Testimony of
Kenneth B. Medlock III
James A. Baker, III, and Susan G. Baker Fellow in Energy and Resource Economics, and
Senior Director, Center for Energy Studies
James A. Baker III Institute for Public Policy
Rice University

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Hearing on
The Evolution of Energy Infrastructure in the United States and
How Lessons Learned from the Past Can Inform Future Opportunities

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Infrastructure is vital for well-functioning markets. It plays a critical role in connecting supplies with demands, and is the architecture through which price carries signals to producers and consumers. Indeed, if deep, well-functioning markets are desired, then sufficient infrastructure is critical. For investments to occur in developing new supplies, access to infrastructure to connect producers to consumers is vital. In fact, this establishes the physical connection that leads to greater market depth and liquidity, which is important for energy security. The absence of sufficient infrastructure can disrupt investment and have bearing on whether there is adequate and reliable supply available to end-users.

This paper discusses the central role that infrastructure plays in price formation and touches on the additional impacts it has on foreign policy and US projection in diplomatic discussions. In addition, the interrelated nature of energy infrastructure with regulatory and legal frameworks establish the rubrics that govern the behaviors of market participants. To be clear, this brief testimony is not meant to be exhaustive, but it will highlight some key points that must be brought forth in any policy discussion related to energy infrastructure.

Altogether, the aim here is to highlight some critical discussion points when considering the role of policy for infrastructure. There are no explicit policy recommendations herein, as there are other issues beyond the scope of this discussion; rather, there are frameworks that must be used to analyze various pathways under consideration. Insufficient infrastructure in the energy domain can present a barrier to investment and growth, largely because commercial returns are unattainable. This, in turn, impacts producers *and* consumers, carrying implications for price and more broadly, energy security.

Energy Security, Trade and the Role of Infrastructure

Energy security generally refers to the concept of ensuring adequate supplies of energy at a reasonable price to avoid the economic dislocations and negative welfare impacts associated with energy price spikes or supply disruptions. So, while economic security is a broader concept that pertains to more than just energy, the concepts of energy security and economic well-being are intimately linked, as the former, if achieved, conveys elements of the latter. If infrastructure is not adequate, then energy security can be compromised and economic activity can be negatively impacted. In fact, infrastructure is critical to realizing the full slate of benefits associated with all forms of energy.

In general, there are several types of policies that can contribute to enhanced energy security. These include:

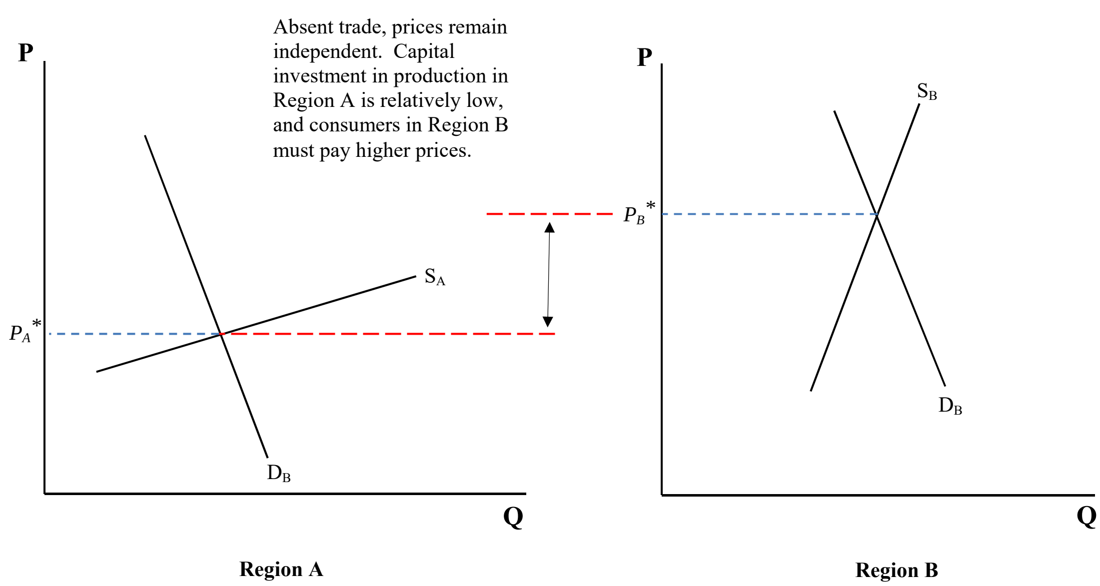
- increase energy efficiency in effort to lower the energy intensity of economic activity and thereby lower the expenditure share of energy;
- diversify the energy mix – through geographic dispersion of trading partners or through different types of resources – to lower the overall impact of disruptions in the supply of any one energy source;
- build inventory response capability (i.e. – storage) to offset the price implications of short term demand spikes or supply disruptions; and
- promote deeper, more liquid markets to provide greater opportunities to trade thereby reducing the impact of unexpected market disturbances on the supply portfolio.

Each of these has relevance to the realization of North American energy security and economic well-being. Moreover, each also indicates a distinct role for infrastructure in facilitating competition and trade. For example, energy efficiency can be enhanced through infrastructure investments in "smart" technologies by electricity consumers. Such technologies can convey real time pricing data to consumers thereby allowing them to adjust consumption patterns in response. When this occurs, it can reduce overall electric system load and allow existing generation resources to operate in ranges that maximize system redundancy and reliability.

Similarly, diversification in the energy mix can be achieved through infrastructure investments that allow substitution of energy sources seamlessly. Wholesale electric power markets have been doing this for years, but the introduction of distributed generation infrastructures have the potential to be disruptive to the status quo while adding another element of diversification to the overall grid. Managing such a turn is, of course, paramount, and it will carry repercussions for other types of infrastructures related to the provision of energy services.

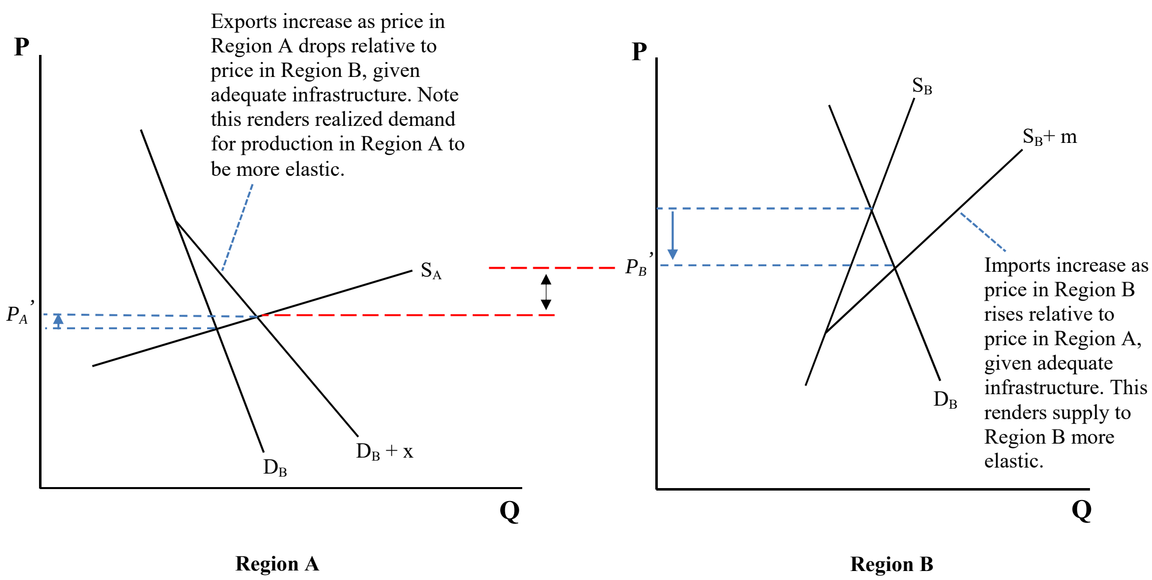
The latter two bullets relate to intertemporal trade (via storage) and spatial trade (via pipelines, wires, tankers, etc.), respectively. In both cases, the existence of infrastructure that allows trade to occur enhances market function and adds elements of reliability and security of supply for consumers. A simple illustration rooted in trade theory can be useful to demonstrate the role that trade facilitated by infrastructure can play. Consider two regions that could be connected by infrastructure to facilitate trade, but initially are not. In Region A, there is an abundance of available supply relative to demand. In Region B, there is less supply available relative to demand. As indicated in Figure 1, absent the ability to trade, prices across the regions will be set independently, and markets will balance at the indicated prices, P_A^* and P_B^*.

Figure 1 – Two regions: No infrastructure and no trade



However, as indicated in Figure 2, if we introduce the physical ability to arbitrage the price differences between Regions A and B, the prices in each region will be set simultaneously, rather than independently and the markets will clear at P_A' and P_B', where the difference between prices reflects the cost of transport between the two regions. Notably, when infrastructure does not exist, the effective cost of trade (shadow cost) is infinite, so prices in the two regions can float within a very wide range of each other. The same thing is true if capacity (infrastructure) is limited and insufficient. If capital is mobile, when trade via new or expanded infrastructure is introduced we will see investments flow into Region A to facilitate greater production. We will also see investments flow into Region B to accommodate greater demands that lower prices incentivize. The exact movements of prices in each region will depend on the relative elasticities (price responsiveness) of supply and demand in each region, which will also determine the amount of trade that occurs (and infrastructure that is required).

Figure 2 – Two regions: Adequate infrastructure and trade

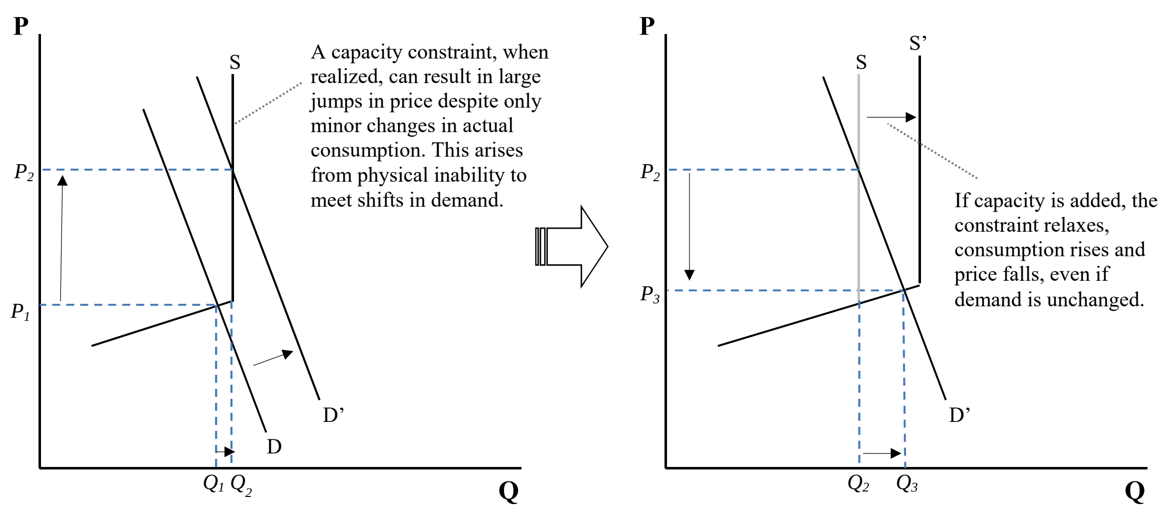


To stop here does not fully explain the value of infrastructure for price formation between the two regions. Notice, in Figure 2, how the elasticities (slopes) of supply in Region B and demand in Region A are affected when there are no impediments to trade. This conveys a very important point. Namely, physical infrastructure enhances market fungibility across regions. If we allow demand to vary seasonally, as is generally the case for energy, the volatility of price is dampened, all else equal, when trade is allowed. As a case in point, we can consider regional natural gas prices – internationally and domestically. Constraints on the ability to meet the unexpected demand shock in the wake of the disaster at Fukushima resulted in the spot price of Asian LNG rising to unprecedented levels. If LNG export capacity had existed in the US at that time, price would not have risen to the levels witnessed. In fact, the rush to seek permits for export facilities in the years that followed indicated a desire by investors to capture the arbitrage opportunity – through infrastructure development – that arose between the US and Asia.

This phenomenon is not unprecedented, nor is it unique to Asian LNG pricing. We have seen similar circumstances in the continental North American market when extreme cold grips certain regions and drives up local demand in excess of what existing pipeline capacity can deliver. For example, an extreme cold weather event in the Northeast has been known to trigger the daily price in Boston (at Algonquin City Gate and TGP Zone 6) to jump more than $70 per thousand cubic feet above the price at Henry Hub because pipeline capacity is not sufficient to meet the sudden surge in regional demand. This is often referred to as a “basis blowout” and is driven by a realized capacity constraint on the ability to deliver supply. Fortunately for consumers in the affected regions, these price shocks are generally short-lived, subsiding when the cold weather event passes. Moreover, the depth of the US market provides substantial liquidity through which price differences are quickly arbitraged as the supply constraint is relaxed.

This raises a very important point about the role of adequate infrastructure for price formation. When infrastructure is insufficient, short term movements in supply and demand can result in significant price dislocations. Consider, for example, Figure 3. Here, we see a region that initially has sufficient capacity to deliver energy for a given demand schedule, then a shift in demand results in the existing infrastructure being insufficient to meet new demands (see Step 1 in Figure 3). The result of the realization of a constraint on the ability to physically deliver supply to the market is a significant increase in price even though actual consumption may not rise very much. Notably, if demand swings due to seasonal factors, this can result in excessive price volatility as the constraint is realized and relaxed over and over again.

Figure 3 – The Role of Capacity Constraints in Price Formation



Step 1 – Inadequate infrastructure renders constraint **Step 2 – New infrastructure relieves constraint**

However, if we add delivery capability to the market, the constraint is relaxed, even at the higher level of demand, and price falls despite actual consumption rising (see Step 2 in Figure 3). In both cases (Steps 1 and 2 depicted in Figure 3), the market clears where available supply equals demand, resulting in a market clearing price and quantity consumed. But, in the case where the deliverability (supply) constraint is relaxed, price is lower, greater consumption is facilitated and price volatility is dampened.[1]

Returning to the example of LNG pricing in Asia, the post-Fukushima price increase did not abate quickly unlike the aforementioned basis blowouts associated with weather-driven demand shocks. But, as new sources of LNG supply have been brought online (Papua New Guinea, East Australia, and others) and demand has been rationalized by price, the binding deliverability constraint to the Asian market has been relaxed (as in Step 2 in Figure 3) and the spot price of LNG has settled back into a range that is more consistent with a globally arbitraged price. While there may eventually be short term constraints that result in temporarily elevated LNG prices, if infrastructure continues to expand, the long term will be characterized by deeper, more fungible markets in which regional prices communicate unimpeded. This is where it becomes important to more generally consider what increased trade in the global LNG market will do to the nature of pricing abroad. Of course, greater LNG trade requires sufficient infrastructure throughout the value chain – in field production, pipelines, liquefaction, shipping and regasification – but as more players enter the market, competitive pressures will mount regardless of the source of LNG. As US LNG exports in particular rise, the global market will become physically linked to North America, the most liquid natural gas market on the world. This should, in turn, facilitate more trade and alter the liquidity paradigm that has characterized the global LNG market heretofore. The credible threat that US LNG serves to incumbent regional suppliers – Russia into Europe, for example – coupled with greater market liquidity will fundamentally alter the nature of natural gas pricing everywhere. Infrastructure is critical to such an outcome.

Infrastructure and the Current US Energy Renaissance

During the past 15 years, innovative new techniques involving horizontal drilling and hydraulic fracturing have unlocked a vast resource potential and resulted in the rapid growth in production of natural gas from shale. The same techniques have also matriculated into the oil sector resulting in a dramatic increase in light tight oil production. Oft underappreciated facets of the so-called “shale revolution” are the regulatory features and market institutions that facilitated the rapid expansion of production in the US. In fact, as production has grown, US supply has become more price responsive, which, in turn, has contributed to greater energy security. This has been propelled by rapid deployment of capital throughout the energy value chain and the consequent development of production and distribution infrastructure.

So, what made the successes witnessed in the US during the past 15 years possible? To begin, geology matters. The scale of the technically and economically recoverable oil and gas resources

[1] “Deliverability constraints” refer to constraints on access to capacity, which can result if physical capacity is short or if capacity is rendered unavailable through other means. In any case, the result is an increase in price.

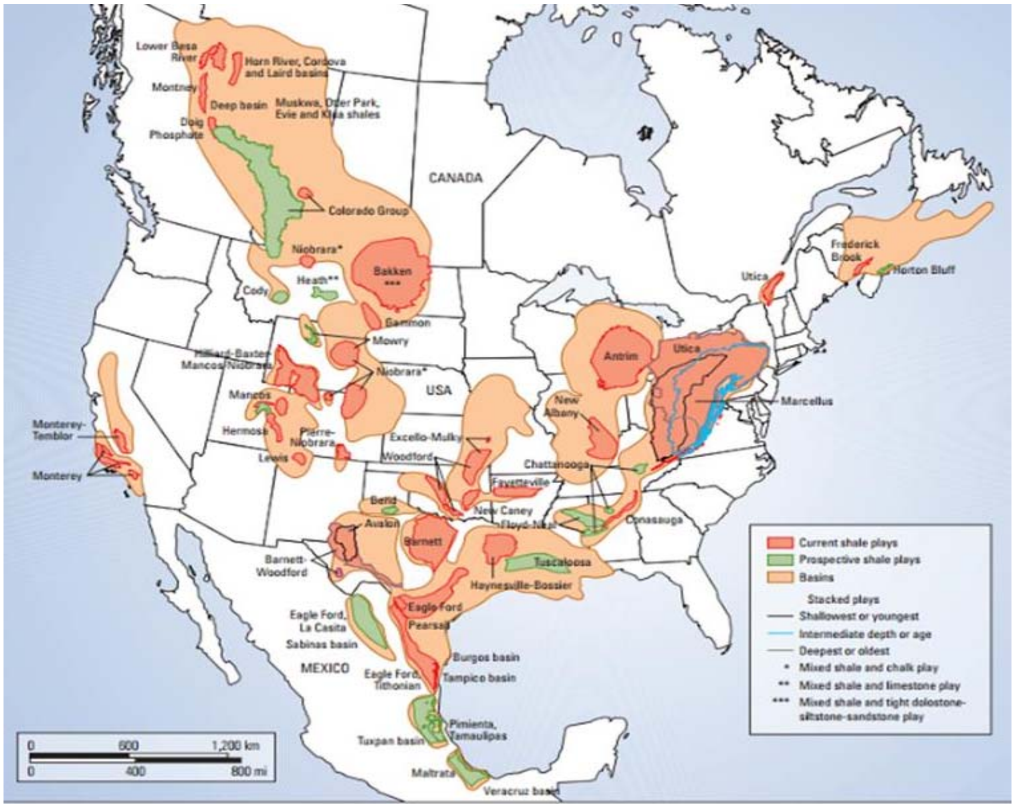
locked up in shale is tremendous and geographically diverse (see Figure 4), and as time passes the understanding of the resource expands. But, while the right geology is a *necessary* condition, it is not *sufficient*. Shale resources assessed in locations outside the US are significant, yet shale oil and gas production on a global scale is still largely limited to the US. This follows because *sufficiency* requires a host of above-ground factors to be appropriately aligned. These include market institutions and regulatory frameworks spanning the energy value chain, such as…

- a regulatory and legal apparatus in which upstream firms can negotiate directly with landowners for access to mineral rights on privately-owned lands.
- a market in which liquid pricing locations, or hubs, are easily accessed due to liberalized transportation services that dictate pipeline *capacity* is unbundled from pipeline *ownership*.
- a well-developed pipeline network that can facilitate new production volumes as they are brought online.
- a market in which interstate pipeline development is relatively seamless due to a well-established governing body – the Federal Energy Regulatory Commission (FERC) – and a comparatively straightforward regulatory approval process.
- a market in which demand pull is sufficient, and can materialize with minimal regulatory impediment, to provide the opportunity for new supplies to compete for market share in the energy complex.
- a market where a well-developed service sector already exists that can facilitate fast-paced drilling activity and provide rapid response to demands in the field.
- a service sector that must compete by reducing costs and improving technologies in order to gain a competitive advantage.
- a sizeable rig fleet that is capable of responding to upstream demands without constraint.
- a deep set of upstream actors that includes independent producers that can behave as the "entrepreneur" in the upstream thereby facilitating a flow of capital into the field toward smaller scale, riskier ventures than those typically engaged by vertically integrated majors.

Every one of the above bullets has some relevance to infrastructure – from permitting to access to market function to price formation to investment, etc. If any of these features is absent, an effective barrier to market development is presented, usually manifesting in the form of higher costs. Moreover, some of the above *sufficient* conditions can be co-dependent on the others, which highlights to the notion that well-designed market institutions and regulatory frameworks can be self-reinforcing. For example, a well-developed service sector relies on a deep set of entrepreneurial (independent) upstream players to create large demands for its products and services, just as the population of independent producers in the US upstream might not be so deep absent a well-developed service sector.

The coexistence of these factors makes the US a unique environment for upstream shale-directed investments. This, in turn, highlights the importance of each in achieving US energy-related geopolitical and foreign policy aims. More specifically, the legacy of domestic regulatory and market institutions engenders significant global influence, and infrastructure has played a central role in fostering the current reality.

Figure 4 – Shale Resources in North America



Source: http://alfin2300.blogspot.com/2012/03/gallery-of-world-hydrocarbon-endowment.html

Why does this matter?

There is much discussion about the US being an "energy superpower." In fact, this terminology has permeated the US State Department and been a recognized facet of diplomacy carried forth by the Bureau of Energy Resources for the past several years. Currently, we can see this directly from the Bureau of Energy Resources website.

> ENR promotes U.S. interests globally on critical issues such as: ensuring economic and energy security for the U.S. and our allies and partners; removing barriers to energy development and trade; and promoting U.S. best practices regarding transparency and good governance. In addition, we review applications for the construction, connection, operation, or maintenance of facilities for the exportation or importation of petroleum, petroleum products, coal, and other fuels (except for natural gas) at the borders of the United States.

> The Bureau serves as the principal advisor to the Secretary of State on energy security, policy, operations, and programs. Through diplomacy and a wide range of programs, ENR works to ensure worldwide energy security by fostering diverse global energy supplies from all sources of energy.
>
> ENR operates at the critical intersection between energy and U.S. national security, and ensures U.S. leadership on global energy issues. U.S. national security is threatened when:
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> - Our allies lack reliable access to affordable energy or a diversity of choices;
> - Foreign energy markets shut out U.S. companies;
> - Poor governance prevents market-based energy solutions;
> - Competition for energy leads to conflict; or
> - Terrorists and rogue regimes seek to exploit energy resources to fund violence and destabilizing activities.
>
> To address these challenges, ENR works with leaders at the highest levels of government, business, and civil society, playing a crucial role in achieving U.S. foreign policy objectives in the energy arena. ENR foreign assistance programs are integral to the Bureau's diplomatic engagement overseas and provide critical support for the Department's objectives and the Administration's global diplomacy priorities.
>
> See: https://www.state.gov/e/enr/, accessed Feb 5, 2018

The emergence of the US as an oil and gas exporter has facilitated the goals set forth by the US State Department. So, the energy renaissance has had direct bearing on US diplomacy. However, the US government is neither the owner nor the producer of mineral wealth in the US, as is the case with government ownership of mineral wealth in many other export-oriented nations. Thus, the soft power afforded to the US government is facilitated by the unique regulatory and market institutions established in the US that allows the private sector's commercial development of oil and gas.

In general, legal institutions that place mineral rights in the hands of landowners and allow intellectual and physical property to be monetized have led to a regulatory framework in the US that is highly conducive to innovation and entrepreneurial activity across the energy sector. In the oil and gas space, incentives for domestic development derive from transparent, market-driven prices and a low cost to lift and move supplies. Hence, domestic production is very sensitive to the availability of capital and infrastructure. If anything disrupts the availability of either capital or infrastructure, production can grind to a halt in the affected region. This complicates the calculus around policy formation at the federal level, particularly when compared to the local level.[2]

As the US increases its exports of crude oil, petroleum products and natural gas, its influence expands into those nations that increasingly rely on imports to satisfy their energy appetites associated with economic growth. In general, expanded US production renders global supply to be more price responsive, and, as a result, carries an energy security benefit to consumers

[2] See "The Market Impact of New Natural Gas-Directed Policies in the United States" (Feb 2015) by Kenneth Medlock and Peter Hartley, available online at https://www.bakerinstitute.org/research/north-american-energy/.

everywhere. As argued in previous Baker Institute research, this also benefits US foreign policy endeavors in dealing with potential hostile oil-producing nations, and provides stability to the global oil market.[3] But, again, infrastructure is required to facilitate these goals.

Infrastructure, Competition and Energy Sector Evolution

The discussion heretofore has focused on a general framework for evaluating the role of infrastructure in trade and in facilitating US shale. But, to be clear, infrastructure plays an equally important role in the commercialization of new energy technologies and resources. One example that highlights the interdependent role of regulatory environment and infrastructure is found in electricity markets in Texas. Wholesale and retail competition were introduced in the State of Texas following the passage of Senate Bill 7. Since, competitive pressures in the retail power sector have forced firms to differentiate themselves by offering specific technologies and energy services. This has, in turn, unlocked the power of *revealed consumer preference* that matriculates through to investments in the wholesale generation and distribution of electricity. For instance, Texas now has more wind generation capacity than the entire rest of the US combined. Make no mistake, wind capacity investments have benefitted greatly from overt policy support, but they have also been propelled by consumer demands that have been made explicit through active marketing of renewable energy by retail providers. Moreover, as wind capacity investments have grown, massive transmission infrastructure investments have been made to connect resources to consumers. Similarly, some retail energy service providers have expanded their offerings into the introduction of smart technologies and distributed generation assets, which represent infrastructure investments at the commercial and residential levels. Thus, the regulatory and market environment along with the expansion of infrastructure have been critical for unlocking wind resource opportunities and pushing distributed generation and energy efficiency (albeit to a lesser extent) in Texas.[4]

Infrastructure also plays a vital role in the evolution of the transportation sector. The transportation sector has historically been dominated by crude oil products, a reality leveraged by a very large and redundant fuel delivery infrastructure. Redundancy, in particular, is a product of scale and is facilitated by multiple points of access to the primary fuel, including storage either onsite or near the refueling location. If other fuels are to successfully compete into the transportation sector, infrastructure is vital. And, the fuel must be reliable, which highlights the role of *redundancy* as an important aspect of fuel delivery infrastructure.

Natural gas is one fuel that has been discussed as having potential to penetrate the transportation sector. Currently, natural gas use for vehicle fuel is only about 0.15% of total natural gas use and

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[3] See “To Lift or Not to Lift? The US Crude Oil Export Ban: Implications for Price and Energy Security” (March 2015) by Kenneth Medlock, available online at https://www.bakerinstitute.org/research/north-american-energy/
[4] See “Electricity Reform and Retail Pricing in Texas” (June 2017) by Peter Hartley, Kenneth Medlock, and Olivera Jankovska, available online at https://www.bakerinstitute.org/research/north-american-energy/

represents about 2.8% of total transportation fuel use.[5] So, natural gas represents a relatively small fraction of the transportation sector. For this to change, scale comes into full focus, meaning substantial investment is required in natural gas fueling infrastructure along the nation's transportation network.[6] The ability to refuel becomes a very salient issue when one considers typical consumer driving behaviors. The flexibility and redundancy in the existing fuel delivery infrastructure (for gasoline) allows drivers the freedom to plan their activities without necessarily planning routes, which means "search costs" are significantly reduced when traveling.

Electrification of the vehicle fleet also poses some infrastructure challenges – with regard to power generation and transmission capacity and recharging outlets. In the near term, the existing generating fleet is sufficient to meet almost any expectation of electricity demand growth associated with electric vehicle (EV) adoption. In addition, recharging may be sufficient for low levels of EV penetration, but as more consumers drive EVs, scale effects begin to take hold and more recharging infrastructure will be required. Just as with natural gas into transportation, the location of re-charging stations also becomes relevant when long distance travel is desired. Even if the proverbial "chicken-and-egg" problem of vehicles and infrastructure can be overcome, the resulting requirements for new electric generation capacity – regardless of fuel type – if EVs adoption accelerates could be significant.[7] While renewable energy sources could arguably meet some of the incremental demand, the majority would likely be met by natural gas. Accordingly, this highlights another set of infrastructure requirements – added power generation and electricity distribution capacity as well as pipeline infrastructure enhancements.

Concluding remarks

Energy is critical to modern economic activity. This is, in fact, why energy security concerns – either discussed in the context of domestic reliability or international access – are such a critical component of energy policy discourse. Although not always explicit in these conversations, infrastructure is a prerequisite to the provision of energy services. It is vital throughout the value chain regardless of the form of energy being addressed. The US has a unique set of regulatory and market institutions that have promoted commercial development of infrastructure that has conveyed significant benefit in the energy security domain. While there are likely things that can be improved at the margin, in the context of the global energy system, the US has a very dense, redundant and relatively reliable energy architecture. Of course, aging infrastructure requires maintenance and modernization to capture the latest technological innovations, and doing so will go a long way to ensuring a 21st century competitive advantage for US interests.

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[5] The figures are derived from annual data for 2016 and are available online from the *Monthly Energy Review* published by the US Energy Information Administration, www.eia.gov.
[6] These arguments apply to compressed natural gas (CNG) as well as liquefied natural gas (LNG) vehicles.
[7] See, for example, "Energy Market Consequences of Emerging Renewable Energy and Carbon Dioxide Abatement Policies in the United States," by Peter Hartley and Kenneth B Medlock III (Sept 2010), available at https://www.bakerinstitute.org/research/energy-market-consequences-of-emerging-renewable-energy-and-carbon-dioxide-abatement-policies-in-the/.