# Investing Under Uncertainty

The Challenges of Building the US Energy Infrastructure of the Future

## Executive Summary

In November 2018, the Gutierrez Energy Management Institute (GEMI) in the Bauer College of Business at the University of Houston held a symposium and workshop on the infrastructure implications of the growth and transition of the US industry. The participants identified a number of insights including:

- US energy infrastructure is huge in scale and scope and critically important to the US economy, capital asset base, and international trade
- Significant investment is required to maintain the reliability and resiliency of the existing infrastructure
- Major investment will be needed in oil and gas production and export infrastructure to support growth
- The electricity value chain will fundamentally change with the de-carbonization of generation and the electrification of many demand sectors although the pace of transition is uncertain
- In addition to the major growth in renewable power generation, there are a number of new investment opportunities in distributed energy resources, carbon capture, use and storage, end use electrification and efficiency, and desalination
- Significant changes in business models are likely to occur in the electricity value chain as well as personal mobility and provision of energy services.

## Importance of US Energy Infrastructure

Energy Infrastructure in the US is large in scale, broad in scope, and an important contributor to the US economy and international trade.

*Huge Scale and Scope*

The energy infrastructure in the US includes a broad range of assets that produce and deliver many forms of energy to consumers. This includes the oil, gas and coal value chains as well as facilities that generate, transport and deliver electricity. In terms of energy production, the US is the world's largest producer of oil, natural gas and biofuels and the second largest producer of coal (after China) (1) . The US is the second largest generator of electricity with over 1.1 million megawatts of summer generation capacity and over 9,000 generation units which generated over 4,000 billion kilowatt hours in 2017 (2). The US is the also the largest consumer of energy overall (3). Connecting energy production to markets and producing finished energy products involves a huge network of midstream and downstream facilities. The US has more than 200,000 miles of petroleum pipelines (4), 300,000 miles and natural gas pipelines (5) and more than 700,000 miles of high voltage electricity transmission lines (6). The US has the world's largest refinery network with over 18mmbd of capacity and the world's largest network of natural gas processing and natural gas liquids fractionation capacity (7).

*Capital Investment*

Capital investment in energy infrastructure in the US was nearly $300 billion in 2017 which was about 16% of total global energy capital investment (8). Figure 1 shows the breakdown of investment by sector. Investment was essentially split between the fossil fuel value chains and the electricity sector. Relative to other industries, investment in the energy industry was about 10% of total US private non-residential fixed investment (9).

*International Trade*

Energy is an important component of US trade. Recent increases in US petroleum production has led to growth of exports and reduction of imports which has had a major impact on the US balance of trade. As shown in Figure 2, in 2006 the US trade imbalance in goods was approximately $980 billion ($2012). In 2017, the US net trade balance in goods was actually $50 billion less as the reduction in net petroleum imports more than offset the over $200 billion increase in net imports of non-petroleum goods (10). The US became a net exporter of refined products in 2011 (11) and natural gas in 2017 (12) with 3.6 billion cubic feet per day of LNG capacity (13). In fact, during the last week of November 2018, the US became a net exporter of petroleum liquids (crude oil and refined products combined) (14).

**Symposium Focus**

In November 2018, the Gutierrez Energy Management Institute (GEMI) in the Bauer College of Business at the University of Houston held a symposium and workshop on the infrastructure implications of continued growth in US oil and gas production, increased electricity demand, and changes in the electricity generation mix and grid requirements. The purpose was to deepen understanding of these trends and identify the emerging challenges and opportunities in building the US Energy infrastructure of the future. Participants included high-level executives from the oil, natural gas, renewable energy and power companies as well as representatives from UH colleges, industry research firms, investment banks, and non-profits.

Participants worked in small groups to exchange ideas and develop insights in a number of areas.

**Infrastructure Investment Drivers**

Investment and growth in US energy infrastructure is affected by a complex set of drivers and challenges. These include significant facts about the existing infrastructure and secular trends which will have a high impact on energy infrastructure investment. The symposium participants identified a number of these which were prioritized to five key drivers.

*Age and Functionality, Vulnerability of Existing infrastructure*

Much of the existing energy infrastructure in the US was built fifty or more years. This is true across the oil, gas and electricity value chains. More than one third of US crude oil pipelines were built before 1960. Nearly 50 percent of the United States' natural gas pipeline infrastructure was built prior to 1970. Most high-voltage transmission infrastructure was constructed prior to 1980 and cannot accommodate growth and anticipated future uses of the grid (15)

This existing infrastructure will require significant investment just to maintain its reliable operation. The API has studied investment requirements for the oil and gas value chains which includes surface production equipment, gathering and processing facilities, oil, gas and NGL pipelines, oil and gas storage, refining enhancements and upgrades, products pipelines and rail transport, and export facilities. The API estimates that oil and gas investment requirements just for enhancement, upgrade, replacement, and refurbishment will approximately $25 billion dollars per year or nearly $500 billion in total between 2017 and 2035 (16). In terms of electricity, utility investment demographics show large plant investments in previous decades are coming due for high cost repairs and replacement. The Brattle Group, in a report for the Edison Electric Institute, estimated that the electric utility industry will need to spend about $75-100 billion dollars per year just to maintain the reliability of electric service (17). This estimate, which was made ten years ago, may be low as it represents only 2% of the calculated replacement value of $4.8 trillion dollars for the existing grid (18).

Energy infrastructure, especially the electricity grid, is vulnerable to weather-related disruptions. Severe storms and floods represent the most significant threat to overall grid reliability with weather-related outages costing $20-30 b per year. Security vulnerability is an increasing concern as cyber and physical threat events are becoming more common. More than half of the cyber incidents the Department of Homeland Security has recently responded to have involved energy installations (19).

*Growth of US Energy Production and Change in Internal Flows and External Trade Patterns*

The continued growth in oil, gas, and electricity production will drive significant investment in energy infrastructure. By 2030, US liquids production is expected to grow (versus 2017) to 17 mmbd (from 13 mmbd) while gas production grows to 104 bcfd (from 74 bcfd) and electricity generation grows to 4500 billion kwh (from 4050 kwh) (20).

Changes in internal trade flows and the shift of the US from an importer to an exporter of oil and gas are also shaping investment needs. The US is becoming a significant natural gas exporter, placing new demands on transmission and storage infrastructure as much of the existing natural gas infrastructure is oriented around imports. Significant investment is required for pipelines, natural gas and NGL processing, and LNG/NGL export facilities. Growing oil production has displaced imports and allowed for exports, reversing long-standing flows of crude oil within the US. Significant investment is required for crude oil pipelines and export facilities. US refinery production is increasing creating investment requirements for light crude processing and product export facilities. The API infrastructure study estimates that approximately $30 billion dollars per year over the next twenty years will be spend on new oil and gas infrastructure projects (21).

*Rapid technology developments*

There are two large areas of rapid technology development which will have a large impact on the amount and nature of investment in energy infrastructure on the US over the next 20-30 years. These include "the electrification of everything" and the growth in renewable power generation. These trends in combination provide a promising pathway to decarbonize energy use (22).

Light duty electric vehicle (EV) costs will soon be competitive with comparable internal combustion vehicles (ICVs). Extended EV range and wide-spread fast-charging networks will make EVs as convenient to operate as ICVs. This will increase demand for electricity infrastructure while ultimately lowering the demand for liquid transportation fuels (23). Building technologies including air-source heat pumps and heat pump water heaters, high efficiency appliances and lighting, and highly insulating building envelope materials (insulation, windows) are developing rapidly. These will allow electrification of nearly all residential and commercial demand as well as significantly reduce energy use (24). Industrial energy demand is more difficult and will require more significant technology progress in electric machine drives, industrial heat pumps, electric boilers, and electric process heating (resistance heating and melting, induction furnaces, infrared and ultrasound technologies) (25).

Renewable electricity generation is essentially competitive with new fossil fuel generation technologies due to significant cost reductions in wind and solar power generation due to 1) technology improvements; 2) competitive procurement processes; and 3) a large base of experienced, internationally active project developers. Global wind capacity reached approximately 540 GW in 2017, and solar reached 405 GW.  On a global basis, the fall in electricity costs from utility-scale solar photovoltaic (PV) projects since 2010 has been especially remarkable. Driven by an 80% decrease in solar PV module prices since 2009 and reductions in other costs, the global weighted average levelized cost of electricity (LCOE) of utility-scale solar PV fell over 70% between 2010 and 2017, to USD 0.10/kWh. By 2020, based on the latest auction and project- level cost data, the global average costs of the most cost-effective technologies could decline to about USD 0.05/kWh for onshore wind and USD 0.06/kWh for solar PV, with solar overtaking wind in terms of installed capacity in 2019. Within the next year or two, the best onshore wind and solar PV projects will be delivering electricity for an LCOE equivalent of USD 0.03/kWh (26).

*Fundamental Change in the Electricity Value Chain and Business Models*

The changing nature of the US electricity generation mix and the changing nature of the grid will have a significant impact on energy infrastructure investment. Decarbonizing the electricity supply will require significant growth in renewable and gas-fired power generation to accommodate growth in demand and replace retiring coal and nuclear plant as shown in Figure 3 (27).

Because of this huge growth in renewables, significant investment will be needed to integrate variable and distributed renewable generation capacity including electricity storage and smart grid technology. Electricity storage will be a critical network component to offset the highly variable nature of solar and wind generating units, both diurnally and seasonally. There are many potential electrical energy storage technologies with different characteristics including their costs, functions, response times, and suitable storage durations (28).

The US grid is changing from a largely patchwork system built to serve the needs of individual electric utility companies to essentially a national interconnected system, accommodating massive transfers of electrical energy among regions of the United States. The modernization of the grid includes electronic intelligence capabilities for power control purposes and operations monitoring. The “Smart Grid” is the name given to this evolving intelligent electric power network. Investments for smart grid modernization projects are estimated to cost $350 billion to $500 billion over the next twenty years (29).

The growth in electric vehicles will require substantial build-out of high speed vehicle charging infrastructure across the country. The Center for America Progress estimates 330,000 new public fast charging outlets are needed to meet demand by 2025 costing a cumulative $4.7 billion (30).

In addition to major changes in physical infrastructure of the electricity value chain, business models are likely to significantly change. The business model of electric utilities is in a state of transformation due to rapidly changes, including demands for improved environmental performance, the expansion of distributed energy resources, a growing need for resiliency, new options to improve the performance of the grid, the advent of big data, and new expectations for customer choice. Organized electricity markets and balancing authorities will also be affected. The role of vertically-integrated electric power utilities and centrally-organized electricity markets (RTOs/ISOs) will also need to evolve (31). Additionally, the relative growth of the electricity sector and introduction of new technology is likely to bring new entrants, including the international major oil and gas companies.

*Increasing regulatory pressures and consumer preferences for clean energy*

While the industry is undergoing significant change, regulatory pressures are increasing. Most energy infrastructure is subject to more than 35 separate permitting responsibilities spread across 18 federal agencies (32). State governments are implementing renewable generation mandates, GHG and pollutant reduction rules and challenging use of eminent domain for infrastructure. Local governments and communities are increasingly imposing zoning and health restrictions and, in some cases, bans. Landowners are increasingly complicating right of way access and environmental NGOs are increasingly targeting infrastructure projects in efforts to slow/stop fossil fuel resource development.

Consumers are also showing increasing preferences for clean energy. Sixty-eight percent of residential consumers surveyed by Deloitte in 2018 are very concerned about climate change and their personal carbon footprints. Seven in 10 businesses say their customers are demanding that they procure a certain percentage of their electricity from renewable sources (33).

**Key Uncertainties Affecting Investment**

While the condition of existing infrastructure and establish trends will drive infrastructure investment, there are significant uncertainties that will affect the nature and pace of investment. The symposium teams identified nearly twenty uncertainties affecting energy infrastructure investment. Five were prioritized based on highest impact and highest uncertainty.

*Pace of the Energy Transition*

Concerns about climate change as well as the business case for renewable fuels and new end use technologies have initiated a transition to a global sustainable energy system (34). However, the pace of change is highly uncertain. Based on the past, neither private markets nor government agencies seem likely to spur a transition on their own. Moreover, transitions to newer, cleaner energy systems often require significant shifts not only in technology, but in political regulations, tariffs and pricing regimes, and the behavior of users and adopters (35). Researchers at the International Institute of Applied Systems Analysis (IIASA) found that successful energy transitions go through a series of characteristic stages: an extended period of experimentation and learning, scale up and cost reduction at both the individual technology and network level, and co-evolution of long lived infrastructures and technological clusters due to network effects (36). Energy transitions typically take decades, but the rate of change is influenced by several factors shown in Figure 4.

While many of these drivers are favorable for a more rapid transition, the sheer scale and complexity of the US and global energy systems will slow progress.

*Pace of development of distributed energy resources technology*

While renewable generation technology becoming competitive with existing fossil fuel technologies, there is more uncertainty around the pace of development of technologies downstream and behind the meter in the electricity value chain. More specifically, these distributed energy resources (DERs) are both physical and virtual assets that can be deployed across the grid. They are often close to load, and typically behind the meter—such as a residential or commercial rooftop solar installation, or wind turbine serving a single household or an industrial facility. The movement toward an integrated grid, with efficiency and consumption working together for mutual benefit, is advancing rapidly. Big data is playing an important role, allowing the flow of information among multiple parties, facilitating dynamic adjustments to real-time market and operational conditions, and promoting efficiencies for transmission and distribution networks. However, there are a number of DER technologies—such as solar arrays, wind turbines, micro-grids, combined heat and power systems, backup generation, and energy storage – that need to evolve to make large scale distributed systems a reality (37). A particular challenge is energy storage, where a number of technologies are being developed as shown in Figure 5.

However, the pace of development of individual technologies and for energy storage, which technologies will best fit different storage situation (duration, location, etc.) are highly uncertain.

*Ability to Make Necessary Reliability and Resiliency Investments*

While the need for investment in energy infrastructure to improve reliability and resilience is clear, the ability to implement those investments is highly uncertain. Smaller scale investments can ultimately be made at the local and regional level by the stakeholders most affected by specific risks or by private firms with significant economic incentives in place. However, large scale infrastructure programs have traditionally required a clear federal policy driver or a federal response to a specific event. Examples of the former include the Federal Rural Electrification program and the development of the Interstate Highway System. Examples of the latter include various federal flood control investments such as the Mississippi River Valley Project in response to the Great Mississippi Flood of 1927 which displaced 1% of the US population (38) and the Big Inch Oil Pipeline build during WWII to protect the US oil industry from German submarines (39). In the absence of such federal drivers, there is considerable uncertainty about the ability to make these types of investments in the existing energy infrastructure.

*Returns on Investment of New Types of Assets*

Much if the investment in the US energy infrastructure will be made in new types of assets involving new technologies operating in significant market and regulatory uncertainty. This makes the likely returns on investment achieved highly uncertain. In the electricity sector specifically, understanding how wholesale and retail prices will be formed when there is significant generation capacity available at near-zero marginal costs. In addition, the revenue models ultimately adopted for distributed generation and storage assets are unclear today. These uncertainties could slow investment in these assets.

*Possibility of Stranding Assets*

Energy infrastructure by definition involved large assets with long lives. As energy systems transition, there are likely to be some assets that are financially/operationally stranded by higher performing/lower cost technologies, policy mandates, or consumer preferences/social pressures. The pace of these technology development and policy mandates that will impact the nature and amount of stranded assets are highly uncertain. Government policy responses to address the financial and employment impacts of any stranded assets are also unclear.

On the positive side, it is possible that zero-carbon technologies will be able to make use of many existing systems built for the fossil age which will reduce the amount of stranded assets. These include things like synthetic fuels in existing jet engines, hydrogen in natural-gas pipelines, or zero-carbon aluminum smelters (40). Perhaps most importantly, developing cost-competitive carbon capture, use and storage (CCUS) technologies could help decarbonize many hard-to-abate large industries including steel, cement, fertilizer and petrochemicals (41).

**Key New/Emerging investment Opportunities**

In addition to the investment trends underway to meet energy system reliability challenges, expand oil and gas production and export facilities and grow renewable power generation, the symposium groups identified a number of new or emerging investment opportunities.

*Distributed Energy Resources*

The second, related opportunity is for investments in distributed energy resources (DERs). Advancing technology is significantly changing the electricity grid, adding new small-scale renewable sources of energy generation and two-way power flows. DERs can include behind-the-meter renewable and non-renewable generation, energy storage, inverters (electronic devices that change DC, or direct current, to AC, or alternating current), electric vehicles and other controlled loads (separately metered appliances like hot water systems). DER also comprises new technology like smart meters and data services. Common examples of DERs include rooftop solar PV units, natural gas turbines, micro-turbines, wind turbines, biomass generators, fuel cells, combined cooling, heat and power (CCHP) units, battery storage, electric vehicles (EV) and EV chargers, and demand response applications (42).

*Carbon Capture Use and Storage (CCUS)*

CCUS is likely to be critical in the transition. It will be especially important in extending the life of large existing industries including steel, cement, fertilizer and petrochemicals. CCUS is also a potential route to making zero emission hydrogen from natural gas. In addition to traditional uses as a feedstock for ammonia and methanol, hydrogen could ultimately be important in terms of liquid synfuels, commercial and industrial heating, fuel cell vehicles, and energy storage (43). Eventually, captured CO2 could be converted to high strength carbon nanofiber materials (44).

*Desalination*

Growing freshwater scarcity in many parts of the US, increased production of brackish water from oil and gas development, and the potential for low cost renewable energy will create a significant opportunity for investment in desalination. . Finding freshwater – whether by drilling deeper into sinking aquifers or treating brackish water – has grown more expensive, narrowing the gap between the traditional costs for freshwater and the price tag for desalination. Many governments and private companies are currently working on advancements that would make the elusive process energy-efficient and cost-effective (45). Most desalination plants, run seawater through a membrane that filters out salt, a process known as reverse osmosis, that uses a lot of power. While reverse osmosis is currently the cheaper option, solar thermal desalination has a much better chance of hitting the point where it can compete with fresh water from conventional sources (46). Experts hope a major breakthrough could come in as soon as a decade and a full roll-out in perhaps 20 years (47).

*Energy Efficiency Investment*

Technology advancements are also creating opportunities for significant improvement in the efficiency of energy use. The IEA projects that annual global energy intensity (energy input /GDP) improvement could will exceed 3% if all available energy efficiency measures were implemented between now and 2040. All these measures are cost-effective, based on energy saving alone, and use technologies that are readily available today (48).

In the transport sector, efficiency investment trends are the most established for light duty vehicles with the continued improvement in efficiency of ICVs (engine improvements, reduced body weight) and the increased deployment of EVs. Opportunities are now emerging in heavy duty vehicles with improvements in ICVs (driven largely by tighter emission standards) as well as shifts to natural gas and electric power trains. Shipping efficiency will increase significantly driven by changes required to meet new restrictions on bunker sulfur levels.

In the residential and commercial sector, retrofit of buildings with new efficiency technologies mentioned previously along with digital building energy management systems will be a significant investment opportunity.

Opportunities in the industrial sector include retrofit of plants and factories with new technologies including more efficient heating and electric motors for both the energy-intensive and less-intensive industries. In addition, new screening and sorting recycling technologies in steel and paper offer opportunities to invest (49, 50).

*New Customer Business Models for Mobility and Energy*

The participants believed that there were likely to be a number of new business models that resulting from the combination of new technologies energy supply and end use along broader "fourth industrial revolution" technologies such as new software (i.e., apps and artificial intelligence), new platforms (i.e., cloud computing), and new networks (i.e., 5G wireless) (51). These technologies will lower costs through a focus on increased asset utilization and increased efficiency.

Many of these are "as a service" models. Mobility-as-a Service (MaaS) is likely to blend new electric vehicle technology with new digital technology and ultimately artificial intelligence to significantly reduce the efficiency and cost of personal transportation. Energy-as-a Service (EaaS) involves bundling technology, financing, procurement and operations solutions to optimize an energy consumer's energy system. Initially, this has included renewable power purchase agreements, energy management contracts, and electricity market retail brokerage services. Ultimately, EaaS is likely to evolve to complete outsourcing of energy procurement and turnkey onsite energy systems installation, management and maintenance with an ultimate goal of more reliable energy supplies at lower, more predictable cost (52).

Figures

Figure 1 - 2017 US Energy Investment

| $ Billion | | | |
|---|---|---|---|
| Energy Supply | Oil and Gas | Upstream | 70 |
| | | Downstream and Infrastructure | 49 |
| | Coal | Mining and Infrastructure | 2 |
| | Power Generation | Fossil Fuels and Nuclear | 18 |
| | | Renewables | 41 |
| | Electricity Infrastructure | Transmission and Distribution | 65 |
| Energy Demand | Energy Efficiency | | 42 |
| Total | | | 287 |

Source: IEA World Energy Investment 2018

## Figure 2 – US Goods Trade Balance

| | 2006 | 2017 | Change |
|---|---|---|---|
| Imports | 2182 | 2644 | 462 |
| Petroleum | 521 | 392 | (129) |
| Non-Petroleum | 1661 | 2252 | 591 |
| | | | |
| Exports | 1,198 | 1708 | 510 |
| Petroleum | 47 | 203 | 156 |
| Non-Petroleum | 1,151 | 1505 | 354 |
| | | | |
| Net Imports | 983 | 935 | (48) |
| Petroleum | 464 | 191 | (273) |
| Non-Petroleum | 519 | 744 | 225 |

Source: US Census Bureau - Real Exports, Imports, and Balance of Goods, Petroleum and Non-Petroleum End-Use Commodity Category Total (Oct 2018)

## Figure 3 – Growth in US Power Generation

| Source | Change in Power Generation (2040 vs. 2017) (tetrawatt-hours) |
|---|---|
| Solar | 900 |
| Natural Gas | 700 |
| Wind | 600 |
| Nuclear | (300) |
| Coal | (900) |
| | |
| Total Change | 1000 |

Source: Wood Mackenzie – November 2018

## Figure 4 – Factors Affecting the Pace of Energy Transitions

| Factor | Impact |
|---|---|
| Scale | • More difficult to transform large systems .<br>• Energy transitions tend to begin at small, local scales and spread nationally and eventually globally |
| Complexity | • More complex and infrastructure-intensive systems transition slower |
| End-use innovation | • Pace of end use innovation is a major driver of transitions<br>• New technologies may be adopted for reasons not emergent from traditional economics. |
| Coordination among multiple stakeholders | • Successful transition depends on consumer adoption, coordination among multiple stakeholders, and institutional and policy support. |
| Risk reduction | • Uncertainty about technology and policy slows transitions<br>• Reducing risk to investors as demand grows and technology changes accelerates transitions |
| Connection | • Comparative advantage across multiple dimensions can accelerate transitions |

Source: Prospects for Hydrogen in the Future Energy System – March 2018

## Figure 5 – Energy Storage Technologies

| Storage Type | Examples |
|---|---|
| mechanical | pumped hydroelectric storage, compressed air energy storage and flywheels |
| electrochemical | conventional rechargeable batteries and flow batteries |
| electrical | capacitors, supercapacitors and superconducting magnetic energy storage |
| thermochemical | solar fuels |
| chemical | hydrogen storage with fuel cells |
| thermal energy storage | sensible heat storage and latent heat storage |

Source: Overview of current development in electrical energy storage technologies and the application potential in power system operation

Footnotes

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