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The Tech-Enabled Energy Future

Transition by Design

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Introduction

Energy innovation is a vital U.S. national interest. The current rapid pace of digital innovation in energy—in particular, advancements in on-demand travel services, self-driving vehicles, big data–assisted logistics, newly automated and decentralized electricity systems, and three-dimensional (3-D) printing—could sharply reduce oil use and lessen the influence of geopolitically problematic oil-producing nations. These technologies also hold great promise to both promote electricity system resiliency and accelerate the transition to cleaner forms of energy. More broadly, energy innovation ensures national security by providing the U.S. military and space program a technological edge over its rivals and by lowering the costs of addressing climate change. Leading in energy innovation contributes to U.S. global competitiveness—not only in spurring new markets, industries, and companies but also in producing more cost-effective supply chains, boosting manufacturing productivity, and lowering the economy's energy intensity.

But there is debate over whether government intervention in markets is necessary to fully tap these benefits. The assumption that the technologies and the businesses that promote them will magically produce these benefits is wrongheaded. As these technologies proliferate, the U.S. government—at federal, state, and local levels—needs to intervene and steer markets to avoid unintended consequences and prevent suboptimal outcomes. Otherwise, the potential of these technologies to reduce oil use, improve energy infrastructure resiliency, and enhance U.S. competitiveness could go unrealized.

Technology often carries the risk of unintended consequences. Sound public policy is important to ensure that emerging technologies benefit society. In terms of transportation, ride-hailing services could in theory incentivize carpooling and help reduce carbon emissions. But in practice, evidence is mounting that ride hailing in some U.S. cities lures riders away from public transit, contributing to congestion and increasing fuel use and emissions. Digitalization is making freight transport more efficient, yet planned warehouses on trucks could increase fuel use and worsen traffic conditions. For manufacturing, 3-D printing could help eliminate oil-intensive, expansive global supply chains. But the machinery used in additive manufacturing, which includes 3-D printing, consumes much more electricity than conventional machinery does.

So far, the pace of adopting new technologies has been erratic and unpredictable. That uncertainty means the digital revolution is no immediate salvo for lessening oil-price swings. Investment decision-making in new technologies remains decentralized among many independent players in the private sector. With no centralized government road map, the outcomes for widespread deployment of digital products so far have varied widely in time and scale, and analysts are divided in predictions on what effect they will have on the oil industry and over what period of time. Volatility of U.S. public research and development (R&D) spending as well as fluctuating government incentives for advancement of products like electric vehicles, solar energy, and 3-D printing has contributed to uncertainty about the time frame for a transition to new technologies. This high unpredictability now plagues statist oil incumbents and has lessened their common interests with consuming nations.

Innovation can lead to progress only if public policy shapes how emergent technologies are harnessed. To maintain its leadership role in the global energy technology sphere, the United States needs to enhance its innovation policies by seeking to collaborate internationally on nonsensitive technology and domestically by promoting long-term investment in advanced manufacturing and energy technologies. States should incentivize utilities to integrate innovative system management techniques into existing infrastructure. And local officials should support innovative pilot programs for ride hailing and self-driving cars and delivery trucks while ensuring that as the programs expand and become permanent, they will be held to environmental performance standards.

Defining the Uncertainties in Mobility and Manufacturing

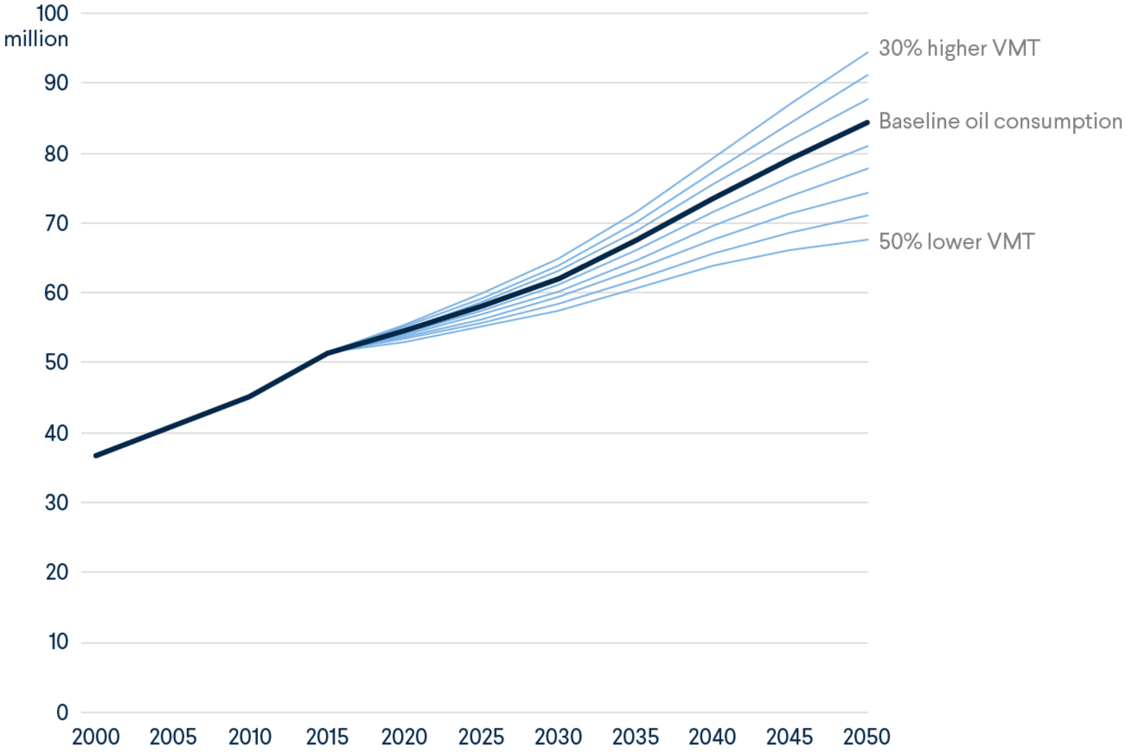
A new wave of energy innovation—driven by the convergence of automation, artificial intelligence (AI), advanced manufacturing, and big data analytics—is remaking the transportation, electricity, and manufacturing sectors. This so-called fourth industrial revolution has also created great uncertainties about the future energy landscape.

TRANSPORTATION

There are a wide number of transformative technologies disrupting the transportation sector now, notably including renewable energy–sourced electrification of vehicles, smartphone-connected ride-hailing services, self-driving automation, and big data–enhanced logistical route planning. Tech innovators tout these advancements as ways to reduce urban congestion and carbon emissions and provide reliable mobility to poorer, underserved populations who are being driven out of city centers by high rents and gentrification. Futurists envision a complex network of intelligent vehicle and road systems that will allow passengers to hail smart, self-driving cars to carry them seamlessly to and from public trains, subways, and buses, which charge wirelessly from solar energy installations backed up by battery storage. Technologically such a scenario is possible, but the transition to this idealized world of "smart mobility" will be hard to orchestrate.

Ride hailing and automation could either increase or decrease fuel use, depending on how or whether it is regulated. If technology increases trip efficiency and the number of riders per vehicle, vehicle miles traveled (VMT) will fall, lowering oil consumption. If ride hailing stimulates more one-person rides, including travelers who would otherwise walk, bike, or take public transport, VMT will rise, raising oil use (see figure 1). The wide range of forecasted outcomes highlights the deep uncertainty in an industry projected to be an engine to economic growth by generating up to $1.2 trillion in revenues by 2026.[1]

Figure 1. Sensitivity of Oil Demand to Changes in VMT (barrels/day)



Source: Daniel Scheitrum, Amy Myers Jaffe, and Lew Fulton, "Changing Oil Market Fundamentals and the Implications for OPEC Production Strategy," *International Association for Energy Economics Conference Proceedings*, 2016.

Ride-hailing services, such as Uber and Lyft, started as responses to the issues of urban congestion and mobility. Such services arose from efforts to use smartphone apps to increase carpooling. Launched in 2007, the app Zimride matched riders for long-distance carpooling trips, initially catering to schools and large companies. Zimride's popularity led its founders in 2012 to launch the ride-hailing app Lyft, which allowed users to summon "unused" cars and peer-to-peer drivers to "reduce the cost of transportation."[2] Operating in the San Francisco area, Lyft took advantage of carpool lanes that only vehicles with at least three passengers could use. Uber, which began as a limousine-hailing app in San Francisco, followed with a peer-to-peer service in February 2013.

The principal innovation of both companies, now global brands, was the use of computer algorithms that optimally matched riders and available drivers. Fares varied based on supply and demand for services at a given time. Soon international competitors emerged, including Didi Chuxing in China, Ola in India, and Grab in Southeast Asia. Micro-transit companies now use the technology to offer rides in vans and small buses for a broad mix of demand-responsive, curb-to-curb services that extend to routes not serviced by public transit.

Theoretically, digital ride-hailing platforms obviate personal car ownership, optimize vehicles to trip purpose, and reduce VMT. The shared-ride model could encourage the adoption of smaller, more fuel-efficient vehicles, including electric and hydrogen vehicles, for shorter inner-city trips that could be accomplished with fewer fueling stations. Vans and buses hailed electronically could service custom routes, replacing inefficient city buses and reaching areas that city buses currently do not reach. To ensure electrification, batteries and wireless fast chargers could facilitate electrified rapid bus systems and reduce inner-city pollution from diesel fuel.[3] UberPool already offers affordable door-to-door shared trips for riders taking similar routes.

Digitalization is already increasing efficiencies for road freight transport. Online shopping is replacing personal trips to the mall, and deliveries are optimized using big data and AI, greatly reducing oil use and miles traveled.[4] Dedicated lanes for autonomous trucks could increase these fuel savings by another 10 to 20 percent by reducing wind shear, braking, and accelerating.[5] Such dedicated truck lanes on highways could further reduce congestion, fuel consumption, and emissions.[6]

However, the reality of shared rides via ride hailing and optimized freight does not match the idealized vision. Congestion in U.S. cities, measured by the total number of hours commuters are delayed in a year, increased 32 percent between 2008 and 2014.[7] Although many factors drive this increase, additional survey data provides evidence that single occupancy ride hailing is so far a contributor to the problem, not a solution. By the same token, same-day shipping services increase the difficulty of optimizing logistics in a short period of time, reducing the efficiency and oil-saving benefits of online shopping. Planned roving pop-up stores or warehouses on trucks could also increase fuel use and exacerbate congestion.

Preliminary data indicates that ride sharing in the United States is replacing, not supplementing, public transit. A survey found that 42 percent of ride-sharing customers in the Boston metro area would have used public transit had ride sharing not been available.[8] In New York City, despite companies' advertising and incentivizing pooling options, single-rider trips dominate app-based ride services, adding significantly to congestion and per-vehicle trips on city streets. Ride hailing has added thirty-one million trips, for a cumulative increase of six hundred million extra miles traveled from 2013 to 2017 in New York City.[9]

Outside the United States, ride hailing can be effective in managing oil use in places with extreme congestion and restrictions on driving. For example, automobile sales in China have slowed. In Nigeria, where severe fuel shortages are commonplace, ride-hailing firms have proposed partnering with the government to stretch limited supplies further by prioritizing fuel access to drivers who provide pooled rides. This model could be used throughout West Africa.

Automating ride-hailing fleets with self-driving vehicles could be beneficial. Proponents of automation claim that by adding light detection and ranging technology (lidar), machine learning, digital maps, and local search to their business models, driverless vehicles will allow ride-hailing companies to coordinate with public transit, use cleaner fuels, and reduce congestion (see appendix).

If all personal trips were curated by autonomous technology, fewer cars could be used to make the same trips.[10] If passengers shared rides solely based on time and cost savings, automated ride-hailing services could contribute significantly to reducing greenhouse gas emissions.[11] One study found that a fleet of electrified shared automated vehicles (AVs) whose size was determined by what was most appropriate for the kind of trip (so-called right-sizing) could reduce per-mile greenhouse gas emissions significantly when the electricity came from renewable energy sources.[12] By using algorithms to ensure that large vehicles are used only when necessary, electric AVs could outperform conventional electric vehicles (EVs), which are already highly efficient.

In this ideal world, fleets of autonomous vehicles would communicate with one another and potentially connect to smart traffic management systems, creating more efficient traffic flow and reducing congestion and accidents. Reduction in instances of braking and accelerating, which currently account for a high proportion of energy use in vehicles, would save fuel and lower emissions. Fewer accidents would mean that vehicle materials could be lighter, lowering the amount of fuel needed for propulsion.

That said, driverless cars require considerable onboard data processing and connectivity, raising questions of how much electric power is needed for journeys. Data sent to the vehicle's controller from cameras and lidar is read by the onboard computer and processed using an algorithm designed to look for statistical patterns and act accordingly. Through machine learning, the computer builds a model of possible outcomes based on patterns and instructs the car how to proceed. Stored maps and Global Positioning System (GPS) data need to be continuously updated. In the same way that drivers using the app Waze share information about the road ahead, driverless cars could wirelessly connect with other vehicles, the police, roadside infrastructure, and data stored in the cloud in a seamless system of "fleet learning." That system will take considerable energy to operate, and it is not yet known what fuel source will provide it.

In Phoenix, Arizona, Waymo has launched a subscription taxi service of driverless cars. The company is building an automated "driver" technology that can be applied to multiple purposes, such as on-demand robo-taxis, last-mile transit buses, and last-mile delivery service. But Waymo's vehicles are powered by combustion engine rather than electricity. Ford is testing its driverless technology in some U.S. cities, with the goal of launching a ride-hailing and delivery service company by 2021 in a limited geographical area. (Its boundaries would be defined by a virtual digital operating perimeter, or so-called geo-fencing.) General Motors also intends to launch a commercial ride-hailing company that will use self-driving cars. The supermarket chain Kroger is piloting AV home delivery of groceries in Arizona. It remains unclear whether or when any of these services will use electric cars.

As driverless cars become more ubiquitous, policymakers will need to consider how to best integrate them into cities. For example, cities can create geo-fenced automated areas—areas with digitally set geographic perimeters—and price the use of streets and public spaces to influence driving patterns and discourage excess fuel consumption and emissions.

Now, companies are mostly free to experiment. The National Highway Traffic Safety Administration has issued only voluntary guidelines on self-driving technologies. Local governments, however, are beginning to impose restrictions and certification processes. In 2018, California enacted a law requiring ride-hailing companies to quantify emissions from their vehicles. But the more ambitious aspects of the proposed law—which would have set emissions targets, mandated that ride-hailing firms have all-electric fleets by 2028, and included funding for subsidies for ride-hailing drivers to purchase EVs—failed to find sustained support in the face of industry and consumer opposition. In August 2018, New York City enacted a yearlong moratorium on new licenses for for-hire vehicles in an effort to reduce congestion. These policies represent the first attempts by governments to bound the operation of ride-hailing firms to reduce their contributions to congestion and emissions. Policy frameworks related to certification, road charges, carbon intensity fees, and required links to public transportation are also being debated.

ADVANCED MANUFACTURING

The energy disruption from advanced manufacturing could be even greater than expected changes in the transportation sector. Additive manufacturing could dramatically shrink oil-intensive globalized supply chains, eliminating the need for a large amount of oil use in global freight.

Because additive manufacturing, such as 3-D printing, is in its early days, it focuses mainly on complex machines, such as engines. Even so, existing prototypes promise engineering and efficiency gains. Advanced manufacturing technologies can reshape how companies manage their production, with important implications for supply chain management and energy use. For example, 3-D printed engines are being made with fewer components and geographically closer to assembly, thus reducing dependence on volatile supply chains. In contrast, traditional manufacturing relies on complex supply chains that bring together for assembly parts produced in industrial plants across the world. Today's diverse supply chains also require heavy machinery and oil-intensive shipping programs to take final products to market. Advanced manufacturing systems could dramatically change that, both by lessening the number of final parts that need to be transported for assembly and by reducing the distance those parts have to travel. In both cases, oil use would be dramatically lowered. The manufactured engines and equipment would also be lighter, requiring less energy to operate.

The trend to reconsider reliance on complex, extended global supply chains is already underway. The rise of populism and protectionist trade policies is forcing corporate and national leaders to rethink trade and materials. The Donald J. Trump administration is reevaluating the reliability of U.S. supply chains for strategic materials and other manufacturing inputs and rethinking vulnerabilities that could give competing countries leverage over the United States during periods of conflict.[13] That reevaluation could encourage the United States to expand the use of additive manufacturing systems to shrink supply chains. Still, analysts are uncertain how long it would take for additive manufacturing to move to the mainstream.

A Delft University of Technology study determined that widespread use of additive manufacturing could, as of 2050, reduce global energy demand in aerospace and construction sectors by 5 to 27 percent.[14] Modeling the development of the Airbus A320 with and without additive manufacturing, the study found that eliminating an intermediate manufacturing step in Taiwan reduced energy used to transport material by more than 50 percent. The model also predicted that by reducing the weight of materials, additive manufacturing would reduce transport costs for the construction industry by up to 40 percent.

Customized parts not only reduce the energy expenditure in supply chains but also improve energy efficiency of the final products. Cessna will soon launch a new plane with a 3-D printed engine. The previous engine for a Cessna aircraft had 855 parts; the new one has only twelve. As a result, the engine is 5 percent lighter and 20 percent more fuel efficient, and has 10 percent more operating power. Cessna once took eight to ten years to develop an engine; it can now do it in two.[15]

Similarly, 3-D printing could revolutionize automobile manufacturing. Local Motors, in conjunction with Oak Ridge National Laboratory, revealed the first entirely 3-D printed concept car in 2016.[16] The ability to print cars, or even just parts, could change the current energy-intensive and inflexible manufacturing tooling and platform system. Design-specific tools such as stamping equipment, machinery, assembly equipment, and tooling support only a handful of designs. These tools are capital intensive and involve long amortization periods, so car manufacturers have difficulty innovating within the constraints of existing equipment. Advanced manufacturing could enable the industry to introduce new designs at more affordable prices. These designs could have higher fuel efficiency and lower manufacturing-energy footprints. The digitalization of advanced manufacturing also allows for computer-driven optimization, which can further improve the process. Automated 3-D printing can improve material choice and structure to create cost-effective, strong, and light products. The automotive manufacturer Divergent 3D, which is pioneering this method, says it can reduce the life-cycle environmental effect of the automobile manufacturing process.[17]

Additive manufacturing could also disrupt oil use in consumer supply chains. The ability to 3-D print even simple items at home could eliminate portions of supply chains and thus reduce energy expenditure in the commercial sector.[18]

In May 2018, Adidas announced plans to mass-produce a new line of custom shoes that will require not only 3-D printing but also a completely redesigned supply chain model.[19] Conventionally, clothing retailers base production in regions with low-cost labor and ship their products from there to markets worldwide. Often the finished goods are stored in intermediary warehouses or transshipment terminal hubs, depending on how far they are traveling and demand for the products. Adidas's new production plan involves shipping barrels of a raw elastomer material to manufacturing points closer to the markets. This plan changes the calculation for energy expenditure. Because the raw materials are far more compact than the final products, greater quantities can be transported in a single load, reducing the number of total shipments. A far greater mass of raw materials fits in the same container than that of the final products.

However, creating raw materials for additive manufacturing could increase energy consumption in the short run, depending on the materials used. Fabricating components with additive manufacturing often requires high-intensity lasers or electron beams and a powerful cooler. This process requires much more electricity than conventional bulk-forming methods. The energy used varies significantly with materials used, design, and product, and continues to evolve. Nonetheless, an important consideration when evaluating the life-cycle energy consumption is the increased electricity usage over conventional methods.

Calculating the precise effect of additive manufacturing on energy consumption has been difficult. Even if specific materials are more energy intensive, advanced manufacturing could still outperform conventional manufacturing by generating less waste. Lockheed Martin uses the term *buy-to-fly* to refer to the ratio of materials needed to materials actually used in the final part. Their bleed air-leak detect bracket was traditionally made with a buy-to-fly ratio of 33:1, which meant that thirty-three pounds of material was used to create a one-pound metal bracket. With advanced manufacturing, Lockheed Martin brought the ratio to nearly 1:1.[20] The product is now made with significantly less waste and cost. Moreover, with fewer materials transported to make the part, further energy efficiency is gained through the supply chain.

Innovation Challenges to Energy Incumbents

Digital innovation has the potential to transform both the electricity sector and the oil and gas industry by improving productivity in both sectors, and thereby reducing the chances of scarcity and lowering the costs of decarbonization. But historically, governments have interfered in energy markets to protect statist or other parochial interests. Adjusting this governance orientation will be critical to yielding the benefits of digital technologies in the energy sector.

ELECTRIC UTILITIES

The electricity industry is facing multiple challenges. The first set of challenges is related to improving the resilience of physical facilities in the face of extreme events, such as wildfires, flooding, and record temperatures, that necessitate upgrades to plants and wires. Societal and regulatory pressures are also mounting on utilities to reduce the amount of carbon dioxide emitted during power generation. Disruptive technologies—such as renewable energy, storage, and smart inverters—could contribute to both resiliency and decarbonization, especially through smaller distributed networks, or mini-grids, that are more closely tailored to local requirements.

Today's electricity grid is mostly built around a large-scale, centralized system designed more than a century ago. Large power plants send electricity over long-distance transmission lines to places where demand is highly concentrated, such as cities and industrial centers. The system is built for electricity to flow in one direction, from generation source to end user. Grid operators need to match the electric load requirements at any given moment with electricity from available generation resources. As they do so, the utility needs to maintain the grid's alternating current, the balance in voltage and frequency of which must be maintained at all times and protected from overload and reverse power surges.

During extreme weather events, forecasting customers' electricity demand is challenging. Undersupply can lead to unintentional drops in voltage (brownouts), oversupply to power surges, and possible explosions. To manage sudden load shifts, utilities have traditionally used pricing to incentivize large-load users to reduce their usage through demand response or interruptible load programs during critical peak events, such as extreme hot days. However, these load-management options can range from being inconvenient to being completely disruptive, since the customer is required to change usage at a moment's notice. Utilities often cope with these issues by upgrading system equipment, even though their capacity is needed for only the few hours or days of peak demand each year. These large system upgrades are costly, and the current utility rate structure forces customers to pay for this built capacity year-round.

New technologies, such as renewables and storage with grid-balancing capabilities, can save money and optimize grid system performance, but so far, government regulators are not providing effective incentives. Distributed energy systems (DERs) or mini-grids—decentralized, smaller-scale generation facilities (often augmented with battery storage) permanently or temporarily delinked from the larger grid—create value in multiple ways. They can save money by postponing or displacing the construction of more expensive system upgrades such as transmission and distribution lines, substations, capacitor banks, and other grid-balancing equipment. They also relieve location-specific congestion in the distribution network, avoiding high marginal costs for electricity production needed during temporary peaks in demand. Finally, they offer environmental benefits.

But more often than not, DERs are not built where they would create the most cost savings for the entire service area of a utility. Rather, the host company, homeowner, or community sponsors DERs at the location that best suits their own parochial needs, instead of where renewables and storage would lower peak demand and thereby costs for everyone using the grid. This poor implementation leaves open the possibility for inequities to emerge in the sharing of costs and services of the larger electrical grid: hosts of renewables and DERs—such as corporations or wealthy households—get the benefits of tax credits, while low-income neighborhoods remain stranded, without alternatives to higher utility rates. At the same time, the large nuclear and coal plants that might supply the rest of the region have inflexible fixed operating costs. Deploying intermittent wind and solar energy then reduces the profitability of operating these large traditional plants by siphoning off demand at peak times, when higher revenues would otherwise have been possible.

A revised electric utility regulatory framework is needed that takes new technology opportunities into account through a revised incentive structure for both utilities and all rate payers. Utilities can improve performance by deploying more storage and using it to better integrate renewables and distributed energy systems into the larger electricity network, but they need incentivizes. Most utilities only earn more revenue when they add large-scale infrastructure, as they are permitted to charge rate payers based on a regulated return on their investment in those assets. Existing policy frameworks do not incentivize utilities to share markets with DER providers because there is no way to get paid for those services.

Right now, utilities have difficulty earning a profit from integrating storage or distributed electricity systems into their operations. In most districts, DERs remain a business cost factor that takes away peak demand that might otherwise have gone to the utility as increased revenues. The historical regulatory framework was developed for a rate base model that rewarded increasing electricity demand and adding more facilities (and thereby additional emissions). In essence, the current utility business model compensates generators for spending money expanding generation capacity, transmission and distribution lines, substations, capacitor banks, and transformers, regardless of whether the investment saves customers the most money. The more money utilities spend, the more money they make, since they are guaranteed a fixed return on all investments.

Some states have begun to give utilities revenue rewards for energy efficiency via programs funded by ratepayer collections. In other words, utilities could collect more money from customers by meeting overall system efficiency targets. Then renewable portfolio standards supported by renewable energy credits (in the case of the United States) or feed-in tariffs (in the case of Europe) offered a payout for adding utility-scale renewables to their generation base. But these incentives have not been sufficient to bring about the level of innovation that could maximize the benefits possible for storage, automation, and other digital innovations to promote system stability and lower emissions.

Technologically, the benefits to storage are clear. Studies comparing the ability of battery storage and traditional turbine generators to respond to a utility's dispatch signal have found that storage's response always tightly followed the contour of the dispatch signal instantaneously.[21] In contrast, the traditional large-scale turbine generator's response to dispatch instructions was unable to provide similar precision in timing and scale. An agile resource, such as storage capable of reliably following dispatch instructions quickly and accurately, is critical during contingency events when the grid is under stress. The faster supply and demand can be brought back to equilibrium, the fewer chances there are for a brownout or explosion, and less curtailment of interruptible customers is required. Increased adoption of smart inverters will allow the release of stored energy to be calibrated via automation so that distributed resources' interactions with the grid will be designed to maintain system stability (for a discussion on smart inverters, see appendix). Different kinds of regulations are needed to give utilities the incentive to deploy more of these kinds of technological solutions.

Beyond stabilizing the power grid with fast and accurate balancing services, storage benefits the residential consumer as well. Homes with a battery storage system can pull electricity from the grid during the evening, when grid load demands and electricity costs are low, and use the stored power during peak hours (when prices are high), which reduces the customer's energy bill considerably. Storage can also provide crucial backup power during outages. In the event of a blackout, storage allows the distributed resource to disconnect from the grid and independently produce its own electricity (provided it is connected, e.g., to solar panels or other kinds of small-scale generators), preserve the self-generated energy, and operate as an island micro-grid until the distributed system can reconnect to the primary grid.

To encourage utilities to accommodate DER systems and more renewable energy, financial incentives need to be created that will allow the utility to reap some financial reward for investment savings realized by integrating a DER solution instead of adding traditional capital infrastructure. Market entrants are testing new business models for deploying storage and automation in the electricity grid. A new innovative system is aggregating home systems (rooftop solar, electric cars, and home battery storage) into a virtual power plant that anyone involved in the system can feed electricity to the grid, instead of requiring the construction of one large, centrally controlled and financed utility-scale facility. In one ambitious project, Tesla Energy is working with the South Australian government to integrate into one system individual rooftop solar generation panels paired with in-home battery storage and smart inverters across Adelaide households in what is hailed as the "world's largest virtual power plant." Any excess energy generated by the system that is not used by a member household will be automatically sent to the grid. This released energy will be centrally controlled by South Australian government entities. When grid conditions are stressed, the virtual power plant will provide energy, via an intermediary company, to the grid, much like a conventional power plant does.

New York State's Reforming the Energy Vision (REV) strategy fixes the problem of utility incentives by restructuring who gets the benefit of the financial payouts from DERs and storage. The financial benefits coming from distributed solutions are assigned equally, one-third each, to the local utility Con Edison, the DER provider, and Con Edison customers. In addition, REV has restructured utility rate-making and revenue models to earn returns from the locational value of distributed energy resources. In other words, New York is trying to create a system wherein deployment of DER is focused where it has the broadest value and thereby creates savings to customers across the system rather than wherever customers prefer clean energy. Typically, today's system of development—based on discrete preferences of individual investors at their location of choice—promotes the development of value only for the DER host customer, often a corporation, and runs the risk of increasing costs across the system.

An example of REV at work is the "request for solutions" for procurement and grid plan implemented by Con Edison in New York City. Rather than building a $1.2 billion substation, Con Edison selected a much cheaper mix of smaller-scale technologies to substitute for the substation. By selecting bids for solar with storage and implementing energy-efficiency projects as well as on-site heat and power systems, Con Edison was able to service rising electricity needs in a particular area of Brooklyn and Queens for 15 percent of the cost of the substation, saving money for all rate payers. Under the REV system, Con Edison shared in savings from avoided costs and received performance-based compensation for system efficiency, and was also able to lower rates to customers.

As DER providers and utilities try to coexist in changing markets, business models will need to adjust. Even in New York, a good model does not exist for how utilities and associated vendors capture revenue streams in retail markets. One model would allow utilities to serve as owners or downstream integrators by aggregating power supplies from a variety of sources for distributed as well as traditional assets. Alternatively, utilities could act as managers that provide and control automation and communications capabilities, using smart grids and managing transactions on behalf of market participants. Utilities could also move into a service role, providing software, supply and demand data, and other market-making activities while providing a final bill to consumers that tallies a range of third-party energy services.

OIL AND GAS COMPANIES

The disruption facing oil and gas incumbents mirrors that facing electricity incumbents, though change to physical infrastructure in the oil and gas industry is slower. Anticipation of a digital energy revolution is already reshaping the geopolitics of oil and gas, but the consequences of the revolution remain uncertain. While digital innovation has empowered major consuming countries like the United States, China, and Japan to reduce geopolitical rivalries with each other over oil supplies, the prospects of shrinking markets for their oil has added to the geopolitical instability already characteristic in major oil-exporting regions.

Historically, the oil industry has operated under the presumption of future scarcity. This view propelled massive capital investment in search of new reserves, with multinational oil companies and major consuming countries such as China, India, and Japan vying for long-range exploration contracts in important oil-producing regions of Africa, the Caspian basin, Latin America, and the Middle East. Companies are now limiting oil and gas resource investment patterns to shorter time horizons to avoid expensive stranded assets that might not be needed in twenty or thirty years. At the same time, digital technologies and automation are contributing to a renaissance in oil and gas development in unconventional resources such as shale in North America. For example, the U.S. tight oil revolution has seen exponential growth, from virtually nothing in 2000 to more than eight million barrels per day in January 2019.[22] Costs for extracting oil from shale and other source rock are falling rapidly, as technologies including smaller automated production platforms, predictive maintenance, and advanced analytics, among other technology advances, speed up drilling, lower workforce costs, and add to recovery and operational efficiencies. These technological developments could, ironically, make oil cheaper just when the world needs less of it, given pressures to move away from oil-based fuels.

Meanwhile, China, India, and Japan are shifting their investment priorities away from oil and toward new digital energy technologies, such as electric and hydrogen fuel cell vehicles, solar and distributed energy, and ride sharing, slowing the geostrategic competition for giant oil fields that characterized the late 1990s and the first decade of the twenty-first century. Geopolitically, as the allure of access to large oil fields in risky locales lowers, the United States finds it easier to impose sanctions against

Iran and other oil-producing nations. Similarly, companies have less interest in expensive Russian Arctic resources that have in the past been a carrot for U.S.-Russia resets.

As digital energy technologies take hold, Saudi Arabia—which has the largest daily oil production and proven reserves among countries in the Organization of the Petroleum Exporting Countries (OPEC)—could find its geopolitical position weakened. Already, uncertainty about long-term demand trends has meant that oil producers need to consider whether their reserves could depreciate in value over time if they delayed oil production and development in an effort to hold up prices in the present and garner short-term revenues. The possibility that the lofty oil revenues that currently support government budgets might dry up over time has destabilized already weak ruling institutions within OPEC countries, prompting some governments to intensify repression.

Significantly, even the possibility that Saudi Arabia would play less of a role in global energy markets is weakening the decades-long impetus within U.S. foreign policy circles to support the U.S. alliance with states in the Persian Gulf region. The reduced importance of the Middle East to global energy security offers one explanation of why some actions by Middle East nations have become more erratic and less considerate of U.S. interests.

Similarly, as stricter carbon policies and oil-saving technologies increasingly characterize European energy markets, Russia is losing the ability to use its energy supply as a geopolitical lever. Instead, Moscow is resorting to military buildups and cyber confrontations in the European theater. Russia has also successfully injected itself militarily into the Middle East and thereby enhanced its leverage with the Middle Eastern OPEC member nations, which now actively cooperate with Moscow on oil prices. Russia's hard power responses offer a more dismal prospect: a digitally transformed energy scenario would lead to more—not less—geopolitical disorder. The United States needs to prepare for this possible future and find ways to steer oil-producing countries toward a softer landing.

China's embrace of digital energy innovation as part of its new industrial strategy, China 2025, also poses new challenges for the United States as it considers its approach toward trade and future economic ties with China. Many U.S. start-ups and innovation companies have turned to China as a source of more patient capital than the limited U.S. private sector venture capital world. The decline in U.S. public sector support for energy R&D spending under the Trump administration is out of step with competition from China.

Rightly, the Trump administration has focused attention on China's statist policies, including forced technology transfers to Chinese domestic firms as a precondition for investment and access to Chinese markets. The administration is trying to reverse this trend via trade negotiations and proposed restrictions on technologies that might have a military dual use, such as AI and lidar. The pressure to outstrip China introduces the risk that some of the downsides to widespread digital technology adoption—such as higher oil use, environmental degradation, and violation of privacy—will not be addressed. The 2019 U.S. National Intelligence Strategy specifically mentions emerging digital technologies and AI as enabling U.S. adversaries, noting, "Without common ethical standards and shared interests to govern these developments, they have the potential to pose significant threats to U.S. interests and security."[23] But even within the context of a growing security rivalry, U.S. policymakers need to be mindful that competition on dual-use technologies—that is, energy-saving technologies that have military applications—does not preclude cooperation on broader kinds of technology with large global benefits. One example is technologies that help address climate change and lessen the risk of oil-price swings to the global economy, such as carbon sequestration and storage technologies that would clean up coal. The United States should seek to ameliorate its tighter trade restrictions by opening other avenues for U.S.-China cooperation on issues of common interest, such as climate change.

Policy Recommendations

Energy technology and innovation are not always synonymous with progress. In fact, technology is independent of the outcomes of its use. Sound public policy is needed to guide emerging technologies to benefit society. As companies craft strategies to unleash the power of sensors, big data, AI, the internet of things, automation, and smart devices in the transportation and energy sectors, policymakers need to consider how to promote practices that harness these technologies in a way that optimizes a geopolitically and environmentally beneficial transition.

RESEARCH AND OVERSEE DEPLOYMENT OF DRIVERLESS VEHICLE AND RIDE-SHARE TECHNOLOGY

City, state, and federal governments should beware unproven narratives that technologists offer during the start-up phase. Policies that unconditionally support digital technologies based on the assumption that they will save energy could end up being counterproductive. Local policymakers should craft a prudent certification process that begins with smaller, isolated pilot projects designed to understand how new products could function alongside existing infrastructure.

Cities should be more proactive in regulating ride hailing to discourage rising single-occupancy trips at the exclusion of public transit or carpooling. This can be done via congestion charges or time-of-day pricing fees for single-rider trips, or more ambitious programs that link public transit services more directly to last-mile ride-hailing company usage via joint government-sponsored smart device applications.

Cities also need to begin preparations for the autonomous vehicle future. To do so, policymakers need more data on the influence of current ride-hailing fleets on vehicle miles traveled, vehicle occupancy, transit use, and private vehicle ownership. Municipal governments should develop reporting standards for driverless vehicles and ride shares to collect and use information to assess and design appropriate policy frameworks to guide technology deployment while protecting data privacy. Data on self-driving vehicle operations, safety records, fuel use, level of occupancy, and contribution to traffic congestion should inform policymaking. Vehicles equipped with monitoring devices should be required to disclose what data they collect, how the data is used, and how privacy is protected.

To guard the privacy of individual customers, regulators should require that the travel data of individuals sent to or accessed by third parties, such as municipal governments, should be abstracted or aggregated. Standards and processes for responsible data collection should address privacy and proprietary concerns, while facilitating sharing and use by both private and public parties to ensure continuous improvement and knowledge-based regulation. The collection and analysis of such data by the appropriate level of government can help increase public confidence in self-driving technology.

Autonomous vehicle regulation will need to include emissions standards for fleet businesses and other pricing mechanisms to discourage single-occupancy use. Cities should establish pilot programs to test a variety of policy options, including road pricing, occupancy charges, or fuel choice incentives or restrictions. Some cities have announced bans on the use of traditional internal combustion engines in designated geographical areas like city centers. Cities need these pilot programs to better understand the potential of and barriers to ride-sharing services using alternative fuel vehicles and to integrate electric vehicles and smart charging into future deployment of self-driving vehicles. Such projects could provide utilities with important information about local grid benefits and demand curves as well as requirements for public charging infrastructure.

RETHINK NATIONAL INNOVATION POLICIES

The United States should rejoin the Paris global climate accord. As part of that process, the United States should re-endorse its participation and leadership in global technology R&D efforts as part of Mission Innovation, an initiative launched in 2015 during the Paris talks by nineteen countries committed to increasing R&D funding for early-stage clean energy innovation. Under Mission Innovation, business and technology leaders planned to work with governments, nongovernmental organizations, corporations, universities, and national laboratories to promote and expand R&D toward energy innovation to achieve performance breakthroughs and cost reductions for clean energy solutions.

To meet the competition from China, the United States also needs to increase public funding for energy R&D and to do more to foster public-private partnerships. The Department of Energy (DOE) should expand to all parts of the United States its existing program of regional centers of innovation, which brings together local business, academic institutions, and national labs to promote critical proprietary R&D in energy innovation. New hubs should be structured to include new kinds of financial mechanisms beyond national lab centers or incubators so that the hubs can attract both early- and later-stage finance. Hubs can do so by bringing together additional, broader kinds of partners such as institutional investors, pension funds, insurance companies, foundations, private endowments and family offices, and mutual funds. New models that should be considered include those that mirror other nontraditional paradigms like Breakthrough Energy Coalition, Prelude Ventures, and the Aligned Intermediary, which aim to address venture and technology risk and overcome the barrier of delayed returns in renewable energy financing. Past DOE R&D initiatives contributed to the development of technology that is now being used in U.S. unconventional oil and gas development in fuel-cell technology.[24] Pentagon funding led to the development of GPS, self-driving capabilities, and other digital technologies now used across the U.S. tech sector. These successes are a model for similar future support.

To promote the development of advanced manufacturing and to encourage long-term investment, the government should expand initiatives through the Small Business Administration, such as the Small Business Innovation Research program, to provide alternative capital for domestic companies looking to finance advanced manufacturing equipment. Given advanced manufacturing's important role in lowering the oil intensity of the U.S. economy, the U.S. government should also support research into and development of advanced manufacturing prototypes, as well as market implementation, by establishing a manufacturing research program similar to the Defense Advanced Research Projects Agency (DARPA). To replace existing supply chains that favor competing countries such as China, the U.S. government should explore public-private partnership opportunities for heavy industrial products and durable goods that can be built in the United States with advanced manufacturing techniques.

As suggested by former Michigan Governor Jennifer Granholm, the federal government can work with states to study existing industrial ecosystems in the rust belt and elsewhere to develop new technology business clusters based on underused factories, skilled workforces, and natural resources.[25] Energy cleantech manufacturing for solar panels, batteries, and smart inverters overlaps with skills that were used in now defunct products across the United States. For example, some of the technologies China is using to dominate the global solar manufacturing industry came from the U.S. technology firm Applied Materials, whose bid to collaborate with the DOE on similar solar ventures was rebuffed by the Barack Obama administration. The federal government can improve job growth and technology advancement by tying government-sponsored R&D more closely to private industry innovation via the creation of research collaboratives that are jointly funded by the private and public sectors. Government agencies such as the Department of Defense could serve as early adopters of technologies that would emanate from the collaboratives. As part of this effort, the public sector, both local and federal, should expand federal and state funding of education initiatives at major research universities, trade schools, and community colleges to plan effective and affordable curricula for workers to train in the new fields, including scholarships for American-born graduate students who agree to work in national laboratories upon graduation. Corporations should adopt reverse-mentoring programs and cross training between recruits and experienced workers to share knowledge to promote innovation.

Once it has its own national innovation strategy well established, the United States should seek viable areas for collaboration with China and ease tensions arising from technology programs that will now be fenced off as proprietary as part of the new Committee on Foreign Investment in the United States rules and other proposed Trump administration policies. U.S. participation in bilateral research initiatives with China should focus on targeted technologies that do not have strategic applications, such as carbon capture and storage, direct air capture, clean water technologies, and technologies that make food supplies more resilient.

REDUCE OIL DEPENDENCE AND DEVELOP NEW ENERGY TECHNOLOGIES

Washington should make the economy less oil dependent. Despite rising domestic oil production, temporary international events that affect oil supply can give OPEC, and even Saudi Arabia on its own, substantial if brief market power. The result is extreme oil-price volatility that can still harm the global economy and financial system, despite long-run expectations of abundance. As the Trump administration's Environmental Protection Agency seeks to weaken performance standards for new vehicles, Congress should push back and maintain, or better yet strengthen, policies that promote advanced automobiles in the United States and consider stronger efficiency standards for delivery trucks and large freight vehicles. Congressional leaders should press the Trump administration to quickly settle favorably with California and the dozen other states that follow California's policies on standards for diversified fuel options. This will curb demand for oil from the transportation sector and thus permanently and effectively help end OPEC's ability to manipulate oil prices. Use of alternative fuels in cars and trucks (biofuels, electricity, and natural gas) meets U.S. national interests, both by lowering the oil intensity of the U.S. economy and by freeing more U.S. oil for export, to water down OPEC market power. To manage the uncertain outlook on oil demand, the United States should also help vulnerable economies that rely disproportionately on energy exports—such as Colombia and Iraq—make economic reforms.

PROMOTE ELECTRICITY REFORM

To improve the resiliency of the electricity system, federal and state governments should consider how battery storage and other innovative system management techniques could best be integrated into existing infrastructure. Symbolic storage capacity and renewable portfolio standard mandates will not be enough to address the challenges facing the utility industry today. Following the models established by California and New York, new market designs need to consider incentives for the siting of distributed electricity networks in locations where they will lower electricity prices and manage grid vulnerability to contribute to overall system efficiency. State governments should revamp utility compensation structures to incentivize utilities to integrate distributed energy and equipment upgrades, which will allow the United States to meet climate adaptation requirements. States should begin with pilot DER projects that demonstrate equity and technical success to build confidence in wider reforms. State governments should also reform regulatory barriers that currently block digital platform companies from participating in retail electricity markets. As part of that reform, state governments should require utilities and DER providers to offer electricity end users the right to data on individual consumption and net metering data (where relevant) and to aggregate and share that data with local government. To facilitate better access to data, states that have not already done so should initiate programs to install smart telemetry and metering, combined with blockchain for transactional accounting.

Conclusion

Globally, governments have interfered in energy markets for decades and will continue to do so. As digital innovation accelerates in the energy sector, the U.S. government—at federal, state, and local levels—needs to fashion policies to ensure that the digital energy revolution produces outcomes that enhance U.S. national interests and improve environmental protection. The regulatory context for the digital age will be critical to aligning new energy technology businesses with democratic national values, including privacy and national security. Regulatory precedents that ensure that digital energy innovation enhances urban sustainability and lowers carbon emissions, instead of worsening current problems, will be as important. How the United States deals with these issues could determine its future leadership role in global technology.

Appendix: Important Technologies for the Energy Industry

The leap to automation may not be as huge as it seems, given that many vehicles already benefit from self-driving technology (as opposed to driverless technology, which requires no human input). Self-driving features include adaptive cruise control to accelerate and decelerate based on programmable rules of engagement, lane assistance to keep the vehicle within a lane, and emergency braking. Soon, vehicles will have the capability to decide when it is best to switch lanes or park. By contrast, driverless cars, now in pilot phases in the United States, are intended to operate in all conditions and under all circumstances without human intervention, using a combination of lidar, machine learning, and maps to navigate specific geographies. Details about some of these technologies follow.

Lidar. Light detection and ranging technology (lidar) sends out millions of laser beams every second and measures how long they take to bounce back to the source. The data generated can be used to build an extremely precise three-dimensional map that is easier for a computer to read than a two-dimensional camera image is. Lidar is a crucial technology component of self-driving cars and is an upgrade from radar, which is already used in vehicles as a way to bounce radio waves from existing surroundings to avoid collisions.

Machine learning. Machine learning involves algorithms that enable computers to learn from and make predictions based on evolving data sets. In traditional computing, an algorithm creates a predetermined path set in motion by programmers' static instructions (code). In machine learning, artificial intelligence systems enable computers to update their models and add "learned" adaptive behavior as they receive new data, identify patterns, and process updated data sets. Machine learning is critical for vehicles to learn from experience and determine how to navigate complex geographies on their own.

Digital maps. A digital map is digital computer imagery and data representation of a geographic location. Cameras and lidar are used to map the territory of operations to create a reference data set or document that helps a vehicle verify sensor readings and know its location down to the centimeter, an improvement over GPS.

Local search (optimization). Machine learning models allow for computerized solutions to optimize transportation routes and choices to reduce fuel use and length of travel (in both distance and time). The logistics industry is now assisted by a mathematical approach to computer problem-solving that searches an array of possible solutions and iteratively and systematically considers options until it finds the optimal solution.

The electric power system is under increasing stress from climate change, aging infrastructure, and changing patterns of use. These challenges are not insurmountable and can be solved by market reform that supports the widespread deployment of technological solutions. A number of technologies can play a critical role in this process by enhancing system stability and enlisting consumers to play a more active role in managing their electricity costs and resiliency. Details of some of these technologies follow.

Battery storage and wireless charging. Wireless technology for charging electric vehicles has been under development for a decade. Electric buses can be supercharged while operating along a route in two ways: by using overhead fast-charging hoods or cables that they access tram-style while stopped at a station for passengers, or by stopping over a ground pad for wireless charging. The wireless method involves a receiving system on the underside of the vehicle that connects to the vehicle's power electronics control system and battery systems as well as a nearby stationary charging control system that manages the ground pad, which transmits power wirelessly to the vehicle's receiving system.

Smart inverters and distributed energy resource management systems. To realize the potential of virtual power plants and digitized energy, increasingly decentralized system information needs to be monitored and managed. Distributed energy resource management systems (DERMS) perform this managing role and, when combined with smart inverters, can direct electricity flow and maintain grid stability using digital automation.

Solar sources generate electricity in the form of direct current, which requires conversion to alternating current. Inverters perform this conversion, but legacy inverters are not well suited to the variable nature of renewable and distributed generation because they cut off at a predefined voltage threshold and are not flexible enough to adjust to sudden surges or dips in electricity. Renewable generation is inherently variable, so the inevitable spikes or sags in solar or wind production will cause the traditional inverter to cut off and disconnect from the grid, exacerbating the voltage discrepancy. Smart inverters mitigate this problem because they allow precise control of grid variation. The utility operator can regulate the smart inverter controls and allow it to consistently supply power to the grid, supporting existing grid voltage even when traditional inverters with more rigid thresholds would cut off.

The utility operator serves a coordinating role because it "sees" the entire grid. The pairing of DERMS with the utility operator would allow the utility to remotely calibrate multiple smart inverters across the network to dynamically adjust to grid conditions. If it is apparent that a condition-altering event will occur, such as cloud cover approaching a solar photovoltaic installation that will lead to a dip in voltage, the operator can adjust the threshold at which the smart inverter drops due to the low-voltage condition. In this way, DERMS allow "voltage ride-through": further drops in voltage will be prevented as smart inverters continue to convert and feed solar energy to the grid during times of low grid voltage. Conversely, during times of excess solar production, DERMS can trigger smart inverters to charge.

Blockchain. Blockchain can be an important technology to facilitate innovation in retail electricity markets. Prosumers—energy consumers in homes and buildings who are also energy producers from solar and other distributed generation systems—can supply the grid with energy from storage at times of high demand. Compensation for the supplies provided to the grid requires net metering to record how much electricity is transferred, as well as a way to record the transaction.

Digitalization and automation are prerequisites to transparently recording transactions and to monitoring consumption, power availability, and system balancing. Automated smart metering and control systems can facilitate decentralized electricity trading and use blockchain technologies to enable peer-to-peer financial settlement. Blockchain permits the secure transfer of electricity in exchange for payments without intermediaries that slow processing. Market clearing, financial settlement, and billing could all be conducted using smart metered systems that participate automatically through a blockchain network. All market participants would thus have financial incentives to make the grid more stable.

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