shaping the three "D" landscape?* Furthermore, history has taught us that for our energy policies to be truly sustainable for the long term, they must maintain a balance between three securities--economic, national and environmental—while also ensuring social equity.

It is fair to say that no one has really figured out the answers to the paramount question because, as noted before, past data and strategies are no guarantee for future success. It is time to experiment with new ideas, knowing some of them will fail, but hopefully fail quickly, and more importantly, teach a lot in the process. Without taking shots on goal, there will be no wins. The key is to *innovate*. This essay attempts to address this by taking stock of the three "Ds".

Diversification

Electricity: Historically, the electricity industry has relied on large thermal power plants (~100-1000 MW$_e$) that convert the energy stored in fossil fuels (coal, oil, natural gas) or nuclear into heat, and convert heat into electrical power with an efficiency of 30-60 percent. The only dominant renewable resource was hydroelectric power, which was also mostly of large size[1].

Over the last decade, there have been two dramatic transformations: (a) the emergence of low-cost unconventional gas (shale gas) in the U.S.; and (b) reductions in the cost of electricity generation from wind and solar (see Fig. 2), to the point that they already are or will soon become the most inexpensive way to produce electricity. The cost reduction has come from technology innovations, which have been given the opportunity to go down techno-economic learning curves due to mandates to install and/or financial incentives in various regions of the world. Both these trends are enabling the decarbonization of the electricity grid, and the world is entering an unprecedented era when carbon-free electricity is the most inexpensive. The challenge is its volatility.

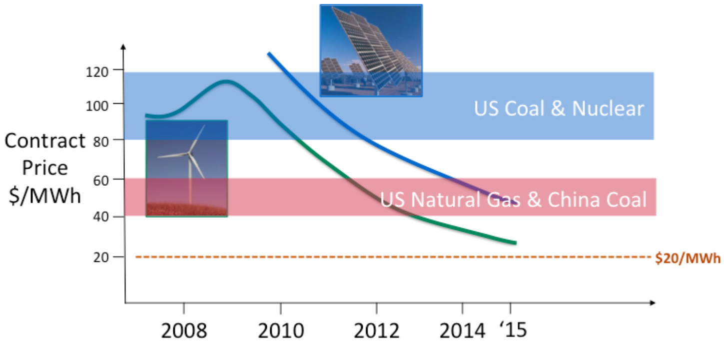

Fig. 2 Long-term power purchase agreement (PPA) prices ($/MWh) in the US, which has a production tax credit of $23/MWh for wind and investment tax credit of 30 percent for solar. In 2016, the world's lowest unsubsidized wind PPA was $30/MWh and that for solar was $36/MWh.

As opposed to thermal power plants, wind and solar come in small modules, which offer new opportunities in financing, installation, market competition, global supply chains, etc. And since there are no fuel costs, most of the cost is in upfront financing, which has recently outpaced that for fossil-based plants. When large-scale solar and wind farms inject their electrical power into bulk electric transmission system, their adoption is determined by wholesale markets. This market bidding is based on marginal or variable costs, whereas the price is determined by when supply matches the demand. In the absence of fuel costs, wind and solar have close to zero marginal costs (except for operations and maintenance) and therefore receive priority purely based on economics. Hence, this has led to an exponential increase in wind (~ 550 GWe worldwide, ~85 GWe in the U.S.) and solar (~ 360

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[1] The reason for large power plants was to achieve economies of scale, so that the cost of producing a unit of electricity ($/MWh) would reduce with size and capacity (MW).

GWe worldwide, ~45 GWe in the U.S.) capacity installations[2], which have grown annually in the range of 10-25 percent over the last decade. With advances in technology, such as taller wind turbines with increased capacity factor or high-efficiency thin-film solar cells, it is likely that the costs will continue to fall over the next decade. Research is needed to enable this cost reduction.

While the increasing integration of wind, solar and natural gas has led to a diversification and decarbonization of the electricity sources, it is not without consequences. They have put a downward pressure on bulk electricity prices, which can be beneficial for customers, as long as their retail price reflects this downward trend (which is not often the case). Since the cost of producing electricity from thermal power plants has not reduced, many of them cannot compete in a market-based system. For example, despite the fact that nuclear power is the largest carbon-free electricity source today and ought to be used more to decarbonize the electricity grid, it cannot compete in the wholesale markets in the U.S. with natural gas, wind and solar, unless some financial support is provided (e.g., state credits)[3]. In the U.S., coal cannot compete either, leading to no new coal-fired power plants being built.

With decreasing costs of rooftop solar panels and due to consumer choice in their adoption, there is increasing penetration of rooftop solar in the distribution system. While they can relieve the need to build transmission lines and reduce losses in them, they can also lead to reverse flow of electricity and potential voltage instability on the distribution system. But these can be addressed with technology.

The consequences of diversification of the electricity system are such that one needs to rethink the electricity grid, which is the most fundamental infrastructure in any modern economy. The electricity grid is about 120 years old and is based on the architecture designed by Nikola Tesla and Thomas Edison. It was designed to operate using slow changing thermal power plants, not volatile renewable generation from wind and solar. Hence, with increasing penetration of wind and solar integration on the grid, new challenges appear. One such challenge is the reduction of net demand during the middle of the day (when solar electricity could be over generated) and a massive ramp in the evening (see Fig. 3), producing the so-called "duck curve"[4], which puts enormous strain on balancing the grid in real time. This could potentially be addressed by: (a) expanding the balancing authority and transmitting renewables over longer distances to geographically separated load centers, thus mitigating over generation; (b) scheduling and/or deferring loads; (c) introducing energy storage (the cheaper of electrochemical, thermal, or pumped hydro) for

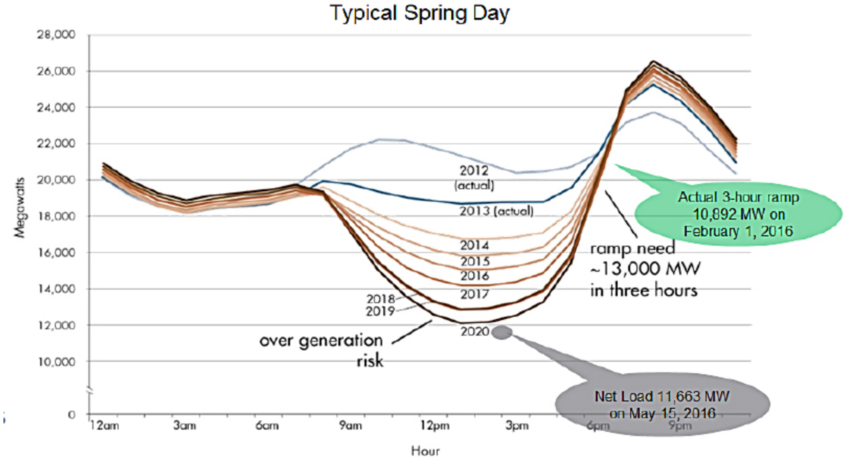

Fig. 3 Duck curve of integrating large entities of solar on the grid, increasing the risk of over generation in the middle of the day and enormous power ramps in the evening. In California, the duck curve projections have already been exceeded.

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[2] The global electrical capacity is ~4-5 TW, with an annual electrical energy production of ~25,000 TWh. The US electrical capacity is ~1 TW, with annual electrical energy production ~ 4000 TWh.

[3] Final report of the Task Force on the Future of Nuclear Power, U.S. Secretary of Energy Advisory Board, September 2016.

[4] "What the duck curve tells us about managing a green grid," CAISO. https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

both load shifting and ramping; or (d) a combination of (a)-(c). Cost effective storage for grid services remains one of the most daunting research and development (R&D) challenges. There is also no doubt that much higher levels of coordination are needed between small distributed (generation, load, storage) resources as well as large centralized assets across the whole grid system. This requires R&D to develop digital technology to increase automation and efficiency in coordination. But technology alone is insufficient—research in new markets and pricing at wholesale and retail levels, as well as new regulatory frameworks and policy to achieve the necessary coordination are also necessary. This is a rather complex problem, and the solutions need to be holistic in nature, not piecemeal[5]. Where the grid does not exist today, the new reality of low-cost and widely available solar, wind and natural gas, combined with digital technology, offers the promising prospects of leapfrogging people and communities from the 19th to the 21st century with the development of microgrids.

Transportation: Mobility over the last 100 years has been achieved via a single paradigm—liquid hydrocarbon fuels (gasoline and diesel), largely fossil-based, used to power internal combustion engines (ICE), both reciprocating (pistons) and rotary (turbines). The increasing trends towards electrification is challenging this paradigm, and is largely in the form of battery hybrids, battery electric vehicles and hydrogen powered fuel cell vehicles. Figure 4 shows the unprecedented rapid cost reduction[6] in lithium-ion batteries. Given the current research on batteries, and the headroom available to increase their performance and reduce their costs, it seems highly likely that within the next decade, battery pack costs will approach or become lower than $100/kWh. At that point, unsubsidized battery electrical vehicles (BEVs) will become comparable in range and cost as ICE vehicles.

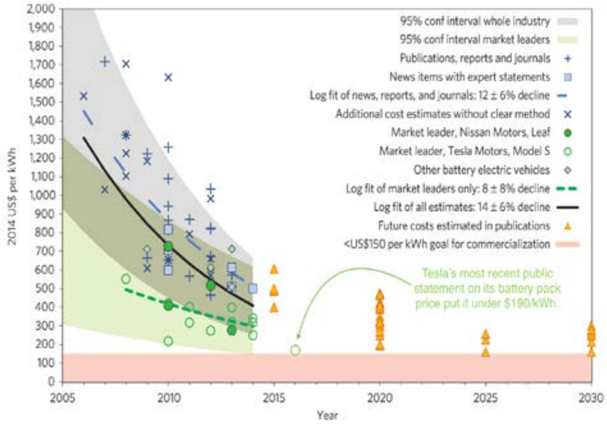

Fig. 4 Up front costs of lithium ion battery packs (in $/kWh). The pink bar at the bottom denotes costs < $150/kWh, when battery electric vehicles start to become comparable in cost and range as internal combustion engine (ICE) cars.

The following decade will then likely see increasing adoption of EVs by consumers worldwide.

While EVs will make significant penetration in passenger cars, and possibly even fleet vehicles such as buses and delivery trucks, there will be competition from higher-efficiency gasoline/diesel-based ICE cars, hydrogen-based fuel cell vehicles as well as compressed natural gas (CNG) ICE vehicles. Gasoline/diesel-based ICE and EVs today have a widely available infrastructure to deliver energy, whereas hydrogen and CNG infrastructures are not as well developed. On the other hand, EV battery charging is a relatively slow process, whereas gasoline/diesel, hydrogen and CNG refueling can occur almost at the speed of gasoline . Hence, the tradeoffs in infrastructure and refueling user experience remain major aspects of this competition, which will play out in the next two decades and depend on technology advancement and consumer choice. But what remains clear is that after 100 years of dominance of a single paradigm, the transportation sector will undergo significant diversification. While high-density liquid-transportation will likely still be used in passenger vehicles, it will

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[5] See Stanford University's Bits and Watts Initiative. https://bitsandwatts.stanford.edu/

[6] B. Nykvist, M. Nilsson, Rapidly falling costs of battery packs for electric vehicles, *Nature Clim. Change* **5**, 329 (2015)

remain dominant in long-haul trucking and airplane transport. However, it is not a question of if, but rather when (most likely between 2025-2040) the world will hit a *peak demand* in oil for transportation[7].

Digitization

The last 60 years marked the birth, rise, and dominance of the digital world as one of the cornerstones of any modern economy. The costs of computing, communication, sensing, control and analysis have reduced exponentially, whereas the power of data analytics and machine intelligence has increased dramatically. So far, the digital world has penetrated personal communication, media, finance, and business automation. However, the next two decades will likely witness increasing penetration in the energy sector, with the primary purpose to increase efficiency, reduce costs and offer new services. This is already occurring in transportation, where the digital world is identifying idle capacity to offer cheaper, faster and better transportation services (e.g., Uber, Lyft, etc). What is not so visible is the use of digitization in the oil and gas sector[8,9] to sense and collect data, to analyze the data and automate to reduce the cost of the oil exploration, extraction and delivery processes. One of the consequences of this is the reduction of manual labor and elimination of jobs, which can have significant societal effects. Finally, the U.S. currently has ~65 million smart meters to measure electricity and natural gas end use as well as about 1,000 phasor measurement units (PMUs) on our high-voltage transmission system of the electricity grid. These are producing petabytes of data that are currently underutilized. The so-called “smart grid” could be much smarter when this data is utilized to increase reliability, resilience, cybersecurity, end-use efficiency and address the challenges (e.g., duck curve) introduced by renewables integration. This requires R&D.

Decarbonization

The transition to a low-carbon economy will not occur overnight. But it needs to be accelerated cost-effectively without major societal dislocations. The key question that industry and society are asking is: What are the available solutions and what new options should be created via R&D?

The electricity grid ought to be decarbonized. Fuel switching from coal to natural gas is a critical first step, which is already underway. Deep penetration of wind and solar can decarbonize as well, as long as the volatility-balancing services are low-carbon and cost effective. Nuclear power, the largest source of carbon-free electricity, is being outcompeted in the wholesale market. Whereas solar and wind have tax incentives in the U.S., nuclear power does not have any direct payment. As opposed to offering incentives piecemeal for various energy sources, a much more equitable approach would be to replace them with an adequate carbon price (~$30-50/tCO$_2$), preferably a revenue neutral tax[10], which would allow low-carbon sources to compete on a level playing field in the wholesale market. Such a price would also incentivize R&D in carbon dioxide capture, utilization, and sequestration, which would help reduce their cost. It would allow the coal industry to participate and compete in the wholesale market. Furthermore, residential, commercial and industrial heating is often achieved by natural gas or via co-generation. Cost-effective and efficient electrification of heating via heat pumps should be promoted, which would require R&D to reduce cost. Energy efficiency encounters market failures because price signals do not often produce change due to its disaggregated nature. Regulatory measures such as efficiency standards for appliances and vehicles have worked well. While individual appliances have become increasingly

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[7] L. Cook, E. Cherney, Get ready for peak oil demand, *Wall Street Journal*, May 26, 2017

[8] M. Scott, Energy Giants Turn to Drones and Sensors in New Embrace of the Digital World, *New York Times*, Nov. 3, 2016.

[9] C. Krauss, Texas Oil Fields Rebound From Price Lull, but Jobs Are Left Behind, *New York Times*, Feb 19, 2017

[10] G.P. Shultz and J. A. Baker III, A Conservative Answer to Climate Change, *Wall Street Journal*, Feb. 7, 2017

efficient, the building stock has not. *Whole building efficiency standards* based on measured performance are critically needed.

While electrification can partially decarbonize transportation, carbon-neutral or carbon-free energy-dense liquid fuels would be necessary for deep decarbonization. R&D is needed to cost-effectively synthesize such fuels at scale.

Lessons Learned from the EU and the German Energiewende

Camilla Bausch, Director
Katharina Umpfenbach, Senior Fellow
Ecologic Institute, Berlin

Technology Development and Policies Drive Global Trends Shaping the Energy Sector

A number of trends currently affect the dynamic nature of global energy markets leading to unexpected transformation and changes in many areas. From an environmental perspective, many of these trends support clean energy solutions[1]:

- The drastic cost reductions that have occurred for, e.g., photovoltaic (PV) installations, wind turbines, storage solutions, electric vehicles and efficiency technologies, open up the prospect that efficiency and renewable energy solutions will become the favored option for many if not most energy related products and services, where they are not already.
- Together with digitalization and/or government policies, the developments outlined above allow for completely new business models, which put often painful pressure on traditional players, such as those in the electricity and automotive sectors.
- Energy efficiency measures across the globe drive up economies' energy productivity while slowing down the world's increasing thirst for primary energy input.

Both technological change and policies drive these developments, with spill-over effects rippling through global energy and product markets. Yet, the interesting question is how interaction between these drivers takes place. Can policy-makers influence technological change and guide investments? If so, what should the objectives be and which instruments can be deployed to reach them? How can policy-makers help their countries or regions adapt to the structural changes that come with these megatrends? How can they make sure, their respective economies remain—or become—competitive with energy affordable for all?

Looking at this from an environmental and therefore normative perspective, one additional question is: How can we speed up energy sector transformation? The UN Agenda 2030[2] defines "affordable and clean energy" as a common goal (Sustainable Development Goal No. 7), pointing to the millions of people who still lack access to modern forms of energy. In the Paris Agreement, 153 nations (so far) have committed themselves to hold "the global average temperature to well below 2°C above pre-industrial levels and pursu[e] efforts to limit the temperature increase to 1.5°C above pre-industrial levels".[3] To have any chance of achieving the international climate goal, the near-to-complete decarbonization of the energy sector by 2050 is a must—a sector, which since its "inception" has been strongly influenced by

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[1] "Clean" in this context refers for example to low or no emissions of particulate matter and/or greenhouse gases.

[2] Resolution adopted by the General Assembly on 25 September 2015, "Transforming our world: the 2030 Agenda for Sustainable Development", United Nations, A/RES/70/1.

[3] Article 2 of the Paris Agreement, which entered into force 4 November 2016 and as of July 2017 has been ratified by 153 countries.

governmental efforts to shape it according to their country's respective vision of a desirable future (or sometimes to benefit a ruling elite).

The stakes are high. Policy-makers, who deal with the rapidly changing energy sector or try to guide this change, face multiple demands and may struggle to identify the best entry points for intervention. They face different interests, structural hurdles, fast moving markets and at times game-changing technological developments. They are challenged by difficult choices in regards to prioritizing or even harmonizing short-term and long-term goals. To explore these questions, this paper presents the European and the German experiences with energy sector transformation.

EU Climate and Energy Policy: A Mixed Picture So Far

In 2009, the European Union (EU) committed itself to the so-called '20-20-20 targets', aiming at reducing GHG emissions by 20% compared to 1990 levels, improving energy efficiency by 20% and providing 20% of all final energy consumption from renewable sources. Currently, the EU is on track to reaching all three of these targets, and energy policies have played a key role in this success. More specifically, the promotion of renewable energies has been successful in increasing deployment, and energy efficiency standards have contributed to moderating energy demand.[4]

This success contrasts with what amounts to clear disappointment in the case of Carbon Capture and Storage (CCS), a technology that aims at capturing CO_2 e.g. from the smokestack and storing it underground or in the sea. Together with the 20-20-20 targets, the EU adopted a legal framework for the safe geological storage of CO_2 and provided funding for pilot schemes. However, this June Uniper and Engie, two major European energy suppliers, announced their intention to pull out of Europe's last major demonstration project for CCS based in Rotterdam. The companies cited the uncertain future of coal firing as the main reason.[5] In countries such as Germany and France, attempts to test CCS have stalled early in the process due to resistance from local populations. The current status of CCS highlights a more general trend: In Europe, public acceptance can make or break new technologies and should thus be taken into consideration in public policy decisions.

With respect to policy instruments, experience to date with the EU emissions trading scheme (EU ETS) has been disappointing from an environmental policy perspective. While the technical implementation was successful and the scheme is often praised as the 'flagship' of EU climate policy, the EU ETS has failed to induce a carbon price high enough to trigger significant technological innovation or fuel switching. The initial over allocation of allowances, banking options, an inflow of offsets from third countries and weak economic growth are likely all to blame for a price that has hovered well below 10 Euro per ton of CO_2 for several years now. Despite ongoing efforts to improve the system, experts do not expect the price to rise significantly over the next decade. As a result, countries such as the UK have opted to supplement the EU ETS with a national instrument, in this case a floor price for carbon.

Building on lessons learned and other experiences from the 2020 climate and energy package, policy makers and stakeholders the EU is currently debating and working on a policy framework for the next decade. In October 2014, the EU Heads of State agreed on an economy-wide target to cut GHG emissions by 40% by 2030 (compared to 1990 levels). As Figure 1 shows, the 2030 target requires a much steeper reduction pathway compared to that achieved in the previous three decades, but is still insufficient relative to the linear trajectory required to meet the EU's long-term goal of cutting GHG emissions by 80 to 95 % in 2050.

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[4] Eurostat 2017. "Smarter, greener, more inclusive? Indicators to support the Europe 2020 strategy — 2017 edition."

[5] Hodgson, R. 2017. "EU's CCS prospects hit as energy majors pull out." ENDS Europe DAILY, 29 June 2017.

The current debate surrounding the EU 2030 framework demonstrates the continuous challenge of rallying political support for ambitious low-carbon policies. Priorities vary between EU Member States due to differing levels of economic prosperity, industrial structure and diverse national energy systems. For example, the governments of Poland and the Czech Republic worry about their coal industry, while countries such as Sweden or Portugal with a strong renewable energy sector and potential push for more ambitious targets and policies. Furthermore, due to different historical experiences and political convictions, many of the Central and Eastern European countries see energy security as a more pressing concern than decarbonization.

Figure 1: EU GHG emissions and projections, 1990 – 2050[6]

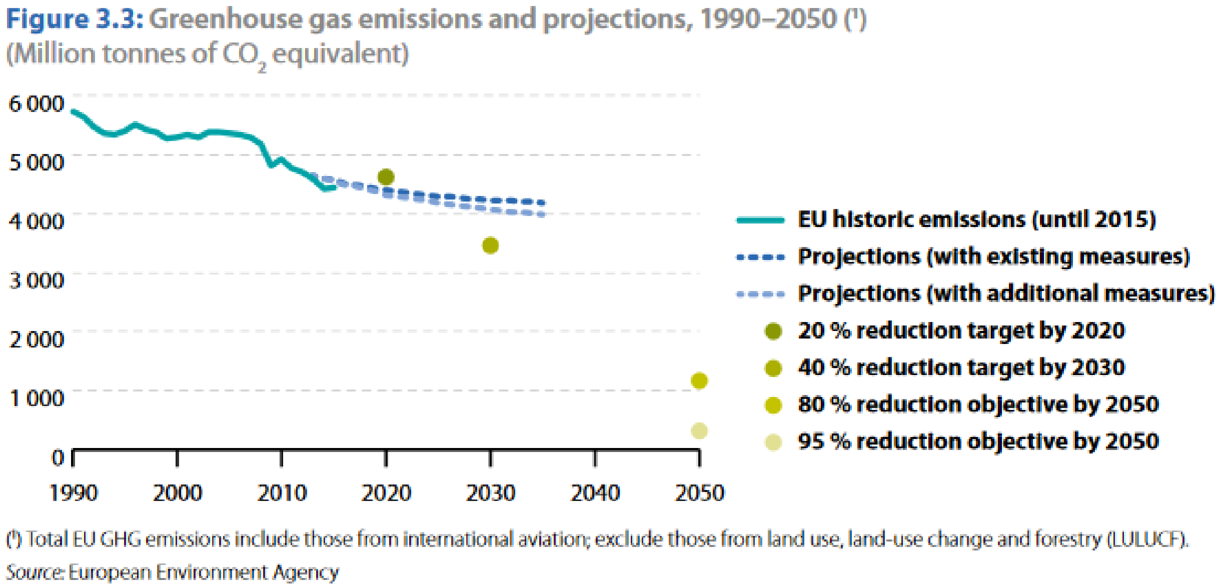

Figure 3.3: Greenhouse gas emissions and projections, 1990–2050 (¹)
(Million tonnes of CO_2 equivalent)

(¹) Total EU GHG emissions include those from international aviation; exclude those from land use, land-use change and forestry (LULUCF).
Source: European Environment Agency

Yet, despite differing national priorities, the EU remains an example of the benefits that energy sector cooperation can bring. Integrated grids and a liberalized, liquid energy market allow for higher stability, increased competition and lower costs for all energy users. They also ease the integration of renewable energies and particularly renewable electricity, as fluctuations in solar and wind power can be balanced out more reliably and at lower cost in an interconnected market.[7]

Moreover, noteworthy synergies exist between remedies to energy security concerns predominant in Central and Eastern European countries and the low-carbon agenda. This is in particular true for building refurbishments, given that a prime use for natural gas in the EU is heating. Energy-efficient buildings provide a route to alleviating concerns about dependence on Russian gas supplies, while delivering climate benefits at the same time. Similar co-benefits exist with respect to air quality and public health.

The German *Energiewende* Delivers on Renewable Energy at Manageable Costs

The German *Energiewende* (energy transition) is the federal government's decision to phase-out nuclear, reduce GHG emissions and boost renewable energies and energy efficiency. It is underpinned by targets and timetables. It has drawn considerable attention due to a number of reasons, not least of which being that a leading industrialized country—Germany—has decided to reinvent its energy sector.

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[6] Eurostat 2017. "Smarter, greener, more inclusive? Indicators to support the Europe 2020 strategy — 2017 edition," p. 88.

[7] Connect 2016. "Upgrading the internal energy market: The power market 2.0."

Germany's aspiration is also marked not only by broad public support but since 2011 a general consensus among all relevant political parties. Over the last two decades, the *Energiewende* has triggered a technological and economic boost in renewable electricity innovation and deployment, the speed of which has surprised many people both in and outside of Germany.

Together with other pioneers, such as Denmark, Spain and Italy, the Germany energy transition has helped to drive down the unit costs of photovoltaics and wind energy. The use of feed-in tariffs for renewable electricity has become famous as a prime example of policy driving technology transformation. Starting with a guaranteed payment of over 0.50 Euro per kWh for solar and over 0.09 Euro for onshore wind in 2000, the feed-in tariff instrument kick-started market growth resulting in global average costs of 0.04 Euro per kWh for wind and 0.05 for solar in 2016.[8] Contrary to initial fears, the grid is still stable and the annual occurrence of power outage in Germany remains among the lowest in the world.

What helped to make renewable electricity a success in Germany? Continuity in political commitment across party lines and stable public support played a key role. Public support was bolstered by the option to actively participate in the transformation through "citizen energy", i.e., direct or joint investments in renewable energy plants.

Other prerequisites for success were a liberalized energy market with guaranteed grid access rights for all suppliers (controlled by grid and anti-trust authorities), the unbundling of vertically integrated incumbents and priority grid access for renewable electricity Furthermore, a favorable policy design providing high investment security was a crucial pre-condition for low financing costs. These policy choices were in part driven by the EU—the liberalization of the electricity market—and in part by national decision-making and policy design—for example the early feed-in tariff. All of these factors allowed new and also "small" actors to become independent power producers for renewable electricity and helped to raise substantial amounts of private capital—often at lower rates of return than utilities would have expected. It has been and is driven by policy entrepreneurs and entrepreneurial frontrunners—e.g. the so-called "Power Rebels"[9] in Schönau, a town in southern Germany. As early as the 1990s, these rebels, i.e., the citizens of Schönau, bought the local grid, after collective funds from 750 locals and a nationwide campaign. As a result, they became a national frontrunner in renewable electricity production. Two decades later, they have a firmly established position in this market. Other players were not as lucky. For example, the solar power company Solon, founded in 1996, established a new business model as a one-stop-shop for solar solutions and grew at impressive rates to become one of the largest module producers in Germany and Europe. However, the company then missed out on adapting to the changing regulatory and economic environment and was forced to file for bankruptcy in 2011. Nevertheless, despite these anecdotal challenges, the data show clearly the successful expansion of renewable electricity. Currently, renewables make up more more than 30% of the overall power consumption in Germany, driving down the market share and stock price of sleepy incumbents like RWE[10].

Finally, the renewable power expansion was also made possible by constant policy learning. Without a single blueprint, monitoring, reviewing and learning were part of the policy design both for single acts like the Feed-In Law as well as for the *Energiewende* as a whole. These elements have been institutionalized through a governmental monitoring process, which is itself reviewed by an independent Expert Commission[11]. As an ever evolving system also faces legal and administrative challenges, further innovative approaches were implemented, for example, a Clearinghouse for the Feed-In Law. The

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[8] IRENA 2017. "Renewable energy auctions. Analysing 2016".

[9] Morris and Jungjohann 2016, "Energy Democracy – Germany's Energiewende into Renewables", p. 84 sqq.

[10] RWE as one of the biggest incumbents in Germany has lost around 80% of its market value in the last 10 years and more than 50% in the last 20 years.

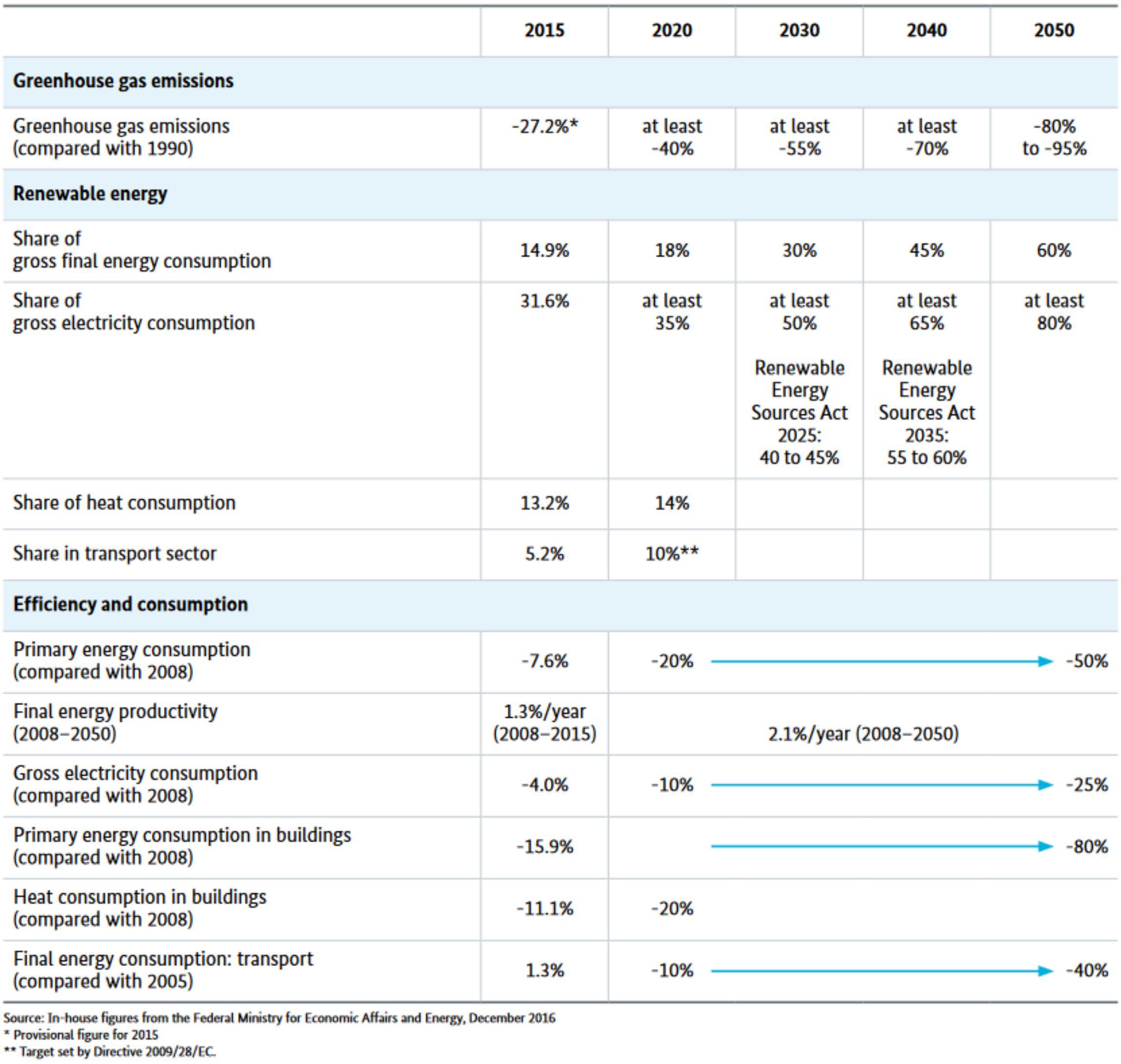
[11] The commission is clumsily called "Expert Commission on the Energy of the Future Monitoring Process". The summary of their most recent assessment is available in English.

Clearinghouse serves as an independent body for timely and efficient dispute settlement outside the court system.

The costs of renewable electricity expansion are significant. In 2016, German electricity consumers spent 22.9 billion Euro[12] for a levy added onto electricity prices to finance renewable energy investments. As a share of disposable incomes, however, consumer spending on electricity has remained more or less flat since the energy transition started, and the majority of the population remains supportive of renewable energy. Energy-intensive companies are exempt from paying the levy, which ensures that industrial competitiveness is not threatened.

It is important to note that the German *Energiewende* is not only a transition to sustainable electricity. It includes a broad package of targets, aiming at an economy-wide transformation (see Figure 2).

Figure 2: Quantitative targets of the energy transition and status quo (2015)[13]



	2015	2020	2030	2040	2050
Greenhouse gas emissions					
Greenhouse gas emissions (compared with 1990)	-27.2%*	at least -40%	at least -55%	at least -70%	-80% to -95%
Renewable energy					
Share of gross final energy consumption	14.9%	18%	30%	45%	60%
Share of gross electricity consumption	31.6%	at least 35%	at least 50% Renewable Energy Sources Act 2025: 40 to 45%	at least 65% Renewable Energy Sources Act 2035: 55 to 60%	at least 80%
Share of heat consumption	13.2%	14%			
Share in transport sector	5.2%	10%**			
Efficiency and consumption					
Primary energy consumption (compared with 2008)	-7.6%	-20%	→	→	-50%
Final energy productivity (2008–2050)	1.3%/year (2008–2015)	2.1%/year (2008–2050)			
Gross electricity consumption (compared with 2008)	-4.0%	-10%	→	→	-25%
Primary energy consumption in buildings (compared with 2008)	-15.9%		→	→	-80%
Heat consumption in buildings (compared with 2008)	-11.1%	-20%			
Final energy consumption: transport (compared with 2005)	1.3%	-10%	→	→	-40%

Source: In-house figures from the Federal Ministry for Economic Affairs and Energy, December 2016
* Provisional figure for 2015
** Target set by Directive 2009/28/EC.

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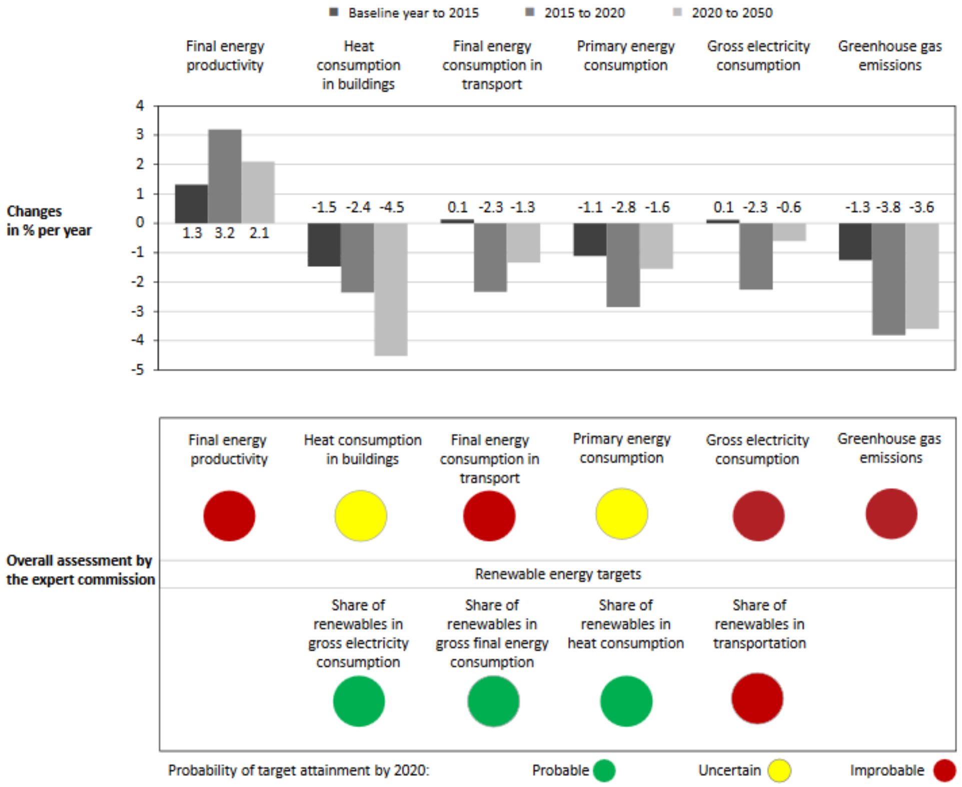
[12] BMWi 2017. “EEG in Zahlen: Vergütungen, Differenzkosten und EE“.

[13] Federal Ministry for Economic Affairs and Energy 2016. “Fifth Energy Transition Monitoring Report –The Energy of the Future – 2015 Reporting Year”.

The energy transition's targets are ambitious and to date progress is mixed. According to the Expert Commission, Germany is on track to reach its renewable energy targets for 2020—with the exception of renewable energy for transport—but is very likely to miss its targets on GHG and overall energy demand reduction.

Figure 3: Overview of progress on energy transition targets for 2020[14]



The main reasons hampering overall success in reducing GHG emissions are continuously high levels of coal-firing and slow progress in the transport and building sectors. While newly added renewable generation has more than overcompensated for the loss in capacity from the eight nuclear reactors that were shut down in 2011 after the Fukushima accident, low global coal prices have driven gas plants out of the market—both in Germany and also in neighboring countries through increasing electricity exports.

With the ETS carbon price signal subdued, the situation is unlikely to change based on market dynamics alone. In the face of this, the already ongoing controversial political and public debate about a government-led coal phase-out will have to be taken up again after the federal elections in September 2017. Politically, it has proven much more challenging to manage the exit from existing technologies than pushing for new technologies.

Clean Energies and Energy Policy Goals

The current technology and market developments in the context of clean energy around the world are very promising. While things have slowed down recently in Europe, developments elsewhere and in countries like China have gained momentum. In many countries worldwide, the electricity sector is in the midst of reinventing itself, with the costs for renewables and storage solutions plummeting and

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[14] "Statement on the Fifth Monitoring Report of the Federal Government for 2015", December 2016.

incumbents like the Italian ENEL working on progressive ideas such as the concept of an “off grid future”. More recently, electric mobility has received a boost in positive public perception from entrepreneurs like Elon Musk of Tesla and in the marketplace by the policy decisions of large players, e.g., China. Such developments fuel the assumption, fear or hope—depending on where you stand—that the energy system of the future will look much different than the energy system of the present.

While energy development pathways around the world are driven by different goals, the benefits of expanding renewable energy sources can be considered favorable for many countries. Some of the main goals[15] and benefits include:

- developing new market opportunities;
- strengthening energy security by developing national or diversifying energy sources;
- furthering energy access, e.g., also in rural areas off the grid;
- containing the cost of energy;
- maintaining international competitiveness;
- protecting the health of citizens, e.g., by reducing coal dust or particulate matter from combustion engines;
- furthering climate protection by GHG emission reduction and
- avoiding high-risk technologies, e.g. nuclear power.

At the same time, there are challenges that greatly impede progress, such as cheap coal (partly due to environmentally harmful direct and indirect subsidies) as well as flawed policy approaches or structural challenges for policies, countries and policy makers. Particularly countries rich in fossil fuel resources will be challenged to define their pathway to react to the new developments and needs. Controversies during the 2017 negotiations of the G7 and G20 signify clear rifts in international policy circles. In addition to different convictions regarding issues like climate change or the specifics of environmentally harmful subsidies, institutional barriers and lock-in effects should not be underestimated.

Nonetheless, research insights and the international policy agenda as expressed e.g. in the global Agenda 2030 with its Sustainable Development Goals or the Paris Agreement support the energy transition plans of the EU and Germany—and may even require an increase in ambition.

German and European policy have been instrumental in driving technological development and change in a desired direction. But there is no simple recipe. In an inter-related, complex world, global technology developments, price trend, and volatile power struggles breed constant surprises. The way to deal with these is to install adaptive and participatory elements in policy-making, which allow not only incumbents but also newcomers and citizens to get involved, embrace and profit from changes and identify options for those forced to change their pathways. Nevertheless, it is crucial that a pathway with overarching goals is defined in order to provide reliable incentives and robust framings. Implementation should include learning instruments with in-built review mechanisms. This is all the more important, as we cannot afford further lock-in effects due to misguided infrastructure decisions and investments. And there are still many decisions and billions of Euros of infrastructure investments left to be made.

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[15] See also IRENA, “Renewable Energy Innovation Policy: Success Criteria and Strategies”, Working Paper, 2013, p.4.

The International Framework for Energy Policy: The Geopolitics of Energy, The Changing Role of OPEC, and Energy Directions in Europe

Amy Myers Jaffe

Executive Director, Energy and Sustainability, University of California Davis

Global energy markets are undergoing dramatic transformation. Unlike past periods where government policy was the chief engine of change, today's drivers go beyond national energy security and climate change policies. New drivers include both technological and demographic influences that are ushering in unexpected disruptions to the status quo. These structural factors include:

1) rapid urbanization,
2) technological innovation (including artificial intelligence, quantum computing/ big data, the internet of things, electricity storage and automation, among other technological breakthroughs),
3) generational shifts in social attitudes and behavior facilitated by the digital age,
4) revolutionary advances in transportation paradigms including shared mobility, autonomous vehicles, electrification, digitized optimization of freight logistics and last mile delivery services, and digitized multi-modal mobility services.

For the energy world, the impacts will be extensive and broad reaching. Oil and gas supplies are suddenly abundant just at the same time as the enhanced viability of lower carbon alternative fuels and energy storage are making substantial cost breakthroughs, intensifying the competitive landscape for fuels and energy providers. Major global cities are increasingly taking the lead on sustainability policies and climate change, experimenting with carless pedestrian centers that reject massive ring roads with conventional passenger car oriented roadways in favor of mobility solutions that reduce congestion and improve air quality and lifestyles.

Geopolitically, the economic, security and geopolitical payoff for harnessing the potential innovation properly is sufficiently high that the major global powers are adjusting their national industrialization policies to reflect the new opportunities and risks. Increased global competition in the digital industrial revolution related both to energy and security is radically changing the nature of international discourse, with particularly stunning consequences for the geopolitical calculations surrounding oil.

The new U.S. administration has talked about tapping America's energy abundance to strengthen U.S. global dominance and to promote U.S. influence, but understanding the competitive framework and economic, geopolitical and environmental challenges for U.S. energy businesses—both traditional and new energy—will be critical to leverage the economic and geopolitical benefits America's changing energy landscape can provide.

What's Changed

U.S. Shale Oil and Gas: Over the last decade, it has become increasingly clear that the U.S. has more commercially accessible reserves of oil and gas than previously supposed. Industry estimates are that stable prices could stimulate a rise in U.S. production back to 20 million barrels/per day, with the bulk (10 million b/d) coming from Texas' prolific and cost effective Permian Basin. Total U.S. production is averaging close to 9.5 million b/d, with 25 % coming from the prolific Permian Basin of Texas. Estimates are that the Permian production could hit 10 million b/d over the next decade. Breakthroughs in drilling technologies have enabled this production at costs between $30 to $45 a barrel for oil, a level that is cheaper than Canadian oil sands, Arctic reserves and many deep-water provinces.   Shale gas breakeven costs are extremely low at between $1 per million cubic feet to $3 per mcf, in some regions.

Unlike operations for traditional oil reservoirs which rely on drilling technologies that create expensive pressurized wells that cannot be cost effectively shut down during times of low oil prices and restarted again when prices rise, shale oil and gas operations are based on a less expensive production system that involves pounding oil and gas source rock with a water-based liquid used in combination with sand that can create tiny crevices in solid geologic formations to allow oil and gas production. Shale operations can be stopped and started at will with less compromise to the integrity of the wells, providing more flexibility for large changes in production levels if prices change. Whereas a traditional reservoir development might take between five and ten years to complete depending on the complexity of the geology and location, new incremental shale operations can be established in a matter of weeks or months, depending on proximity and access to existing infrastructure.

The speed at which U.S. shale producers can respond to changes in oil prices has dramatically altered the geopolitics of oil and limited the market power of the Organization of Petroleum Exporting Countries (OPEC) and Russia because any manipulation of oil prices through collusive supply cuts would stimulate additional drilling for U.S. shale that could potentially replace supplies within three to six months. U.S. exports of liquefied natural gas (LNG), as more export facilities get opened, could also be utilized to replace any cutoffs of Russian gas if all U.S. natural gas export terminal potential is not committed under long term contracts.

For decades, countries such as Saudi Arabia, Iraq, Iran and Kuwait have opted to restrain their own oil production to keep the price of oil above its marginal costs because they believed that eventually, oil reserves of other producers, especially those in the countries of the industrial West, would be depleted, leading to a slow but steady appreciation of the value of their remaining oil reserves. But the shale revolution calls this view into question. The better the industry's ability to recover oil from shale and other source rock in the U.S., Canada, Mexico, and beyond, the farther away the time is that oil reserves will near depletion.

The implications of delayed depletion for OPEC are significant. If OPEC countries can no longer rest assured that they are going to be financially rewarded down the road from future resource scarcity, they each have to rethink their entire strategic calculus. Does it still make sense to hold back reserve development and production in exchange for higher prices today if there is a possibility that those reserves will depreciate, not appreciate, over time? For a country such as Saudi Arabia with 100 years of oil and gas resources and little else, the issue is existential—if holding back production today means its oil reserves will eventually become stranded and lose their value, if demand for oil falters over time. For OPEC, the benefit of high oil prices now brings more risk if they facilitate shale producers to quickly monetize their assets first, at the expense of future OPEC production. OPEC also needs to consider whether it should pursue lower oil prices to try to delay the deployment of advanced vehicles and alternative energy technologies.

OPEC's new strategic calculus changes the energy policy context for the United States and raises the following policy related questions.

Does the United States now have to worry that OPEC countries or Russia will attempt to lower oil or gas prices so much as to bankrupt the U.S. energy industry?

At the present time, Saudi Arabia, Kuwait and the United Arab Emirates' economic and security interests are sufficiently aligned with the United States in a manner that would discourage them from flooding the market to wreak havoc on the U.S. shale industry. Saudi Arabia is not currently pursuing investments to increase its oil production capacity—which limits the amount of extra oil it has available to add to markets if growth is robust, leaving potentially sufficient room for U.S. producers. However, under weaker global demand conditions, competition for market share could still produce dramatically lower prices that would negatively impact U.S. oil and gas producers as well as advanced vehicle and battery storage companies. Iran and Iraq are limited by the level of foreign investment that can be raised to increase export capacity.

Russia remains a major wildcard and rival to U.S. energy producers. Russian costs are low and Russian exporters have access to advantageous pipelines to Europe and China versus more expensive waterborne shipping and U.S. regasification (in the case of natural gas). European buyers have balked at suggestions that they should pay any premium to lock in U.S. energy supplies, giving Moscow an opening to exploit market share opportunities through discounted pricing. Like the U.S., Russian oil and gas production can increase substantially in a relatively short period of time and it has its own shale resources. Russia has increased its oil production by 500,000 b/d to over 11 million b/d over the last two years.

If U.S. shale can swing production upward during times of high oil prices, does the United States still need a strategic petroleum reserve?

The new reality of the shale revolution and changing pipeline flows within the continental U.S. means a reevaluation of whether the Strategic Petroleum Reserve makes sense. The U.S. Department of Energy is already undertaking a major review and can be consulted by Congress. The U.S. still imports nine million barrels a day of crude oil for refining to meet U.S. oil demand. Much of this crude is heavy sour crude that is required by many U.S. Gulf coast refineries that were built originally to refine oil from Saudi Arabia, Mexico and Venezuela. Production from the U.S. shale regions is a different quality of crude oil (light, sweet) and cannot in many cases replace foreign imports for technical refinery configuration reasons. Thus, the U.S. needs to continue to stock heavy crude to replace foreign barrels for the foreseeable future. The U.S. currently imports very little foreign light sweet crude oil, given the rise in domestic shale production.

The United States is also part of the International Energy Agency (IEA) emergency stockpiling system. Under that system, all countries in the Organization for Economic Cooperation and Development (OECD) agree to keep on hand 90 days of oil for a strategic release during a supply crisis. The IEA system functions, conceptualized under Secretary of State Henry Kissinger in the aftermath of the 1970s oil crises, in great measure as a deterrent to producers to thwart political blackmail of oil consuming countries and to protect the global economy from a major disruption. Not only is the U.S. still requiring imported oil and so it is still beneficial for the U.S. to be part of the IEA system, but the global oil market is fully integrated so disruptions to one is a disruption to all.[1]

Can the United States leverage its emerging importance as a global exporter of oil and gas to enhance its global influence and geopolitical relationships?

There is no question that the U.S. benefits geopolitically from becoming an exporter of oil and gas. To date, U.S. crude oil exports have averaged 1.1 million b/d this year and are projected to rise to 2.25 million b/d by 2020, according to consultants Pira Energy. Canada and China were the largest buyers along with several European countries, South Korea and Japan. The U.S. exports roughly 116 bcf of natural gas to Mexico by pipeline. New U.S.

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[1] Think of the global oil market like a swimming pool where subtracting water at one end impacts the water level equally to all swimmers and adding water raises the level to all swimmers.

liquefied natural gas exports have been averaging 50 to 60 bcf a month and been sold to Japan, South Korea, Spain, Portugal, Italy, Turkey, Argentina, Chile, Kuwait, and the United Arab Emirates, among others. These exports have already led to a weakening of the ability of countries such as Venezuela and Iran to utilize oil and gas exports as a diplomatic tool and give the U.S. more freedom of movement in pursuing national defense policies that might otherwise be resisted by consuming countries worried about oil supplies.

The U.S. has large additional resources of natural gas in Pennsylvania and Ohio that could be commercially suitable for export to Europe (including via the Cove Point LNG terminal in the Chesapeake Bay) and could serve as a lever against Russia's use of energy exports to blackmail U.S. regional allies.

Will U.S. production rise sufficiently for the United States to be energy self-reliant and if yes, does that matter?

It remains possible that the U.S. could achieve net exporter status in the coming decade if a combination of sufficient investment in domestic energy and continued demand management policies keep the U.S. on its current trajectory. It is not enough, however, for the United States to simply see its oil production rise to 20 million b/d via increased drilling in the Permian Basin and U.S. Gulf of Mexico. Virtually all of the credible forecasts for U.S. self-sufficiency assume the United States will remain steadfast in its pursuit of advanced automobiles that achieve both better fuel economy performance or utilize electricity as a fuel and other trends such as other alternative fuels, optimized freight and commercial and residential building efficiency that will lower American oil use over time.

Even the prospect of increased energy self-reliance is already expanding U.S. foreign policy options and removing constraints that previously influenced policy. Reduced dependence on Mideast oil is enabling the U.S. to press its Arab allies harder to take a stronger stance on the fight against jihadist terrorist groups, especially on policies surrounding terror finance. It is also creating a different psychology for American policy makers towards the Middle East, opening up the possibility of considering more independent stances on regional Middle East conflict resolution that cater less to preferences of key allies and more pre-emptively to perceived U.S. interests. It may also weaken U.S. resolve to remain militarily active in the region over time. That's in part because the region's oil producers have less leverage over the global oil and gas markets given the possibility of rising U.S. production and exports. Over time, OPEC oil production changes will increasingly impact exports to China and India more than to the U.S. and Europe as Western oil demand falls and availability of North America supplies increase. Still, global oil markets are highly integrated, meaning a supply disruption to one country has a fuel price impact on all nations.

But in time, self-reliance will reduce the burden on the U.S. economy of mounting trade deficits, balance of payment issues and vulnerability to sharp rises in global oil prices. Self-reliance also means that dollars spent by Americans on energy costs stay within the U.S. economy and stimulate our economy as well as fostering American jobs and income for U.S. energy workers and owners instead of transferring wealth to other nations in the Middle East, Latin America, Africa and former Soviet Union. In other words, the burden of high oil prices on the U.S. economy will decrease over time as imports lessen, reducing trade deficit effects, and more U.S. regions benefit economically from rising oil and gas production. The negative impact on U.S. consumers of globalized fuel price rises will also lessen over time as more Americans access dual fuel plug in hybrid technologies or advanced vehicles with better fuel economy performance, limiting the percentage of household income that must be spent on gasoline. The latter point is an important reason to stay the course on corporate average efficiency standards and programs to promote advanced vehicles.

Given the U.S. energy potential, how important is free trade in energy in North America for the U.S. energy industry?

For U.S. oil production in the Permian Basin to reach its full potential, associated natural gas will also be produced as a by-product. It remains unclear how easily the U.S. economy can absorb this additional volume of natural gas, leading producers to seek customers outside the U.S. A key destination for U.S. exports of natural gas is Mexico and continued and expanded sales of natural gas from Texas to Mexico will facilitate the economics of rising Texas oil production.

The U.S. refining industry also benefits vitally from ready access to secure heavy crude imports from Canada and Mexico.

If oil and gas will be more abundant, should the U.S. still take active policies to support a healthy clean tech industry?

For those who are fundamentally concerned about reducing greenhouse gas emissions to mitigate climate change, the answer to this question is obviously yes. However, the policy to promote advanced energy makes sense for other reasons as well. U.S. export of goods and services are an important driver of U.S. economic growth, jobs and global status. We need to position our economy to be able to compete with the products and services that will be most desirable and competitive in the future global economy as well as the present. Technology innovation is an American value and strength and positions the U.S. economy as a top global competitor. Failure to compete on advanced automobiles in the 1980s, for example, hurt U.S. auto workers and ceded market share to Japanese manufacturers. In positioning the U.S. for future global market competition, clean tech will continue to be an important part of a growing economy. The International Energy Agency (IEA) estimates an additional $36 trillion in clean energy investment is needed through 2050 —or an average of $1 trillion more per year compared to a "business as usual" scenario over the next 36 years.[2]

Many countries are deeply serious about mitigating climate change and therefore their markets represent a large commercial opportunity for clean tech products and services; moreover, many of the energy saving technologies and advanced transportation technologies will be desired based on other metrics and criteria as well because the products and services are superior to current products in many applications and geographies on the basis of cost, convenience and efficiency. Some products may offer opportunities for better protection and resiliency against cyber-attack or natural disasters. Others may match better with the digital economy and habits and preferences of the upcoming millennial generation. By analogy, were the U.S. to improve its manufacturing of wired payphones for use on street corners and airports, those products would not find a market in a globalized market place where low cost cell phones offer superior services to customers even in the most remote and poverty stricken locations. By contrast, digital products that can be made at a lower cost point represent a large opportunity across the world where digital services such as banking, education and medicine are proliferating in markets previously underserved.

Institutional investors with patient long term capital such as pension funds, endowments and family offices represent a promising source of new finance for investing in energy innovation and clean tech but creative mechanisms and supportive government policies are needed to overcome the hurdle of venture and technology risk and to generate the level of return that is needed to match asset managers's earnings targets and payout obligations. Increasingly, institutional investors are showing interest in rebalancing their energy asset holdings to reflect climate change risk and the long-range transition to cleaner energy sources. The volatility in fossil fuel commodity prices over the past few years is motivating investors to desire a more diversified energy portfolio, and many U.S. pension funds and university endowments are facing pressure from stakeholders to play a more proactive role in fostering climate change solutions. It remains

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[2] International Energy Agency (IEA), Energy Technology Perspectives 2012: Pathways to a Clean Energy System, (Paris: OECD/IEA, 2012), 1, http://www.iea.org/Textbase/npsum/ETP2012SUM.pdf.

in the U.S. national interest to facilitate successful private investment in energy solutions in the coming years to keep the U.S. globally competitive through innovation and to continue to reduce American dependence on foreign energy sources.

Government has a role to play in promoting the regulatory and commercial conditions that allow American energy tech developers to attract the needed capital from willing institutional investors to beat out competition from other major players such as China and Europe. Additional financing structures and solutions are needed that can align direct investing opportunities with the long-term objectives of institutional investors.

The U.S. government should continue to develop public-private investment vehicles and facilitate those entities to better leverage the DOE loan guarantee programs and pilot projects to bring in investment participation by institutional investors. Congress could also reinvigorate the Small Business Innovation Research Program (SBIR) and the SBA Equity and Debenture programs and expand funding of these programs to provide seed funding for clean energy startups[3] that could create a larger pipeline of investable companies for institutional investors over time.

Previous administrations have used the purchasing power of the U.S. federal government for clean energy infrastructure projects, energy efficiency projects and advanced vehicle procurement. For example, in recent years, the Pentagon has begun building utility-scale solar farms in several locations in the United States, including Georgia and Arizona, to electrify bases in part to enhance national security by diversifying away from traditional electricity grids that can be subject to cyber-attacks. To tap the purchasing power of the federal government, the current administration and Congress should consider how future construction of federal clean energy infrastructure projects could be done with tie-ins that could facilitate opportunities for private funding participation via green bonds or infrastructure investment vehicles, creating more clean energy investment opportunities for willing institutional investors with predictable government-backed returns.

Tweaks to the tax code could also help propel more institutional private capital into renewable energy. In particular, Congress should authorize the use of Master Limited Partnership treatment for energy sales generated by renewable energy infrastructure[4] to facilitate more institutional money to enter this arena. MLPs allow investments to potentially provide the kind of predictable, stable cash flows to institutional investors as dividend payments.

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[3] Andrew B. Hargadon and Martin Kenney, “Misguided Policy?: Following Venture Capital into Clean Technology,” *California Management Review* 54, no. 2 (Winter 2012): 118–139. The SBIR program has also been found to be effective in moving technologies from academic-based laboratories to commercialization. (C. Wessner, ed., *An Assessment of the SBIR Program* (Washington DC: National Academies Press, 2008). Utilizing the SBA Equity and Debenture program for cleantech venture capital could also play a similar role.

[4] Master limited partnerships (MLPs) are publicly traded companies that are taxed as a partnership. To qualify for MLP status, a partnership must generate at least 90 percent of its income from qualifying sources, as stipulated by the Internal Revenue Service (IRS). The IRS code on statutory qualifying income includes oil and gas exploration, production and oilfield services, mining, midstream gathering, processing, transportation and storage, oil refining and processing, refined products transportation and terminaling, real property rent, timber processing and wood products, fertilizer production, and certain kinds of financial products.

Policies That Work:
A Guide to Effective Federal Energy Strategy

Jeffrey Rissman, Head of Modeling and Energy Policy Expert

Hal Harvey, CEO

Energy Innovation: Policy and Technology LLC

INTRODUCTION

To remain a world leader in technology, sustain economic prosperity through the 21st century, and address the threat of climate change, the United States needs energy that is **clean**, **affordable**, and **reliable**. America is well-positioned to build the energy system of the future, with a strong economy and a rich menu of technology options. However, the best outcomes will be realized only with a policy environment that rewards forward-thinking energy suppliers who help the U.S. to meet its goals. Smart, well-designed policy is the key to promoting an environment where our energy supply meets these objectives and businesses can thrive.

***The Energy Policy Simulator** is an objective, cutting-edge tool to assist in policy selection. It allows users to explore the effects of policies on emissions, costs and benefits, human lives saved, and more. Try it by going to the following URL:*

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In order to design policies that successfully achieve U.S. energy goals, two crucial questions must be answered: First, which policies can achieve these goals at reasonable cost (or while saving money)? Second, how should these policies be designed so as to maximize beneficial interactions, ensure compliance, avoid loopholes, and achieve a positive outcome? This paper is an objective guide to the design of efficient policies that work as intended. Just as there is no such thing as a partisan technology, the principles of good policy design are non-partisan—there is no thumb on the scale.

FOUR KINDS OF ENERGY POLICY

For energy policy to be effective, a suite of policies is needed—there is no silver bullet. To design an optimal suite of policies, policymakers should consider policies of four broad types—support for research and development (R&D), performance standards, economic signals, and enabling policies. Together, they create a powerful symbiosis that can drive more benefits than policies in isolation.

- **Support for R&D:** Government support for R&D can accelerate innovation. New technology spurs economic development and reduces reliance on expensive and volatile power sources. One of the most powerful ways government can support R&D involves creating an environment where private sector R&D can thrive. Examples include the sharing of technical expertise and facilities (such as national laboratories); adopting appropriate intellectual property protections; promoting robust science, technology, engineering, and mathematics (STEM) education; and structuring immigration laws so companies are not prevented from hiring foreign STEM talent. Federal R&D, when properly managed, can unleash powerful new industries as well—and has done so for every major energy technology.
- **Performance standards:** Performance standards set minimum requirements for energy efficiency, renewable energy usage or product performance. Examples include vehicle fuel economy standards, energy-efficient building codes, renewable portfolio standards, and power plant emissions limits. Just as fire codes have drastically cut fires, structural requirements have made buildings much safer, and food sanitation requirements have greatly reduced sickness, well-designed federal energy performance standards can drive innovation and deliver benefits to consumers and industry.
- **Economic signals:** Economic signals are policies designed to accelerate the adoption of clean energy technologies, ensure that positive and negative externalities are incorporated into product costs, or otherwise use the market as a tool for efficiently achieving America’s energy goals. Examples include carbon taxes and subsidies for clean energy production or efficiency upgrades.
- **Enabling policies:** Enabling policies enhance the functionality of the other policies, often through information transparency or reducing barriers to better choices. For example, pre-zoning areas for transmission lines or energy facilities can reduce construction costs, a policy requiring clear energy use labels on products allows consumers to make smarter decisions, and human-centric urban design gives people a wealth of transportation options.

CHOOSING THE RIGHT POLICY

The right energy policy for the job varies depending on the maturity of relevant technologies and the characteristics of the market that the policymaker seeks to influence. For example, economic signals, such as a carbon tax, are best for sectors that are highly price-sensitive and for which there are low-carbon alternatives at near-competitive prices. However, a carbon tax is weak without all of these conditions. Support for R&D helps ensure a pipeline of attractive, low-cost technologies in the future, but this strategy does little in the near term (as R&D efforts take years to bear fruit) and may fail to affect the practices of incumbent companies seeking to amortize old technology, such as inefficient, aging coal plants.[1]

An effective way to visualize the task of policy selection is to map the technology, or problem to be solved, on a “learning curve,” which shows how a technology price changes as the volume of production increases.

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[1] Public utilities commissions allow utilities to charge their customers to recover the costs of building and operating technology used to generate power, but they may not allow utilities to recover the costs of these power plants if they stop using them before they are paid off, even if the utilities could switch to more efficient, cleaner, lower-cost options.

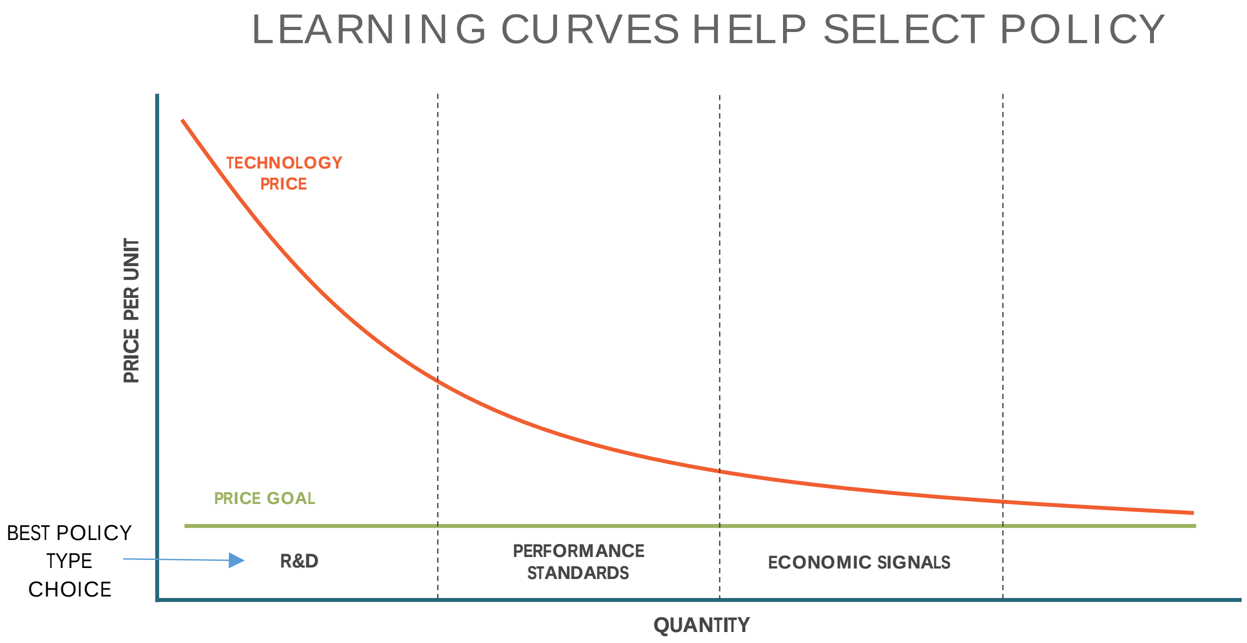

Figure 1. Different policies are most effective for technologies at different points on their learning curves.

Advanced nuclear power, carbon capture and sequestration, fuels from algae, and dozens of other intriguing options require serious, sustained research and development. Government support for R&D has been crucial in the development of past advances in the energy sector, including solar panels, efficient trucks, 3D seismic imaging, directional drilling, and hydraulic fracturing (fracking) for natural gas and oil. Robust government support will continue to be necessary to ensure we have the high-quality options we need.

Once the basic principles of a technology are proven and early production is underway, a big effort is required to drive the price down to a reasonable level. We have seen this work dramatically in the last decade with wind and solar, which experienced price drops of more than 80 percent and 60 percent respectively. They achieved this improvement because a number of jurisdictions set clear performance standards for those technologies. Today, offshore wind, central station solar, zero-net-energy buildings, and other technologies can improve quickest if backed by clear performance standards. It's worth noting that performance standards are omnipresent and commonly accepted by politicians of both parties: Our building codes ensure that buildings don't easily burn or fall down; food handling standards prevent innumerable cases of poisoning; clean water is considered a right.

Finally, for many sectors and technologies, pricing is the key. Removing subsidies for all energy sources is the first step. A carefully-derived carbon tax, or setting a carbon cap with trades allowed, can ensure that the full costs of each energy source are reflected in its price, allowing the market to find more socially-optimal outcomes.

Selecting the right policies, and designing them well, creates rapid, low-cost improvements. That's the key.

POLICY DESIGN PRINCIPLES

There is more to good policy design than selecting policies from the four policy categories discussed above. Each policy must be well-designed in order to function as intended and achieve a policymaker's desired outcome—and a number of policy design principles can help. Careful application of these design principles can make the difference between a policy that works and a policy that fails. Principles are divided up by policy type: Support for R&D, Performance Standards, and Economic Signals.[2]

SUPPORT FOR R&D

Create long-term commitments for research success

Performing research and developing new technology is a lengthy process. Government support for R&D must be robust over the long term, allowing research directors to select suitable research projects and make the necessary investments in equipment, and in hiring and training staff. This applies both to government commitments to its own research (performed in government labs) as well as to private sector research (such as financial support for R&D).[3]

Use peer review to help set research priorities

When prioritizing different research projects to receive government funding, the government should conduct peer review of the options, involving experts both from within the government and within industries that might benefit from technological progress in the relevant field. Consulting with experts can help ensure projects are technically feasible, would be useful to society if accomplished, and have an acceptable risk-reward profile.

Use "stage-gating" to shut down under-performing projects

Research is an inherently risky endeavor, and there is always a possibility that a line of inquiry will produce no results or will produce too few results to justify the required investment. To ensure large amounts of money and staff time are not wasted, it is important to establish "stage-gates" or milestones that a research project must pass in order to continue to receive funding. A project should be shut down if it fails to achieve these milestones, so the staff and funding allocated to that project can be reallocated to more fruitful endeavors.

Concentrate R&D by type or subject to build critical mass

Providing a small quantity of R&D funding to each of many different institutions is inefficient, as coordination between these institutions and duplication of work will consume an inordinate share of the R&D investment. It is better to concentrate R&D funding on a specific topic into a smaller number of institutions—potentially co-located with each other or with relevant industry players—to reduce coordination challenges, facilitate knowledge-sharing, and avoid duplication.

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[2] Enabling policies are heterogeneous in nature—ranging from energy use labels to smart urban design. As such, this paper does not include a list of common policy design principles for enabling policies.

[3] Government has supported private-sector R&D for many decades, and this has been an engine of U.S. economic growth and technological leadership. Government funding of private-sector activity is not unusual; federal, state, and local U.S. governments routinely funds private companies to perform work that is regarded as beneficial for society. For example, they pay private companies to build roads that private businesses use to transport goods. They fund healthcare, which involves handing government money to private hospitals and doctors. They help pay for sports stadiums used by for-profit teams. They provide loan guarantees, loans, tax breaks, or outright grants to help companies build industrial facilities. Etc.

Make high-quality public sector facilities and expertise available to private firms

The U.S. government has invested in the development of extremely expensive, high-quality scientific and engineering research facilities, such as the Department of Energy's National Laboratories, which are staffed with skilled experts and outfitted with state-of-the-art equipment. A private company that wishes to conduct R&D to improve the performance of its products might be unable to afford to build its own cutting-edge laboratories and staff them with experienced scientists. A research partnership with a national lab allows the company to benefit from high-quality facilities and expertise for a comparatively small payment, enabling them to gain the benefits of research without replicating R&D capabilities. These partnerships can also provide a source of revenue for the national lab, making it less dependent on taxpayer funding.

U.S. engine manufacturer Cummins has relied upon Sandia National Laboratory's expertise and combustion research facilities to improve their engine designs.

Protect intellectual property (IP) without stymying innovation

Intellectual property (or patent) protections are necessary to protect private firms' investments in R&D. If patents are not protected, then any firm can make use of research results in its own products, reducing or eliminating the incentive for firms to engage in R&D in the first place. However, it is also important to avoid allowing patent and IP protections to stifle innovation. Patents that are too broad or granted too liberally can form the basis of lawsuits used to drive new entrants to a field out of business. Appropriate IP protections must be designed with great care to provide necessary protections to genuine innovators while preventing patent-holders from blocking innovation.[4]

Ensure companies have access to high-level STEM talent

In order for private companies to conduct R&D successfully, they need a ready supply of talented people with skills in science, technology, engineering, and mathematics (STEM). There are two ways that government can assist. The first is to establish top-quality STEM education programs, helping students start to acquire science and math skills early and providing a route to further develop these skills at the university and graduate school levels. The second policy mechanism is to ensure immigration laws enable companies to hire skilled STEM talent from other countries. Researchers are highly skilled individuals who contribute to a country's economy. To enable R&D success, these people should be granted permanent residency status without lengthy waiting periods, restrictive quotas, or unnecessary bureaucratic burden.

PERFORMANCE STANDARDS

Create long-term certainty to provide businesses with a fair planning horizon

It is important for policymakers to set standards with schedules that extend out many years and to make these schedules known to businesses and consumers. Policy certainty reduces risk and therefore lowers the cost of investments. It allows business to set R&D budgets, start up new production lines, and organize their marketing and

In 2012, the U.S. Environmental Protection Agency announced CO_2, or fuel efficiency, standards for new vehicles that extend through 2025, thereby making targets for the following 13 years known to vehicle manufacturers.

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[4] The topic of appropriate IP protection is complex. For more detail, consider materials from United for Patent Reform, an NGO that has developed guidelines on this topic, supported by many respected member companies, including Amazon, AT&T, Ford, GM, Google, Macy's, Salesforce, Verizon, Walmart, etc.

business planning. Uncertainty confounds all of this, and short deadlines erode a business's ability to manage resources intelligently.

Build in continuous improvement

If a performance standard does not have a mechanism for automatic review and tightening, or simply increment at a steady percentage improvement every year, then it can become stagnant and ineffective. To continue making progress toward a long-term goal, standards should be written from the start to automatically update to take advantage of evolving technology and market conditions. This kind of "ratcheting" mechanism can drive innovation.

Japan's Top Runner program is a performance standard for appliances, electronics, and similar energy-using devices. Every four years or so, each class of device is reviewed: The top quintile in energy efficiency of the product becomes the new floor for all *such products for the next four years. It creates a "race to the top" and rewards the best performers.*

Standards should be technology-finding

Standards should be set based on desired performance outcomes (fuel efficiency, pollutant emissions, etc.), rather than mandating the use of specific technologies. This gives companies the maximum leeway to innovate and apply different solutions, helping to achieve the performance outcomes at least cost.

Prevent gaming via simplicity and avoiding loopholes

Standards must be written carefully so businesses cannot comply with the letter of the law while undermining its purpose. To insulate a standard against gaming and loopholes, it is helpful to write the standard to maximize simplicity and clarity and to state in broad terms the targets that must be achieved, rather than making exceptions or different rules for equipment with different features.

The EPA set more stringent fuel economy standards for "cars" than for "light trucks" and allowed vehicles to be classified as light trucks based on minor design features (such as a vehicle that is "available with special features enabling off-street or off-highway operation and use"). Manufacturers were able to exploit the two standards by making the minimum number of design changes necessary to allow them to classify many of their cars as light trucks, even though these vehicles were marketed and usually used for on-road, personal transportation.

ECONOMIC SIGNALS

Create a long-term goal and provide business certainty

Economic signals must be provided over a timeframe that provides business certainty, allowing firms to adapt their product design choices. For example, a subsidy for fuel-efficient vehicles that expires in a year does not provide enough time for manufacturers to adapt. It may shift consumer choices to existing, efficient vehicle models, but it will not incentivize the development of improved models. Economic signals should progress toward a long-term goal (such as eventually phasing out a subsidy or incorporating the full cost of pollution externalities in a carbon tax).

Price in the full value of all negative externalities (if the externality cost is known)
Or
Use a price-finding mechanism (if the desired performance outcome is known)

Economic signals start with either a known quantity or a known price, and use the market to find the other outcome. If the price of a given policy objective is known (e.g. the value of the externalities caused by an activity), then a tax or subsidy can be set at that price, allowing the market to identify the appropriate level of mitigation action to be undertaken, as well as the least-cost options to achieve that mitigation. If instead policymakers know how much of something should be achieved (such as a specific quantity of clean energy that must be on the grid), then a price-finding mechanism (such as a reverse auction where providers bid to provide the outcome at the lowest cost) can be used to identify the economically-efficient price.

Clear out unnecessary "soft costs"

Many infrastructure projects, including projects that reduce pollution (such as renewable power plants, transmission lines, and rail transportation systems) face unduly long, costly, and uncertain requirements for obtaining the required permits, siting permission, and other documents required to commence construction. The government should reduce this uncertainty for projects that promote economically and environmentally positive ends. This can be done without relaxing environmental standards, for example, by pre-zoning some areas as renewable-ready.

Texas used Competitive Renewable Energy Zones to spur rapid growth in its wind industry. Today, Texas is the national leader in wind power, with almost four times as much installed capacity as California.

Reward production, not investment, for clean energy technologies

Economic incentives for clean energy should be based on the amount of clean energy that is generated and used in the grid, not on the amount of money invested to purchase or install clean energy infrastructure. This ensures that the public incentive is only paid when the public interest is served, via the production of useful, clean energy.

Apply the policy to the smallest set of actors that nonetheless enables coverage of 100 percent of the market

An economic signal becomes harder to administer and more likely to garner political opposition when it directly affects a larger number of actors, especially individual consumers. For example, a carbon cap that tries to reward or punish millions of consumer energy efficiency steps is bound to fail, as the sheer transaction costs swamp the policy goal. A cap set upstream on the coal, oil, or gas producer (or importer) is easier to administer and captures 100 percent of the market.

Ensure economic incentives are liquid

Policies that offer economic signals in the form of subsidies should ensure these incentives are liquid and do not have unnecessary transaction costs. For example, in the United States, to avoid the appearance of providing subsidies, the government usually offers incentives in the form of tax credits. Often, the entities who earn the tax credits don't have enough qualifying income to offset with the tax credits. Therefore, in order to take advantage of the credits, they are forced to partner with entities that have sufficient qualifying tax liabilities. These entities are generally investment banks and other large financial institutions that typically take more than 50 percent of the value of the tax credits, so less than half of the government's subsidy is actually being used to promote the subsidized activity. This structure also increases risk because it requires developers to form business partnerships with these companies, which complicates their process. Ensuring subsidies are liquid and usable by the intended recipient (for instance, by providing them in the form of cash grants) would avoid these problems.

ASSESSING COST OR SAVINGS

It is sometimes assumed that any policy that would reduce pollutant emissions must necessarily increase costs to manufacturers and consumers. This is not the case. There exist a large number of policies that can simultaneously reduce direct economic costs and lower emissions, before even considering the indirect economic or social benefits of reduced emissions, such as fewer premature deaths. This happens because there are many market failures, quirks of human psychology, and other barriers to efficient market operation. Some examples include split incentives, inconsistent discount rates, habituation to pricing levels, inability to capture and monetize benefits of R&D, coordination failures (leakage), imperfect information, high transaction costs, and more.[5]

Marginal abatement cost curves are one tool that can be used to visualize the abatement potential and cost effectiveness of various policies (or technologies). For example, a marginal abatement curve for a variety of potential U.S. policies is shown below. (This curve was made using the Energy Policy Simulator, mentioned in the box on page 1.) Each box in Figure 2 represents a policy at a particular stringency setting. The width of each box (along the X axis) is the emissions abatement caused by the policy. The height of each box (along the Y axis) is the financial cost or savings per ton of carbon dioxide abated due to that policy. Policies below the X axis save money, while policies above the X axis increase costs, and are organized from left to right in terms of their cost-effectiveness.

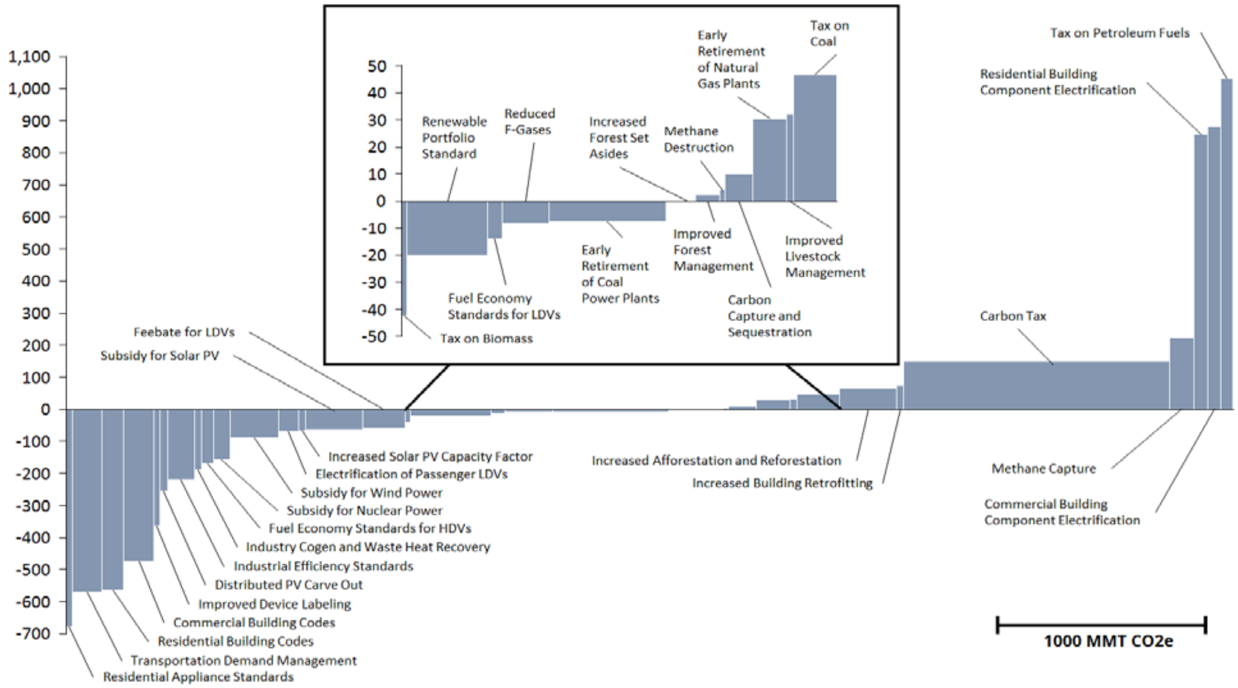

Figure 2. A marginal abatement cost curve for policies in the U.S. (at high stringency levels)

Some of the most cost-effective policies include appliance standards, building codes, transportation demand management (human-centric urban design and public transit), and improved device labeling. These policies help to overcome barriers, provide options, and spread information that enable better choices and allow the market to operate more efficiently.

The single most effective policy at reducing emissions is the carbon tax: a tax on fuels and potentially on other chemicals that scales with the magnitude of their contribution to climate change. A carbon tax affects all aspects of the economy, influencing demand for products as well as incentivizing efficient equipment upgrades and the use of carbon-free electricity generation technologies.

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[5] For an explanation of these and other market failures, see “It Takes a Portfolio: A Broad Spectrum of Policies Can Best Halt Climate Change” in *Electricity Policy*, Aug 2016.

A policy such as a tax on petroleum fuels is relatively ineffective, due to its high cost and low abatement potential. This is because the elasticity of demand for gasoline, diesel, and jet fuel is low: people need transportation services, and there are not always good alternatives to driving or flying. This is why a policy that provides viable alternatives (transportation demand management) is more effective than a policy that applies an economic signal to an inelastic good (a petroleum fuel tax).[6]

Quantitative tools such as the Energy Policy Simulator can help policymakers assess the costs or savings and emissions abatement associated with different policy options.

CONCLUSION

To achieve economic prosperity, technological leadership, and public health, the U.S. requires energy that is clean, affordable, and reliable. Effective public policy creates the environment that makes this possible. Good policy enables the power of the free market to drive these goals. Policies should be tailored to market conditions and technological maturity, encompassing support for R&D, performance standards, economic signals, and enabling policies. Policies will be more likely to be successful if policymakers keep in mind a set of design principles. These principles help to ensure the policies are implementable, avoid loopholes, and do not repeat the mistakes of the past. When assessing policy cost, it is important to remember that a great deal of abatement can be achieved at cost savings through policies that help to overcome market failures. Marginal abatement curves and quantitative policy analysis tools can help take the guesswork out of this process. Aided by good policy, the U.S. can achieve a clean, prosperous future for all.

CLOSING NOTE

This paper is just a taste of a larger Policy Design Guide being assembled by Energy Innovation, which will include details on the best way to implement specific policies, such as vehicle fuel economy standards, urban design, and carbon pricing. Please do not hesitate to reach out if you would like more policy design information or if Energy Innovation may otherwise be of assistance.

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[6] As electric vehicles become more common, they will be an increasingly viable alternative to gasoline vehicles, and a tax on petroleum fuels will become more effective.

The Future Grid and How to Make It More Reliable, Cleaner and Affordable: Lessons from California

Steve Berberich

CEO, California Independent System Operator

The electric grid is evolving quickly as public policy and the technology revolution drive a transition to a new energy economy dominated by three macro trends—growth of renewables and their associated integration, decentralization, and regionalization. Together, they offer new opportunities to improve public health and reduce emissions while keeping electric service efficient, resilient, and dependable. Developed properly, these dynamics will reduce the long-term costs of energy use, take advantage of new technologies, and integrate electricity into the transportation and building infrastructure to extend the benefits to our entire economy. Done in a non-coordinated fashion, they risk driving up costs and undermining essential grid reliability. This paper outlines common challenges and highlights solutions that the world's energy industry faces over the coming decades.

We see the energy transition first hand in California. Through California's aggressive policies for deployment of renewables, growing use of storage, and energy efficiency programs the system is being reshaped. We see three macro trends emerging from these policies but also through a myriad of other factors such as technology evolution and cost pressures acting on the system. Broadly, we see the following dynamics:

- **Renewable deployment and integration:** Low-cost wind and solar resources, combined with advanced clean technologies, make it feasible to meet a significant part of our energy needs free of the costs, risks and environmental damage related to use of fossil fuels.
- **Decentralization**: Distributed solar power is growing in California and continuing to fall in cost and it is serving as a complement to energy generated by traditional power plants. Decentralized distribution networks are beginning to operate in harmony with the bulk power system, where consumers, utilities and the grid operator are managing their specific supply requirements through better forecasting techniques to predict renewable output as well as remote sensors.
- **Regionalization**: Many parts of the world are employing regional grid models that enable collaboration among neighboring regions. Operating a regional grid improves reliability, drives down costs, reduces new transmission needs and provides access to a larger pool of both traditional and renewable resources to manage an increasingly intermittent supply.

Major Trends Shaping These New Dynamics

Energy leaders foresee the development of a number of trends as the electricity industry undergoes a transformation to meet the energy and environmental needs of the future. These trends include increased electricity usage efficiency, declining fossil fuel generation, relying on a system shaped by variable wind and solar resources, managing demand as a supply, electric service that is increasingly decentralized, coordinated regional grids, and integrating transportation and building energy use.

These trends are more than evident in California as it continues on a path toward decarbonizing its electric grid and the overall economy. Getting them to work in harmony to sustain a reliable, cost effective system is the tone of the exploration of the trends shaping not only the California grid but also the broader electric industry.

Increased Electricity Usage Efficiency

Modern economies depend heavily on a reliable supply of electricity. To optimize the value of installed infrastructure, the utilization of that energy must be thoughtful and well-planned, and conservation and energy efficiency lead to improved standards of living by increasing productivity and lowering costs. Standards and incentives that promote the efficient use of electricity must be strengthened or reinforced as energy efficiency should be the top priority for policy making. A unit of power not consumed is a unit of power not produced and that increases productivity and standards of living. California has historically focused on energy efficiency on a number of fronts. These efforts have kept California's energy use some of the lowest in the United States. Many of those efforts are highlighted below:

- Improved measurement and verification protocols to ensure energy efficiency programs meet or exceed demand reduction targets;
- Developed a long-term plan for statewide building energy efficiency upgrades;
- Created a Net Zero Energy Buildings (that produce as much energy as they consume) implementation plan;
- Developed policies and education programs to promote consumer acceptance of direct load control of some appliances in new and upgraded buildings; and
- Implemented policies to incentivize homeowners to retrofit inefficient HVAC systems with combinations of heat pumps, ice storage, thermal storage and solar hot water.

Declining Fossil Fueled Generation

When combined, renewable energy, distributed energy resources and energy efficiency have the potential to serve the majority of electricity needs in most hours. In turn, fossil fueled—mostly natural gas units—generation will be used primarily when clean resources are unavailable. Gas units will need to be modernized to provide quick starts and ramping (i.e. to quickly increase or decrease output) and can operate at low output. Grid operators will need to carefully manage the phase-out of less efficient gas generation while ensuring energy markets support remaining gas-fired plants through capacity compensation schemes or paying more for the unique reliability services the gas fleet provides. The challenges during this process will be immense as zero marginal cost resources put tremendous financial pressure on gas fired units. Key trends driving this pressure are well seen in California but spreading across areas that are deploying large amounts of zero marginal cost renewables. As those resources come off the grid the following implications can be expected:

- Local capacity reliability needs may largely have to be met by non-fossil technologies and resources, including distributed energy resources and local micro-grids with battery storage;
- Transmission and distribution system upgrades will be needed to address or eliminate local constraints that have previously required operation of fossil resources. These upgrades include fast-

acting automated devices to divert flow away from constraints, smart inverter technology that provides voltage support and stability, and synchro-phasor monitoring devices that identify and self-heal potential network stability vulnerabilities. Much of the technology required exists but regulatory constructs based on a traditional system will need to flex;

- To make up for the loss of fossil-fueled resources, regional sharing of scarce resources will need to increase. For example, regional infrastructure planning and resource commitment and dispatch can share regional hydropower resources and associated storage capabilities much like Germany and Norway have done.

Shaping the System with Variable Wind and Solar Resources

As the trend toward cleaner sources of energy grows, energy needs will be served primarily by non-fossil, non-nuclear resources. That supply will revolve around the variable output of wind and solar resources, with gas generators filling the gaps in the clean power supply. Renewables will have to supply an increasing share of Essential Reliability Services (ERS), including primary frequency response, regulation, voltage support, and spinning reserves, all of which had previously been provided by fossil, nuclear and hydroelectric power. Oversupply of mid-day solar generation will have to be mitigated by a combination of measures, including exports to other states (and countries), market bidding by renewable generators, storage, and increased use of electricity in transportation and buildings.

To accomplish this transformation, regions must be ready to re-orient regulatory policies to base system operations on non-fossil resources, including:

- Developing tools to guide procurement of resource portfolios capable of meeting grid reliability needs. Diversity is the key and procurement policies cannot simply rely on one type of renewable technology;
- Ensuring procurement takes advantage of least-cost clean energy supply while considering overall integration costs, including from regional resources;
- Accelerating implementation of time-of-use rates to reshape demand patterns and demand response programs where entities are paid to reduce consumption by a set amount to better align electricity use with renewable output and to minimize flexibility needs;
- Developing new power purchase agreements that require and compensate renewables for providing ERS, ancillary services, energy and capacity, and require market bidding by all resources; and
- Stimulating industry innovation to improve the capabilities of geothermal, wind, solar, biomass and storage technologies to provide flexible output, ERS and increasingly sophisticated grid services.

Improving Demand Management

Future demand is expected to become increasingly flexible and controllable with widespread adoption of internet-based technologies that help consumers automatically respond to changing grid conditions. New technologies can unlock thousands of megawatts of controllable supply and demand that exists on distribution systems. Distribution system operators can manage residential, commercial, and industrial devices, and electric vehicles can provide essential grid services. Combined, these strategies can successfully converge power demand with clean resource supply. More specific future trends include:

- Millions of smart-charging electric vehicles offering thousands of megawatts of controllable demand;
- Electrification of residential, commercial and industrial building energy use and industrial processes reducing carbon emissions while providing essential grid services like fast-response flexibility for load following, frequency regulation and utilization of surplus renewable energy;
- Consumers becoming "prosumers" (producers and consumers) by installing energy management systems to enable demand resource aggregators to automatically provide grid services. Rooftop and community solar resources will provide local generation and micro-grids incorporating battery storage and automated controls can create options for improving resilience and security of local electric service. Other customers will take advantage of opportunities to provide and be compensated for services to the distribution operator and to engage in peer-to-peer transactions through local distribution-level markets operated by the distribution utility.

To unlock these advantages, regulators must build a long-term strategy for basing electric service on demand as much as supply. Potential actions include:

- Developing and implementing data security and data privacy standards covering all customer energy use;
- Deploying sustained educational campaigns to inform consumers of the central role of demand in low-carbon electric systems, and the importance of two-way information flows between customers and system operators;
- Adopting policies and rate structures that enable customers to become active "prosumers" and be compensated for providing services to distribution and transmission system operators, aggregators and other customers;
- Encouraging distribution operators to adopt business models that accelerate development of responsive demand.

Decentralizing the Electric System

The widespread deployment of local solar generation and new technologies is changing the structure of electric service. Local generation, together with smart meters, sensors, advanced information technology and storage, create the infrastructure for local smart grids. And, the continued price declines of these technologies combined with the continued climb in center station delivered power will cause this to accelerate. Properly designed with the appropriate technology, distributed resources can provide a reliable, resilient and secure electric service, and are capable of disconnecting from the main grid in case of large-scale disturbances. Specific trends include:

- Local solar generation becoming available to all customers due to declining roof-top solar costs;
- Formation of local micro-grids enabled by declining battery costs and new IT technologies;
- Customers increasingly becoming "prosumers," with electric vehicles, storage and sophisticated energy management technologies. "Prosumers" can take power from and provide electrical services back to the grid for compensation.
- Distributed energy resources and micro-grids can decentralize distribution grids and minimize need for new high-voltage transmission upgrades. Distribution system upgrades can facilitate bi-directional flows between local generation and the bulk electric system. Growth of local generation can change energy flow patterns, reducing

congestion on existing transmission lines and minimizing the need for new transmission.

To achieve these advantages, regulators should develop a framework for coordinating decentralized electric service with the bulk power system. Specific actions include:

- Accelerating adoption of national standards that define transmission-distribution interfaces, system architectures and the scope of responsibilities of both local and system-wide grid operators;
- Allowing non-utility providers to compete with utilities; and
- Upgrading distribution grids to enable two-way flows of power and information in ways that facilitate development of DERs and local micro-grids.

Regionalizing Electric Grids

Many regions use a Regional System Operator (RSO) model to improve reliability and reduce costs and emissions. Sharing resources across state or international lines reduces the need for new transmission infrastructure, makes low-cost power available everywhere and increases security of supply. Today, 38 separate balancing authorities operate in the Western U.S. grid. This is inefficient and increases costs to consumers. Transitioning to larger, regional grids offer a number of advantages:

- Diversifying peak load and expanding resource sharing allows a unified grid operator to use resources not needed in one area to serve demand in another, reducing the number of power plants required, thus reducing costs and emissions;
- Improving liquidity, driving down costs and easing access to all resources;
- Optimizing electric supply by market bidding, replacing bilateral contracts with security-constrained economic dispatch. Point-to-point transmission makes greater use of existing transmission assets and minimizes the need for new transmission;
- Providing access to a larger mix of clean resources. Clean, low cost resources drive down system average costs while utilizing surplus wind and solar to the benefit of all customers;
- Improving operational control of generation and transmission and eliminates seams and internal transmission charges.

Integrating Electric Service with Transportation and Building Energy Use

By 2030, electricity may power an increasing share of transportation, building heating and cooling and industrial processes. Electric vehicles (EVs) could replace large numbers of internal combustion engine vehicles. Public transportation will become increasingly electric-driven with electric buses and delivery vans displacing some diesel fleets. We believe there will be an increasing trend toward electrifying the broader economy to decrease carbon output. To achieve that goal, a number of initiatives will be required including:

- Equipping new buildings with solar thermal technologies, heat pumps, and electric or solar water heating, while retrofitting existing buildings to replace gas space and water heaters;
- Re-engineering industrial processes to reduce overall energy consumption and take advantage of periodically-available, zero-marginal-cost renewable electricity;
- Electric vehicles may provide a large volume of widely dispersed and

dispatchable storage capacity. Electric vehicle charging—at homes, workplaces or via public charging infrastructure—absorbs excess renewable generation, reduces peak demand and helps optimize the use of electrical system assets;

- Repurposing second-life EV batteries to provide a low-cost source of storage capacity for homes, commercial and industrial micro grids and grid-scale applications; and
- Enabling commercial and industrial building energy management systems to help balance the grid, much like peaker plants did in the earlier part of the 21st century;

Regions should develop policies and programs to integrate transportation and building energy use with electric service. These policies include:

- Base planning in all sectors on total energy use, including direct and indirect use of fossil fuels and electricity used for all purposes;
- Developing educational campaigns which explain the rationale and benefits of approaching energy use holistically, targeting, especially, business and public sector leaders;
- Developing government and utility incentive programs and support mechanisms sufficient to bring millions of EVs into service, including accelerated, widespread deployment of vehicle charging infrastructure;
- Clarifying rules and technical standards for wide-scale participation in distribution system and wholesale electricity markets by behind-the-meter resources such as EVs and buildings; and
- Establishing the sustainable potential of using biomass for energy purposes, including transportation fuels and process heat.

Transforming Vehicles and Energy Needs of Transportation: How Will the Electric Vehicle Revolution Proceed?

Dr. Ulrich Eichhorn

Director of Research and Development, Volkswagen Group

The future world of mobility will enable people and goods to be transported by largely autonomous systems and optimize flows of traffic and travel in order to meet the rise in demand for mobility. From 2020, highly and fully automated vehicles will be put to a range of uses in many regions. The premises of 21st century mobility systems differ radically from those of the 20th century: the ways in which we move people, materials and products are shifting with new technological possibilities, changing values and economic innovations. Intelligent and integrated systems will have an impact on our mobility habits, lifestyles, urban communities and global supply chains. These systems will set the benchmarks against which the mobility providers of the future will be measured. Besides, the demand for mobility tailored to many different locations and deployment scenarios will also grow in the future.

Against the backdrop of the ongoing reduction in CO2 and emission limits, the automotive industry is performing a major transformation. As a result of the fuel consumption, emission and technology legislation emerging worldwide, a trend towards electrified drive trains has arisen in the passenger car segment. Various technologies have been introduced and are frequently based on segment-specific requirements. In addition to all-electric drives, these technologies include modules for electrification such as drive train generators, integrated or additional electric motors and various operating strategies and onboard voltages, hybrid electric vehicles (HEVs), plug-in hybrid electric vehicle (PHEVs) and battery electric vehicle (BEVs).

The especially broad vehicle portfolio, which ranges from microcars to the midsize and luxury classes to the premium and sports car segments, poses a particular challenge for the Volkswagen Group. With regard to vehicles and drivetrains, special emphasis will be placed on e-mobility, not only caused by the expected strong acceleration in electric vehicle sales from 2020 onwards. Nevertheless, there will still be many applications for which a different drive technology is more suitable. In addition, not only the Volkswagen Group has to deal with different wishes and requirements in large markets and in a global comparison. Japan, for example, relies on the fuel cell, China on electric cars and Brazil on ethanol as a fuel. In Europe, plug-in hybrids will play an important role. In America, customers are increasingly looking for more conventional hybrids. This alone shows that the Volkswagen Group needs a mix to serve not only the political framework but also the diverse needs and desires of the customers all over the world and to enable affordable and sustainable mobility. The Volkswagen Group strives to provide their customers with the best quality in all drive types, while at the same time offering reasonable prices and efficient work. This is, of course, ambitious, but it must also be the aim, because no one can say with certainty which technologies will be in demand in the future. For this reason, the Volkswagen Group continues to pursue a selection of technologies in order to remain successful worldwide. The size of the Group benefits because it allows dividing the tasks.

The Volkswagen Group's fuel and drivetrain strategy is paving the way for sustainable, carbon-neutral mobility. The goal is to increase drive system efficiency with each new model generation—irrespective of whether the means of propulsion are combustion engines, hybrids, plug-in hybrids, pure electric drives, or fuel cell drive systems. The drivetrain portfolio will expand and coexist between traditional drivetrains and e-mobility will increase in the future. In the coming years, the Volkswagen Group intends to launch more than 30 different types of purely battery-powered electric vehicles (BEVs) and to sell between two and three million BEVs by 2025—equivalent to around 20–25% of the Group's expected worldwide sales—and up to 50% of sales in 2030. Thus, the challenge for the future will be promoting market acceptance for electric or electrified transport, for example, by increasing the driving range of electric vehicles, by consolidating technologies to lower system costs and leverage synergies as well as to meet individual mobility demands. As the battery is the heart of an electric vehicle, its energy content is the deciding factor in determining the vehicle's range and performance. In light of the gains in market volume and unit sales of electric vehicles over the coming years, the Volkswagen Group has established battery technology as a new competency with a Centre of Excellence and pilot plant at its Salzgitter factory. The price and the range of BEVs will be addressed through accelerated research and development in battery technology, while the charging infrastructure requires local, regional and national investment and regulation. With regard to e-mobility, the Group also closely monitors what new players—mainly Chinese—are doing with heavy government backings. Furthermore, for Volkswagen as the market leader, China in general, as the world's most important growth market, will still play a crucial role in this large transition, though state controlled in many ways.

Undoubtedly, automated vehicles can improve traffic efficiency and safety greatly, congestion and energy consumption somewhat. In the future, mobility will not only mean moving from place to place, but will be expected to create safety and health benefits, too. People's understanding of health will undergo a fundamental shift, with ever more of us taking responsibility for it into our own hands. Health will be understood not only in the physiological sense, but will encompass our all-round personal well-being. The design of future mobility systems will take this broader concept of health into account.

Today already, governments are setting standards to steadily drive down pollution and promote new technology. Most notably and recently the EU set standards to limit to important vehicle emissions in real driving. The so-called RDE ("real driving emissions") regulation extends the limits that used to apply to bench tests to real driving on the streets. Because the regulation aims to include as many driving situations and styles, the regulation produces a large scatter of results that vary depending on location, test conditions, weather and drivers. This renders the test results rather useless for comparison of vehicles, consumer information or fiscal purposes. RDE test results work best as a "not to exceed" standard complementing more repeatable, better-defined methods on the test bench.

Corporate Average Fuel Economy (CAFE) and Greenhouse Gas (GHG) regulations are measures, derived from the global UN Climate Change agreements and target (e.g. Kyoto-Protocol, Paris Agreement) as translated in targets for the automotive sector. This is an important part to ensure that every sector contributes to achieve the global CO2-emission levels and ensure that the greenhouse gas effect is limited to 1.5°Centigrade. In a world of conventional engines, CAFE and GHG regulations caused an improvement of the vehicle efficiency. The worldwide CAFE and GHG targets now are at a level which requires a transition into electrification to meet these targets. The automotive industry is currently in the situation that the transition into electrification in the market is still in the beginning. CAFE and GHG regulations cause the development of these technologies and the market introduction. Nevertheless the market uptake and the consumer acceptance are also based on infrastructure. Regulators, infrastructure and automotive manufacturers need to work hand-in-hand for a successful transition.

But innovations and new technologies for reducing or measuring emissions and fuel consumption are not enough to minimize the effect of vehicles on the environment. That is why Volkswagen Group examines the entire product life cycle of our vehicles—including the production of both raw materials and components—and prepares life cycle assessments.

The issues we will face in the run-up to 2025 are challenging, and therefore cooperation will be required over the next decade if we are to solve them. Cooperative solutions are essential to answering the questions that will be asked of the future mobility as well as meeting the needs that will arise. Besides that, the car manufacturers will face further consolidation. Thus, the Volkswagen Group not only takes all new players very serious but in many cases works with them, too. In the field of connectivity, the Volkswagen Group works closely, for example, with Apple, Google and Microsoft in using their expertise and combining it with their own. In the field of e-mobility, the Group closely monitors what established competitors and new players are doing in different regions. Concerning the automation of vehicles, the Volkswagen Group has been active in this field more than a decade—starting with “Stanley”, who won the first Defense Advanced Research Projects Agency (DARPA) Grand Challenge in 2005, “followed” by the self-driving Audi A7 “Jack”, who drove itself 900 kilometers from the Bay Area to Las Vegas in 2015—and holds more patents in automated driving than the above mentioned companies combined. Yet the Group has not considered a level-3-system ready for market until this year with the new Audi A8 due to the exacting levels of reliability, maturity and functional safety that the Volkswagen Group demands.

Regarding this game changer, which drives the current transformation of the automotive industry, the Group’s approach is not necessarily to be the first to market, but the best—because the Volkswagen Group wants to shape a desirable future by democratizing mobility in a responsible and sustainable way. Over the coming years, the Group will make major investments in the technologies of the future that are necessary to realize their vision. This includes the electrification of the model range, the digitalization offensive throughout the Group, safe autonomous driving and the offerings of mobility services. To do so, the Volkswagen Group is establishing a cross-brand mobility solutions business, in which the Group is setting up mobility services. In this context, the Volkswagen Group has established a new business unit called MOIA whose aim is shared mobility on demand with purpose-designed electric, automated vehicles. Subsequently, further attractive and pro¬fitable services that are tailored to customer requirements, such as robotaxis, car sharing, or on-demand transport for the logistics industry, shall be developed or acquired. In order to achieve this, Volkswagen will rely to a greater extent than previously on partnerships, acquisitions and venture capital investments.

However, industry cannot shape mobility alone. Especially for the market success of electric mobility the build-up of charging infrastructure and standards are central. This can only be accomplished by governments—be it on the national or the European level. It is also on these levels that market support policies are formulated that can support the market uptake. While it is up to the individual government and its specific interests to formulate individual policies, it is important policies do not favor individual companies and do not contradict other policies of that government.

In addition to the activities of national governments, strategies to further develop mobility solutions must also be developed in cities and regions.

Smart cities are the first step toward rethinking the future shape of urban life. Integrating relevant infrastructure and optimizing the flow of supplies and transport are the key action areas. An awareness of sustainability and the realization of social, environmental and economic goals to ensure the world remains livable for generations to come—these are the major challenges that we are facing. Though there have been positive developments, many questions concerning the realization of set goals remain unresolved. To limit adverse effects on climate change, consistent measures and regulations will have to be implemented in all areas in the near future. As it can also be assumed that purely technological solutions will be unable to meet this challenge—given that some environmentally friendly technologies cannot be produced without an impact on the climate, and therefore involve feedback effects—it will also be essential for individuals and institutions to change their behavior. Sustainability means simultaneously striving for economic, social and environmental goals in a way that gives them equal priority. The Volkswagen Group wants to create enduring value, provide good working conditions and handle the environment and resources with care. The Group's goal is to run their business responsibly along the entire value chain. Everyone should benefit from this—the customers, the employees, the environment and society.

Strong, progressive regulation of the mobility sector can therefore be expected in the near future, and will shape the mobility of the future in a way that reaches beyond the question of how vehicles are powered, striving for a unconditional sustainability and a planetary consciousness. Proposals, models and strategies by individuals, cities and regions all around the world are already leading this development. The Group's future program TOGETHER – Strategy 2025 is addressing forward-looking topics, thus laying the foundations needed to achieve our global sustainability goals. The Volkswagen Group wants to make a decisive contribution to shaping not only today's mobility, but tomorrow's as well.

The Future of Transportation

Drew Kodjak

Executive Director, International Council on Clean Transportation[1]

Mary Barra, Chief Executive Officer of General Motors, has repeatedly said, "I believe the auto industry will change more in the next five to 10 years than it has in the last 50."[2] Investment bank UBS wrote that it is "more convinced than ever that electric cars are about to reach the tipping point in the penetration curve in the next few years."[3] And California Department of Motor Vehicles Chief Information Officer Bernard Soriano, speaking about autonomous vehicles, said, "I'm not one to use hyperbole, but this one is a game-changer. It will change the way we function as a society, for the better."[4]

These quotes illustrate major trends that are driving profound change in the auto industry: increasing numbers of electric cars and trucks, declining interest in car ownership, expanding use of ridesharing and carsharing services, and, eventually, emergence of autonomous vehicles.

Within this context, this paper explores these central questions of the day: In what ways, and how fast, should we expect the auto industry to change? And what, if anything, should policymakers do to guide the industry through this coming transformation?

Setting the Stage: A Brief History

Our starting point is the city of Los Angeles after World War II. Its residents were experiencing difficulty breathing and stinging eyes due to fog. No one knew what was causing the fog, until a Caltech chemistry professor linked pollution from automobile tailpipes to smog in the 1950s. That discovery led the state of California in 1961 to impose the first motor vehicle emission control—positive crankcase ventilation. Over the next 50 years, California and the U.S. Environmental Protection Agency continued to tighten pollution controls. Thanks to that sustained period of incremental change, today's vehicles emit less than 5% of the emissions of a 1950's uncontrolled vehicle. Today, the cost of these controls—such as the catalytic converter, better air-fuel ratio, and evaporative emission controls—is a relatively modest $400 for a four-door gasoline sedan.[5] Over the last half-century, air pollution in the United States has declined by more than 70%, largely because of the success of motor vehicle emission standards, while vehicle miles traveled have nearly doubled, and Gross Domestic Product has grown by 246%.[6]

Today, a similar story is evolving with respect to fuel economy and greenhouse gas standards. California and the United States have once again set the pace for the world, by implementing passenger car standards that double fuel economy by 2025[7] and heavy-duty truck standards that are expected to cut new vehicle fleet emissions by a third from 2010 to 2027.[8] No other country in the world has established standards as stringent or far-reaching as those of the United States.

Globally, 10 nations have established some form of passenger vehicle fuel economy or carbon dioxide (CO_2) emission standards, covering more than 75% of the 77 million passenger vehicles sold last year. Heavy-duty vehicles are a close second to passenger vehicles in terms of total CO_2 emissions. In many developing countries, including Brazil, China, and India, heavy-duty vehicles account for the largest share of transportation energy consumption. Considering the continued adoption of passenger vehicle efficiency regulations, coupled with the projected increase in global freight demand, in the next 20 years, heavy-duty vehicles are likely to surpass passenger vehicles to become the Number 1 source of transport-related CO_2 emissions.

Efficiency standards for heavy-duty vehicles are in their infancy compared to those for passenger vehicles. Only four countries in the world currently have heavy-duty vehicle efficiency standards—Canada, China, Japan, and the U.S. A number of other countries/regions have indicated they are currently working toward a heavy-duty standard—Brazil, the EU, India, Mexico, and South Korea. The ICCT's global target—developed in collaboration with the International Energy Agency—for all types of heavy-duty vehicles is a 35% reduction in fleet average, new vehicle fuel consumption by 2035.

Progress is rarely linear, and is not without occasional digressions. One widely covered scandal involved Volkswagen's cheating on U.S. emissions tests with its passenger diesel vehicles from 2009 to 2016, commonly referred to as "Dieselgate." Several European governments—France, Germany, and the United Kingdom—subsequently tested diesel passenger cars and discovered that nearly all diesel cars sold in Europe exhibited elevated emission levels during normal driving.[9] The progress on fuel economy standards is also not without its challenges. In Europe, about half of the expected CO_2 reductions have not materialized due to use of overly lenient test methods. And in the United States, the shift to larger cars and trucks has led to a downward adjustment in the 2025 fuel economy target from 54.5 mpg to 50.8 mpg.[10]

The question for government policymakers is how to guide the industry to make long-term investments that improve competitiveness as well as protect public health and the environment. The journalist Gerald Traufetter recently published an introspective editorial in Germany's most read weekly newsmagazine *Der Spiegel*, in which he concluded that protecting the existing German auto industry sometimes harms its future:

> *That the German car industry is facing this dilemma is also due to the failure of German policy. Germany looked away from all the dirty tricks for far too long. Germany gave lobbyists the lax limits they asked for. Germany always protected the car companies—and diminished their future prospects. And Germany still does: Chancellor Merkel and her Vice-Chancellor Gabriel recently insisted in Beijing that German car companies would not impose a sales quota on electric vehicles.*[11]

The United States faces a similar question. The federal government has announced its intention to review, and likely roll back, the 2025 passenger vehicle fuel economy and greenhouse gas emissions standards. Senator Blunt has introduced legislation that would relax these fuel economy standards from 2022 to 2025 (S. 1273, cosponsored by Senators McCaskill, Moran, Peters, Stabenow, and Young).[12] An alternative, forward-looking pathway is being created in California, where the state is developing the next iteration of post-2025 greenhouse gas emission standards, including separate production quotas for zero-emission vehicles.

The outcome of this current policy discussion will have broader implications regarding how effectively the U.S. Congress and the executive branch embrace, support, and engage with the suite of emerging trends in transportation.

The Next Revolution: Electric Cars on the Verge of Cost Parity with Conventional Vehicles

The early seeds of widespread vehicle electrification have already taken root. In Norway, for example, a third of new vehicle sales were electric in 2016. Norway is the leader but it is not alone: In other major markets, including the Chinese cities of Shanghai and Shenzhen; the Dutch markets of Amsterdam and Utrecht; and the U.S. market of San Jose, California; electric vehicles make up at least 10% of new vehicle sales.[13]

How have these markets done it? The short answer is policy. Direct policy interventions are needed as next-generation technologies are entering the fleet. The leading markets, to date, have taken direct aim at the prevailing electric vehicle market barriers and have developed policies to overcome them. Key policy interventions include consumer incentives, vehicle efficiency regulations, charging infrastructure deployment, electric vehicle sales requirements, and local electric vehicle support policies (e.g., preferential parking or access to bus and carpool lanes). These policies have worked. More than 90% of global electric vehicle sales are in China, Europe, and the U.S., where technology-forcing policies have been in place. And the 14 metropolitan areas where the strongest policies are in place account for a third of all global electric vehicle sales.[14]

Governments have many good reasons to nurture electric vehicle development: to protect local air quality; maintain independence from foreign energy sources; mitigate the threat of climate change; and, perhaps most importantly, encourage the development of the new industry in their region. Governments should be as concerned about losing the race to support future vehicle technologies as they are about boosting the growth of their current automobile companies.

It is difficult to overstate the important role that Tesla is playing in setting the pace and the vision for leading-edge technology and business plans. It is clear that German car executives fear they will lose market share to upstarts like Tesla. German auto executive Dieter Zetsche, chairman of Daimler, said that “Tesla has promised a lot but has also delivered most of it,” and Daimler is now developing its own electric car with a range of 310 miles.[15] Other European automakers see Tesla as a threat as well; Volvo CEO Håkan Samuelsson has said that “Technologywise, things will probably move back to the U.S. to an extent after Europe was the center of premium carmaking for the past 30 years.”[16] China-based companies are also emerging as a threat, as these companies see electric vehicles as a key step toward elbowing in on global markets.

There is a great race underway to spur and own the electric vehicle market. From 2010 through January 2017, two million electric vehicles have been sold worldwide—a far faster launch than that of hybrids, primarily because favorable policies have brought more automakers into the game, developing the supplier base for batteries and motors and driving costs down.

The growth has clear early market leaders, with Chinese automaker BYD already building 100,000 electric cars per year, and BMW, Renault-Nissan, Tesla, and Volkswagen each producing more than 60,000. In fact, 15 companies are making more than 20,000 EVs per year, a clear indication that the electric car industry is well beyond early market testing and that a real competition is on. Of the 15 leading companies, eight are headquartered in China, four are headquartered in Europe, and three are in the United States.

Today, the vast majority of electric vehicle sales have been in China, Europe, and the United States. Many companies and countries have indicated that the electric vehicle share of new vehicles will be at least 20% by 2025, up from about 1% in most places today. This is because automakers expect electric vehicles to be cost competitive for first vehicle owners by about 2025.[17] The most progressive markets—with stronger vehicle policies—will be ahead of the curve, while those without supportive policies will lag. It should be noted, however, that cost competitiveness could come sooner than expected—investment bank UBS estimates that even long-range electric vehicles may reach cost parity with internal combustion engine vehicles in 2018.[18] By 2019, Volvo has committed to electrifying its full line up of passenger cars, both demonstrating an accelerating global trend, and showcasing the ambition of China's largest domestic auto maker—Geely—that purchased Volvo in 2010.

The United States can continue to feed, and benefit from, this market growth. The U.S. has been a leading global market for electric vehicles, but most of that growth is in California and the states that have adopted California's clean car rules. To continue to play a role in the electric-drive vehicle future, the U.S. will need efficiency standards that will promote more efficient conventional vehicles and—increasingly as prices drop—electric vehicles. Furthermore, it's valuable for California and other leading states to continue to implement zero emission vehicle mandates, particularly as other markets (e.g., China and Europe) are likely to adopt similar policies. Policymakers can provide a bridge to that future by continuing electric vehicle incentives until performance standards and greater traction among consumers drive the market. Finally, automakers, utilities, and governments can build more charging infrastructure—creating greater public awareness—and more aggressively market electric vehicles to help grow the market. The electric vehicle growth markets will be the ones to benefit most greatly from the fuel savings, environmental benefits, technology innovation, and industry development of electric vehicles.

Decarbonization of Trucks and Buses Could Follow Multiple Technology Pathways

As electric passenger vehicle technology takes hold in vehicle markets across the world, forward-looking policymakers are turning their attention to commercial trucks and buses. There are at least five options for alternative fuels and powertrains: natural gas, biodiesel, hydrogen fuel cells, and electric motors powered by batteries or electrified roadways.[19]

Two of these technology pathways—natural gas and biodiesel—provide only marginal climate benefits. Natural gas engines are much less efficient that diesel engines, and even small amounts of upstream methane leakage can offset the marginal climate benefits from a shift to natural gas. Full lifecycle accounting is also an issue with biodiesel, since biodiesel made from vegetable oils such as rapeseed or soybeans cause significant indirect land use change emissions, and in some cases, are worse for climate than fossil diesel.[20]

More promising options include various forms of electrification, such as plug-in hybrids, full battery electric, electrified roadways, and hydrogen fuel cells. Plug-in electric technologies are particularly attractive for vehicles traveling short distances on set routes with frequent "stop-and-go" duty cycles, such as urban buses, delivery vans and trucks, refuse trucks, and short-haul trucks at ports.[21] Plug-in electric buses have become increasingly more popular, with manufacturers like Ashok Leyland, BYD, Gillig, New Flyer, Proterra, Tata, Volvo, and Yutong producing electric bus models globally. China is leading the pack in terms of deployment of electric buses with the government providing subsidies and promoting the adoption of electric buses.

Electric road technology, either through overhead catenary wires or in-road inductive or conductive charging, eliminates the need for large, onboard batteries while still benefiting from the high efficiency of electric drive technologies. As of early 2017, the German and Swedish governments are carrying out a joint study on the development of electric roads to determine technology feasibility, business models, and cross-border interoperability, and encourage European-level support.[22] In terms of corporate involvement, Siemens is at the forefront of catenary electric heavy-duty truck development with three demonstration projects to date in Germany, Sweden, and California. Catenary electric and fuel cell trucks have shown particular promise in drayage applications around ports and logistic centers, with numerous demonstration projects currently being carried out, especially around the ports of Los Angeles and Long Beach.

Fuel cell vehicles are a viable solution for heavy-duty vehicle applications, offering longer ranges with shorter refueling time compared to battery-electric vehicles. Applications that require more flexibility and faster refueling times can be satisfied with fuel cell technologies, making them appealing for suburban delivery trucks, drayage trucks, shuttle buses, and possibly long-haul tractor-trailers. Toyota and the new startup Nikola Motors have announced the development of class 8 fuel cell trucks.

In 2016, Elon Musk announced that Tesla is developing a battery electric, long-haul tractor trailer.[23] While some researchers are skeptical due to battery weight, range limitations, and cost, one possible solution would be to develop a system of swapping smaller batteries. Further information is expected from Tesla in September.

In terms of policy options, governments have a portfolio of available measures that can be leveraged to achieve efficiency improvements in the HDV (heavy-duty vehicles) sector. These include: efficiency standards, improved infrastructure, financial incentives, carbon taxation, green freight programs, and advanced technology investment. Of these, the single most powerful tool is new vehicle efficiency standards. Well-designed and enforced standards ensure that the average vehicle efficiency of the new vehicle fleet continues to increase at a mandated rate. Historically, these types of standards have proven the most effective at driving incremental technological improvements.

Zero-emission HDVs are a step change technology. The two zero-emission technologies that are relevant for long-haul freight trucks, the most fuel-consuming HDV segment, are electric-drive trucks on electric roadways and hydrogen fuel cells. Facilitating large-scale deployment of these technologies requires the construction of new support infrastructure, either electric roadways or hydrogen fueling stations. Up-front and well-defined, government-backed investment in infrastructure will be needed to give fleets and manufacturers the confidence to heavily invest in development, production, and deployment of zero-emission HDVs. Governments that are committed to decarbonizing their HDV fleets should start investing now for a significant transformation of their highway infrastructure.

The Great Unknown: When—and How Many—Vehicles Will Be Autonomous and Shared?

Almost every day, carmakers, technology giants and start-ups, private sector mobility providers, governments, and university research centers are launching new mobility initiatives around the globe. Many imagine that new mobility will unlock a future free of traffic congestion, where driverless, electric, robot cars provide immediate and inexpensive pay-as-you-go, door-to-door transportation anywhere, anytime. Other, more skeptical voices warn of clogged roads, sprawling infrastructure, increased air pollution, and inequitable access to essential transportation services. The potential impacts of new mobility are wide-ranging and uncertain, but they will fall between the “heaven or hell” images used to introduce the topic. Public policy will have a crucial role in shaping this future—and ensuring that the future leads to less congestion, better air quality, and improved mobility.

One key question is what role the government should play at the national and local levels to ensure that this future mobility market lives up to its promise to ensure low-cost, clean, and efficient mobility for people and goods in our cities. Before answering this question, it is helpful to define some key terms and examine the trends that are driving the transformation of the mobility landscape.

Ride-hailing services (e.g., Uber, Lyft in the U.S., Didi in China) will dwarf the taxi industry by 2030, according to Goldman Sachs.[24] Uber was launched in 2009, delivered 1 billion cumulative rides globally by late 2015, surpassed 2 billion rides in mid-2016, and reached 5 billion rides in May 2017. Other ride-hailing companies have reached similar or greater volume in China and Europe. In the United States, ride-hailing services are especially popular in major metropolitan areas; they have been estimated to account for 20% of the total vehicle miles traveled on a typical day in San Francisco, for example.[25]

Carsharing services (e.g., Zipcar in the United States, car2go in Europe) have also increased significantly worldwide over the last decade. Providers offer station-based and free-floating systems that include conventional and electric cars. By 2015, over seven million members were using 112,000 vehicles worldwide. Frost & Sullivan predicts a growth of the global carsharing market to about 36 million members and 427,000 vehicles by 2025.[26]

All of these providers rely on smartphone applications to connect passengers with their services. That combination of smartphones and connectivity has been key to the growth of new mobility business models. Numerous private sector players are staking claims in this space. As of mid-2016, dozens of partnerships and investments had formed across several major auto manufacturers, technology giants and start-ups, and mobility providers.[27]

Goldman Sachs predicts an eightfold increase in the use of ride-hailing companies, such as Uber, because it believes fully autonomous vehicles will exist.[28] Today, there are a handful of semi-autonomous vehicle models (incorporating, e.g., Tesla's autopilot, Audi's traffic jam assist, Mercedes-Benz's intelligent drive), but there are no fully autonomous vehicles yet available to consumers. In 2013, researchers at Morgan Stanley said autonomous vehicles are no longer in the realm of science fiction, and predicted fully autonomous vehicles would be on the market by the end of the decade.[29] The same report estimated trillions of dollars of annual benefits from several factors, including improved safety, reduced traffic congestion, fuel savings, time savings, and new business revenues. Research in 2016 by IHS Automotive predicted that early deployment of autonomous vehicles will occur in the United States as early as 2020.[30] Ford says it plans to deliver mass market fully autonomous vehicles for ridesharing in 2021.[31] Many other companies have announced they intend to market semi- and fully autonomous vehicles between 2020 and 2030.[32]

Although autonomous vehicles clearly have many boosters, their widespread deployment depends on how quickly manufacturers can overcome barriers, including high price, safety concerns, and a lack of regulation around self-driving vehicles. If these are successfully overcome, McKinsey estimates that by 2030 15% of new vehicles could be fully autonomous and 50% could be semi-autonomous.[33]

At the center of these changes is an evolving perception of the private car. Research shows that young people do not have the same emotional attachment to the car that older generations have. For young people coming of age in cities today, obtaining a driver's license is no longer synonymous with freedom, flexibility, and independence. A study of millennials in France, Germany, Great Britain, Japan, Norway, and the U.S. showed that, in recent years, fewer obtained their driver's licenses or owned cars, and they traveled less by car.[34] Other studies have found that fewer young adults obtained driver's licenses because of the high cost of car ownership and the availability of transportation alternatives.[35]

In large cities, the personal car is only one mobility option out of many, and sometimes it is not the cheapest or most convenient. This is especially true for cities that have good public transportation networks and well-established sharing systems. In those locations, potential car owners now compare the costs of buying, fueling, and maintaining a private car; the time spent in traffic; and the time parking with the costs and comfortability of alternative mobility services, such as ride-hailing, public transit, or car-, scooter-, or bikesharing services.[36] And with more and more cities—especially in Europe—seeking to restrict access to diesel and gasoline vehicles, buying a car may not be worthwhile.[37] Athens, Madrid, Mexico City, and Paris have announced plans to ban diesel vehicles by 2025; London is planning an ultra-low-emission zone starting in 2020; and Stockholm is considering introducing low-emission zones that only allow electric cars and low-emission diesel and gasoline vehicles.

Taken together, these new technologies, increasingly popular mobility services, and underlying social trends have implications beyond the automotive sector. They will potentially affect public safety, labor, transportation costs, transportation equity, traffic congestion, and the environment.

Governments around the world are welcoming transportation technology and innovation. In 2016, the U.S. Department of Transportation issued a federal policy to facilitate the introduction of autonomous vehicles.[38] In 2017, the German Bundestag and the Federal Council adopted a bill allowing for automated driving on German roads. An Audi spokesperson suggested that the new law "paves the foundation for Germany to be the pioneer for autonomous driving."[39] Japan has set a target to deploy a fleet of autonomous taxis to serve visitors to the 2020 Tokyo Olympic Games.[40] There are reports of planning documents in China showing that the country aims to be the global leader in autonomous and electric cars.[41] Other national and local governments, such as Dubai,[42] Shenzhen,[43] and Singapore,[44] have similar visions.

Yet there is no assurance, given the policies currently in place and the market conditions, that innovative mobility will have positive impacts for society. For example, a study by Schaller Consulting shows that the growing popularity of ridesharing has led to increased traffic in New York City,[45] and there are concerns that the services do not provide equitable access for all residents, widening the gap between the served and underserved.[46] In contrast, carsharing typically results in reduced vehicle usage, ownership, and miles traveled, providing environmental, social, and transportation benefits.[47]

Cities are on the front line of these changes, pushing innovation. In the United States, federal investment has been critical in establishing and funding local pilot projects. The U.S. Department of Transportation, for example, sponsored the Smart City Challenge, offering $40 million plus an additional $10 million in private investment for the winning city's proposed Smart City vision. Seventy-eight cities applied, demonstrating how many are looking for innovative ways to improve their transportation sectors.[48] Columbus, Ohio, won the challenge and will use the funds to improve transit equity, access, employment, health, and safety through heavy investment in autonomous and connected transportation technology, mobility-on-demand services, and transportation electrification. This is just one of several U.S. federal grants available for new mobility pilots, including a $65 million Advanced Transportation and Congestion Management Technologies Deployment Project, an $8 million Mobility on Demand Sandbox, and a $45 million connected vehicle Pilot Deployment Program.

Strong and thoughtful policy will help to address the social and economic impacts of the coming mobility revolution. There is a risk that new mobility emerges as an exclusive convenience for the wealthy, clogging city streets with unoccupied vehicles and leaving vulnerable communities underserved. And automation could displace hundreds of thousands of professional drivers from their occupation. Better understanding of the implications for the economy, society, and the environment is needed. There is a clear role for government to help fill these gaps; facilitate understanding at the local level; accelerate learning; and send strong market signals that can lead to a clean, safe, affordable, and equitable transportation system.

Recommendations for U.S. Policymakers

1. Passenger vehicles. Consider encouraging U.S. DOT and EPA to open discussions with California, auto companies, suppliers, and environmental organizations over the next iteration of federal standards from 2022 to 2030. Effectively negotiating such a complex and long-term policy will require full engagement from regulatory staff at DOT and EPA. Engagement with Canada could also be useful given Canada's close relationship with the U.S. on trade and standards.
2. Electric vehicles. Congress could consider renewing consumer EV subsidies (currently at $7,500) with a phase-down to 2025 when most EVs should reach cost parity. Volkswagen is required to invest $2 billion in recharging infrastructure over the next decade due to "Dieselgate", and Congress could supplement with additional resources. Congress might also establish a task force to make recommendations on how best to inform and encourage the public about EVs.
3. Heavy-duty vehicles. The two most likely zero emissions long haul trucking options are (1) hydrogen fuel cell or (2) electric-drive trucks on electrified roads. Both of these technologies are likely to suffer from the "chicken and egg" problem and will therefore require massive infrastructure investments to facilitate widespread deployment. Therefore, the U.S. should consider setting long-term plans for infrastructure investment to make sure that the lack of infrastructure won't be a barrier to the deployment of these technologies, and states and cities should be empowered to invest in pilot projects to test drive these emerging technologies.
4. Autonomous and shared vehicles. DOT's Smart City Challenge demonstrated the enthusiasm of U.S. cities to invest in transportation technologies and mobility services. Standardized collection of relevant data to track key social metrics across multiple cities would be an excellent use of federal resources to better understand which policies and technologies and business models have positive results, and which do not. Possible metrics could include oil security/climate impacts, increased mobility to underserved communities, reduced traffic congestion, increased safety, and reduced air pollution.

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[1] ICCT staff contributed to key sections of this paper, including Nic Lutsey, Peter Mock, Rachel Muncrief, Ben Sharpe, Fanta Kamakaté, Pete Slowik, Sandra Wappelhorst, Marissa Moultak, Stephanie Searle, and Stephen Naimoli.

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Energy for America:
Opportunities, Challenges and Solutions

August 9 – 15, 2017

The Aspen Institute Congressional Program

WEDNESDAY, August 9:

American participants depart the U.S.

THURSDAY, August 10:

All participants arrive in Oslo

Working Dinner

Seating is arranged to expose participants to a diverse range of views and provide opportunity for a meaningful exchange of ideas. Scholars and lawmakers are rotated daily. Discussion will focus on the opportunities, challenges and potential solutions regarding energy policy.

FRIDAY, August 11:

Scholars-Only Breakfast Meeting to Review Conference Format

INTRODUCTION AND FRAMEWORK OF THE CONFERENCE

***Dan Glickman**, Executive Director, Aspen Institute Congressional Program*

Roundtable Discussion

HOW A MAJOR OIL COMPANY POSITIONS ITSELF IN A WORLD OF LOW OIL PRICES, RAPIDLY CHANGING TECHNOLOGY, AND PUBLIC POLICY DEMANDS

Statoil is one of the world’s largest and most successful oil companies, with outstanding technological and operating resources, and special skills and experience in deep offshore oil. The government of Norway is a majority shareholder. But it is facing major challenges, as oil prices have been soft for years, demand in many nations seems to have peaked, and the world is moving to low-carbon energy sources. Indicative of changing trends, Statoil, which has investments in off-shore wind generation, recently announced that it would increase investments in renewables from 5% to 15-20% of its mix.

- How can Statoil prosper in a low oil price world?
- What role do oil companies have in renewable energy?
- Is “peak oil” real? Will it be driven by peak demand or peak supply?
- Will all of the world’s oil eventually be consumed? Does it matter if a proportion of the world’s oil will be “stranded”—left in the ground?
- How is Statoil positioning for the future given the low price of oil and the growing demand for low-carbon energy?
- What is Statoil’s perspective on climate change?

__Lars Christian Bacher__, Executive VP for Development and
Production International, Statoil, Oslo

Roundtable Discussion

ENERGY AND TECHNOLOGY: WHAT ARE THE BIG TRENDS AND WHAT DO THEY MEAN FOR THE WORLD? WHAT ARE THE STATUS AND PROSPECTS FOR OIL, NATURAL GAS, COAL, SOLAR, WIND, NUCLEAR, & ENERGY EFFICIENCY?

Our energy options depend on our technology: A diverse menu of technologies provides a rich menu of choices of energy for transportation, electricity, home heating, and industry. Technology development depends on a complex mixture of (a) market demand; (b) public policy; (c) government and private research & development (R&D); and (d) innovation ecosystems.

- What are the trends in technology development—in conventional and new energy sources; and are they driven by the private sector or by government-sponsored research?
- How do technology prices differ in character from commodity prices? What are the implications of recent price trends?
- How have today's energy technologies been impacted by public policy—including, e.g., directional drilling, fracking, nuclear power, solar, and wind.
- What policy strategies can rapidly accelerate new energy technology? What are the most fruitful or necessary new frontiers in energy technology?
- What are the best practices for federal energy R&D? What is working? What is missing? Are the magnitudes correct? Can federal policy incentivize privately funded research?
- How can utilities effectively deal with the intermittency issue of supply of renewable power (depending on the wind and the sun), given the constant demand for electricity from consumers?
- How crucial is development of better battery storage power to a successful Electric Vehicle (EV) evolution, and does this have promise?
- Will technology provide a gateway for clean coal and carbon sequestration?
- Why is nuclear power on the decline in the U.S. while its use is expanding in Asia?

Eric Beinhocker, Executive Director, Institute of the New Economic Thinking,
University of Oxford

Arun Majumdar, Director, Precourt Institute for Energy, Stanford University;
former Founding Director of Advanced Research Projects Agency-Energy

Working Luncheon

NORWAY'S UNIQUE APPROACH TO ENERGY POLICY CHALLENGES

Norway has made a series of deliberate moves to decarbonize and strengthen its economy at the same time, and has also played an outsized role in global efforts to reduce deforestation. Norway's grid is now 95% carbon-free, its building stock is the most efficient (for new construction) in the world, and its adoption of electric vehicles is now the highest. The country's sovereign wealth fund, created by its oil resources, has had a significant impact in these developments. These policies, and Norway's international engagement, have allowed the country to prosper as it drives an energy transition.

Vidar Helgesen, Norway's Minister of Climate and Environment

Individual Discussions

Members of Congress and scholars meet individually to discuss U.S. energy policy. Scholars available to meet individually with members of Congress for in-depth discussion of ideas raised in the morning and luncheon sessions include Lars Christian Bacher, Eric Beinhocker, Arun Majumdar and Vidar Helgesen.

Pre-Dinner Remarks

NORWAY'S ROLE IN ENERGY POLICY

Norway is uniquely positioned to be a world leader in innovative energy policy. Creation of its sovereign wealth fund, which draws revenue from off-shore oil production, has been a source of funding to spark innovative approaches to energy policy, leading to a substantial increase in the mix of renewables as well as advanced development of electric vehicles.

Børge Brende, Norway's Foreign Minister

Working Dinner

Scholars and members of Congress will explore topics covered in the conference. Seating is arranged to expose participants to a diverse range of views and provide opportunity for a meaningful exchange of ideas. Scholars and lawmakers are rotated daily. Scholars will discuss with members of Congress their perspective on the successes and failures of Norway's energy policies and anticipated trends in technology and energy.

SATURDAY, August 12:

Roundtable Discussion

THE INTERNATIONAL FRAMEWORK FOR ENERGY POLICY: THE GEOPOLITICS OF ENERGY, THE CHANGING ROLE OF OPEC, AND ENERGY DIRECTIONS IN EUROPE

Energy can be a cause of both serious economic and national security challenges. The U.S. has suffered recessions from oil embargos and high energy prices, and our national security has been vulnerable to our dependence on Mideast oil. America's appetite for foreign oil has also been a financial lifeline for some unsavory groups and governments. The U.S. has also at times made low cost oil or electricity an economic asset. Europe has a complicated mix of European Union-wide and national energy policies, along with liberalizing energy markets and strong climate targets, and some of these policies may provide applicable lessons for the U.S.\

- What are the strategic implications of the current approach to energy policy in the U.S., and how can we better position America in the future?
- How is the EU-wide energy trend working out? Is the *Energiewende* (Germany's energy transition) working, or not?
- How are the geopolitics of energy evolving?
- What kind of energy mix best positions the U.S. economy going forward?
- Has the U.S. already achieved energy independence, and if so, how? Is this sustainable? What are the global implications?

- How have oil imports affected the U.S. strategic position in the Middle East?
- How are U.S. military operations affected by military oil consumption-both in terms of supply chain logistics and vulnerabilities?
- How will U.S. military capabilities be affected by rising sea levels?
- What are the human migration/ refugee implications of climate change, and how will they affect the political order?
- Is the EU carbon trading system working and are there lessons to be learned?
- Do the Paris climate accords drive energy policy?

Amy Myers Jaffe, Executive Director, Energy & Sustainability, UC-Davis

Camilla Bausch, Director, Ecologic Institute, Berlin

Working Luncheon

THE CHANGING GLOBAL ENERGY PICTURE: A CORPORATE VIEWPOINT

Shell Oil, the world's second largest publicly traded energy company, faces the dual challenge of weak oil prices and a global demand for new fuels and methods of transportation, including the growth of electric vehicles. How will this oil company evolve? What is the appropriate role for an oil company in this complex environment? How do Shell scenarios position the company for a robust future?

Charles O. "Chad" Holliday, Board Chairman, Royal Dutch Shell

Individual Discussions

Members of Congress and scholars meet individually to discuss U.S. energy policy. Scholars available to meet individually with members of Congress for in-depth discussion of ideas raised in the morning and luncheon sessions include Camilla Bausch, Amy Myers Jaffe, and Charles O. "Chad" Holliday.

Working Dinner

Seating is arranged to expose participants to a diverse range of views and provide opportunity for a meaningful exchange of ideas. Scholars and lawmakers are rotated daily. Scholars will discuss with Members of Congress the impact of OPEC, and the changing dynamics of energy sources and energy needs.

SUNDAY, August 13:

Roundtable Discussion

POLICIES THAT WORK: HOW TO DESIGN ENERGY POLICIES THAT MEET U.S. GOALS; KEY DESIGN PRINCIPALS TO MAXIMIZE PRODUCTION, EFFICIENCY AND INVESTMENT; AND THE ROLE OF RESEARCH AND DEVELOPMENT

Our energy future is deeply affected by government policy. The U.S. has a complex mix of federal policy, and 50 more brands of state policy—with many inconsistencies and inefficiencies. What kind of policy maximizes the power of the market, accelerates technology, and enables the country to meet its goals of reliable, affordable, and clean energy?

- How can energy policy be set for key national goals rather than to favor one or another technology?
- Many technologies, such as advanced nuclear or fuel cells, are currently non-competitive, but could become so if their prices drop through R&D and early deployment. How should such "learning curves" inform policy?
- How should government subsidies be structured for new technologies so that they can be weaned as quickly as possible? Are subsidies for traditional energy sources still needed? For solar and wind?
- What kinds of performance standards are the best for meeting national policy? Is this an appropriate federal or state role?
- What is the right role for pricing—in the form of taxes, or subsidies, including for example a carbon tax?
- What is the appropriate role for states in energy policy?
- How can the federal government help (or avoid hindering) good state policy?

Hal Harvey, Chief Executive Officer, Energy Innovation, San Francisco

Roundtable Discussion

THE FUTURE GRID AND HOW TO MAKE IT MORE RELIABLE, CLEANER AND AFFORDABLE: LESSONS FROM CALIFORNIA

The power mix on the national grid is changing rapidly. By 2030, for example, both New York and California will be 50 percent renewables; adding in existing hydro and nuclear will make them 65 percent carbon-free. Variable energy sources require a new operating paradigm. There are some great technologies and techniques—including new power markets—that can help. But these will often require both new wholesale electricity markets, and new business models for utilities.

- Is the national grid vulnerable to technical failure or sabotage?
- Does the national grid need an upgrade? If so, what are the roles and responsibilities of utilities and government?
- What are the trends for power supply in California? In the U.S.? Are brown-outs on the horizon?
- What are the new challenges faced from a growing renewable energy mix?
- Can the grid run on 50 percent renewable energy? More?
- Are there new technologies that will help manage large-scale renewables? Demand-response? Efficiency? Better grids? Fast-ramping fossil? Batteries or other electricity storage?
- Do wholesale electricity markets need to be restructured?
- If so, what can the federal government do to enable this transition?

Steve Berberich, Chief Executive Officer,
California Independent System Operator, Folsom, CA

Working Luncheon

Discussion continues between members of Congress and scholars on the challenges for the U.S. energy policy.

Individual Discussions

Members of Congress and scholars meet individually to discuss U.S. energy policy. Scholars available to meet individually with members of Congress for in-depth discussion of ideas raised in the morning and luncheon sessions include Hal Harvey and Steve Berberich.

Working Dinner

Scholars and members of Congress will explore topics covered in the conference. Seating is arranged to expose participants to a diverse range of views and provide opportunity for a meaningful exchange of ideas. Scholars and lawmakers are rotated daily. Scholars and Members of Congress will discuss designing policies to achieve US energy goals and how to have a reliable and cleaner grid in the future.

MONDAY, August 14:

Roundtable Discussion

TRANSFORMING VEHICLES AND ENERGY NEEDS OF TRANSPORTATION: HOW WILL THE ELECTRIC VEHICLE REVOLUTION PROCEED?

The auto industry is in the midst of two revolutions at once: electrification and self-driving vehicles. And both are in the context of public health demands for lower conventional pollution, and global demands for lower greenhouse gas emissions. How will this unfold? What is the role for federal policy? With millions of drivers wasting hundreds of hours annually stuck in traffic congestion, there must be more sensible, energy efficient means to move around.

- How fast is electrification of vehicles really moving? What are the hindrances, opportunities, economic and policy challenges?
- Can trucking fleets be converted?
- What is the role for autonomous vehicles and their energy impact?
- Will self-driven cars reduce or increase congestion, pollution, and greenhouse gases?
- How can the auto industry be moved toward a set of real-world emissions standards, and away from the test-focused approach we now follow, with all the defects of those approaches?
- Will the auto industry survive the invasion of Google, Uber, and Apple? Can auto companies keep up with the technological change?
- Will the auto companies face further consolidation?
- What is the role of China, the world’s largest auto market, in this transition?
- How essential is required advances in battery technology for wide adoption of electric vehicles? Is installation of a new system of charging stations feasible, and will industry take this on?
- Does the government have a role in incentivizing or accelerating the shift toward these new paradigms? Do federal and state tax credits for electric vehicles make sense?

Should electric car owners pay more fees to support infrastructure since they pay less gas taxes? States are reducing their incentives for electric cars—will this affect demand?

- What role do CAFÉ standards play in these changes?
- How can the federal government build a set of policies that give clear signals to automakers, steadily drive down pollution, promote new technology, and protect the consumer?

Ulrich Eichhorn, Director of Research & Development,
Volkswagen Group, Wolfsburg, Germany

Drew Kodjak, Executive Director,
International Council on Clean Transportation, Washington, DC

POLICY REFLECTIONS FROM MEMBERS OF CONGRESS

Working Luncheon

Discussion continues between members of Congress and scholars on the challenges for the U.S. policy on energy and environmental issues.

Individual Discussions

Members of Congress and scholars meet individually to discuss U.S. energy policy. Scholars available to meet individually with members of Congress for in-depth discussion of ideas raised in the morning and luncheon sessions include Ulrich Eichhorn and Drew Kodjack.

Working Dinner

Scholars and members of Congress will explore topics covered in the conference. Seating is arranged to expose participants to a diverse range of views and provide opportunity for a meaningful exchange of ideas. Scholars and lawmakers are rotated daily. Scholars and Members of Congress will discuss the electrification revolution of automobiles as well as other key topics discussed during the conference.

TUESDAY, August 15:

U.S. participants return to the United States

Energy for America:
Opportunities, Challenges and Solutions

PARTICIPANTS

August 9 – 15, 2017
Oslo, Norway

Members of Congress

Representative Joe Barton

Representative Brendan Boyle
and Jennifer Boyle

Representative Ted Budd
and Amy Kate Budd

Representative Bradley Byrne
and Rebecca Byrne

Senator Tom Carper
and Martha Carper

Representative Chris Collins
and Mary Collins

Representative Susan Davis
and Steve Davis

Representative Dan Donovan
and Serena Stonick

Senator Dick Durbin
and Loretta Durbin

Representative Gene Green
and Helen Green

Representative Brian Higgins
and John Higgins

Representative Ann McLane Kuster
and Brad Kuster

Representative Rick Larsen
and Tiia Karlen

Representative Nita Lowey
and Stephen Lowey

Representative Mark Meadows
and Debbie Meadows

Representative Pat Meehan
and Carolyn Meehan

Representative Chellie Pingree
and Hannah Pingree

Representative David Price
and Lisa Price

Representative Bobby Rush
and Kacy Rush

Representative Scott Tipton
and Jean Tipton

Representative Fred Upton
and Amey Upton

Non-Congressional

John Arnold
The John and Laura Arnold Foundation

Lars Christian Bacher
Executive Vice President for Development
and Production International
Statoil
Oslo

Camilla Bausch
Director
Ecologic Institute
Berlin

Eric Beinhocker
Executive Director
Institute for New Economic Thinking
University of Oxford

Steve Berberich
CEO
California Independent System Operator
Folsom, California

Børge Brende
Norway’s Foreign Minister

Deborah Burke
Rockefeller Brothers Fund

Ulrich Eichhorn
Director of Research & Development
Volkswagen Group
Wolfsburg, Germany

Hal Harvey
Chief Executive Officer
Energy Innovation
San Francisco

Betsy Hawkings
The Democracy Fund

Vidar Helgesen
Norway’s Minister of Environment

Charles O. “Chad” Holliday
Chairman
Royal Dutch Shell

Amy Myers Jaffe
Executive Director
Energy and Sustainability
University of California-Davis

Debra Knopman
The Henry Luce Foundation
The Rand Corporation

Drew Kodjak
Executive Director
International Council on Clean Transportation

Arun Majumdar
Director
Precourt Institute for Energy
Stanford University

Rapporteur

Marika Nell
Cornell University Graduate School

Aspen Institute Staff

Dan Glickman
Vice President, Aspen Institute
Executive Director, Congressional Program

Melissa Neal
Congressional Associate, Congressional
Program

Bill Nell
Deputy Director, Congressional Program

Carrie Rowell
Conference Director, Congressional Program

Pat Walton
Program Coordinator, Congressional Program