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Executive Summary

This report builds and expands on topics originally discussed in "U.S. LNG Exports: Truth and Consequence."[1] The basic international trade concepts discussed therein are highly applicable to current discussions about U.S. liquified natural gas (LNG) exports. This report also recaps several points highlighted in the 2023 Baker Institute study, "US LNG Exports: Supply, Siting and Bottlenecks," which contained a brief summary of past LNG market studies and their implications for infrastructure.[2]

Since 2012, several different studies have been commissioned by the U.S. Department of Energy (DOE) to support efforts to make a public interest determination regarding U.S. LNG exports. As noted in a 2023 Baker Institute study, each of these DOE-commissioned studies found a net gain from trade across a wide range of different scenarios considered and concluded the net benefits increase with resource availability. While often framed in the context of a larger resource base with more elastic cost-of-supply, these findings also indicate that any impediments to the development of infrastructure will reduce net gains to the U.S. from trade.

In general, it appears that all the DOE-commissioned studies conducted prior to 2024 use an elasticity of supply that is too small. In other words, at a given price, actual U.S. production has exceeded what was anticipated even in the high domestic resource cases. It follows directly that the supply response of the modeling exercises is increasing over time.

- The National Economics Research Associates (NERA) 2012 study had the steepest, or least elastic, supply curves.[3]
- The Baker Institute for Public Policy Center for Energy Studies (CES) and Oxford Economic 2015 study's supply curves were flatter.[4]
- The NERA 2018 supply curves were even flatter.[5]
- The recently released DOE 2024 study prepared by OnLocation, Inc. with Industrial Economics, Incorporated, National Energy Technology Laboratory, and Pacific Northwest National Laboratory appears to have the most aggressive assumption about elasticity of supply.[6]

That stated, all DOE-commissioned studies are long-run studies. Hence, they do not capture short-term variations in demand and the resulting impacts on price. This is what the models were built to do. The studies are constructed to examine the long-term, structural impacts of increased LNG exports. Any short-term model should recognize

the difference between short-run and long-run elasticity. In the short run, prices tend to be more volatile due to the realization of capacity constraints that are not present in the long run. In fact, a long-run constraint would signal an investment opportunity that, when captured, would alleviate the constraint. This is a subtle but important point in the policy context.

Any forward-looking study should recognize the role that associated gas production is playing in U.S. market balance. Associated gas is an inframarginal source of supply that stretches the supply curve, which helps prevent prices from rising when demand or exports increase. It also connects the gas supply situation in the U.S. directly to oil-directed upstream developments, which is another important point in the policy context.

Any future study will likely be hard-pressed to not find positive net macroeconomic benefits from trade. Not only is this a basic outcome of international trade theory, but it also follows directly from previous work, which all found net positive benefits. In this context, if a trade is "in the money" (ITM) in a competitive equilibrium, then value must matriculate to all actors along the supply chain, lest the investments necessary to support supply chain development will not occur. Moreover, the value must be higher than alternative uses of investment capital because capital will seek the highest returns. This is why previous studies find net positive macroeconomic benefits associated with exports, despite underestimating domestic supply at a given price.

It directly follows that a license to export LNG is not a guarantee that exports will occur. Rather, a license is an option that the holder can choose to exercise if the export opportunity is ITM. In other words, an export project that is unable to earn a sufficient return on investment along the full supply chain will not move forward, leaving the option unexercised. This has already been witnessed at scale in the history of U.S. LNG trade; for instance, in the early 2000s, over 45 LNG import terminals received a license to import LNG, but those options were not exercised because market conditions rendered them "out of the money" (OTM).

There is now attention being given to examine the environmental implications of U.S. LNG exports, both domestic and abroad, as part of the public interest. This is inherently difficult to model, and the outcome can be entirely dependent on assumptions made about sources of supply and destination markets. Domestic environmental impact analyses have been conducted to examine pathways for emissions reductions. However, the sources of supply and pathway from wellhead to liquefaction are not necessarily the same across different existing and proposed export terminal. As such, no macro-level analysis emissions will suffice. Each terminal must be evaluated independently.

International environmental impacts are complicated by the fact that U.S. LNG export cargoes are very flexible. U.S. LNG is loaded free on board (FOB), so predicting where it will land is akin to predicting relative international price movements. U.S. LNG can be, and has been, redirected to chase the highest price. As such, cargo destinations can be influenced by a variety of factors that carry different implications, including:

- Seasonal demand fluctuations.
- Regional deliverability constraints and storage movements.
- Geopolitical disruptions.
- Weather-induced disruptions, among others.

Beyond cargo destination, predicting the fuel mix in different regions is also difficult. A probability weighted approach could be used to estimate how and when gas may compete in different regions, but the uncertainty is inescapable. Moreover, the role of policy in shaping the competitive landscape for different fuels is highly variable from region to region. Any approach that ignores this uncertainty is flawed from the outset.

It is important to note that estimating environmental impact is distinctly different from estimating potential gains from trade. All that is required to assess gains from trade is sufficient international demand to incentivize export flow, regardless of where it lands. While there is uncertainty therein, the uncertainty is amplified when trying to estimate environmental impacts because information about specific markets and the energy mix therein — now and in the future — is also required.

Finally, if the path forward is to expand the scope of a public interest determination, then the energy security dimensions of U.S. LNG exports should be incorporated. The recent experience in Europe following the Russian invasion of Ukraine and disruption of supply is a very recent, very salient example of why this is so. U.S. LNG demonstrated significant flexibility in responding to the market signals in Europe, helping to mitigate the economic damage that Russia's actions inflicted. If these events transpired in 2015, or any year prior to U.S. LNG exports commencing, it would have likely produced a very different outcome. In short, U.S. LNG is a credible threat deterrent to hegemonic intent with energy resources and trade.

Introduction

In January 2024, the U.S. DOE announced it would "Update Public Interest Analysis to Enhance National Security, Achieve Clean Energy Goals and Continue Support for Global Allies."[7] In doing so, there was an explicit pause on the evaluation of pending permit applications for LNG exports. However, the pause did not apply to permits already issued and LNG export facilities already under construction.

Nevertheless, the pause created significant uncertainty around the future of U.S. LNG exports, particularly because the proposed update on public interest broke with previous approaches that established a precedent for how the concept of "public interest" is defined. Prior to January 2024, the DOE had recognized analyses of environmental issues, but did not explicitly include them in its public interest determination.

In December 2024, the DOE released a study of the public interest of U.S. LNG exports. That study, as one's prior to it, included a macroeconomic assessment of U.S. LNG exports, but it also included an evaluation of greenhouse gas (GHG) emissions in destination markets, as well as a discussion of local community impacts of associated infrastructure development in the U.S. Energy security was referenced, but the study detail was primarily focused on GHGs and community impacts.[8] In any case, during 2024, due to the pause, the politics of LNG exports moved into the spotlight.

Natural gas already plays a significant role in the U.S. energy system due to deeply interconnected interstate, intrastate, and utility-scale distribution pipeline infrastructure connecting producers to end users that has developed over decades. In addition, U.S. natural gas is heavily connected to Canada and Mexico, which is why the market is often referred to as the "North American natural gas market."[9] This connectivity owes to expansive infrastructures to produce, move, and use natural gas in multiple end-use sectors. It also means the three countries all influence each other as regional supply-demand balances shift. However, this subtle but important point is often missed when assessing the future of natural gas in the lower 48 states. Canadian natural gas resources are large, and they serve as a long-term backstop for U.S. natural gas price movements, as long as trade can occur unimpeded.

Events over the last two years have served as an acute reminder that energy prices matter to policymakers, industrial consumers, power market participants, and the general public. The reopening of the world's economies in the wake of the COVID-19-induced shutdowns in 2020 triggered a rise in energy prices as well as other prices due to various supply chain constraints. This led to calls from policymakers for more investment in new oil and gas production, which was a notable contrast to previous calls to phase out hydrocarbons.[10] Energy prices matter.

Since the beginning of 2022, heightened geopolitical tensions spurred by the Russia-Ukraine war have pushed energy security back to the top of national policy concerns. This has reinvigorated discussions about the role of natural gas in achieving various economic, security, and environmental goals, which also has reintroduced energy balance into these discussions. This reinforces that natural gas is likely to remain an important part of the energy mix for decades to come, but despite this evolution in discourse, attention to the environmental sustainability of the supply chain will remain an important determinant of the role natural gas plays. Balance is key.

Make no mistake, the global energy system continues to transition, but transitions will look different everywhere due to differences in natural resource endowments, physical capital and human capital, and other regional comparative advantages. Much like the current energy mix is different across regions, the future energy mix will also look different everywhere. Unfortunately, regional distinctions are also not always reconciled in broad proclamations about the future of energy, but regional heterogeneity will have tremendous bearing on the future of natural gas. In the end, market forces will dictate market outcomes. The path will be choppy, as has always been the case, but the volatility of the path can be influenced by policy.[11] The inconsistent nature of discussions about the future role of natural gas creates uncertainty for investors across the entire supply chain — from production to transport to delivery to end use — and the LNG export authorization pause is a prime example of this. Uncertainty is negative for investment, and, in turn, it is deleterious to long-term market stability.

Diversity of supply — both the diversity of fuels to provide energy services and the diversity of suppliers for any single energy source — is central for enhancing energy security. Placing too much of a region's energy fortune on either one energy source or one supplier exposes the region to a higher risk of disruption, and history has taught that energy disruptions are highly correlated with macroeconomic dislocations. In general, energy security has historically been a central consideration to policymaking, with different regional approaches prioritizing domestic energy sources whose supply chains are less exposed to being influenced by international events.[12] There is a wealth of evidence that supports this point, and the ongoing issues in Europe have provided the world with a stark reminder of the importance of affordable and reliable energy.

Market structure also matters. When there are many market participants who can interact with minimal friction, markets are typically characterized as having depth and liquidity. Investments along the supply chain in deep, liquid markets face lower transaction risk, which, in turn, facilitates greater levels of investment.[13] In this context, the U.S. natural gas market is in a favorable position because it is competitive, most resources are privately-owned, and investments are dictated by market conditions.[14] This combination is attractive to investors who wish to diversify sources of supply while minimizing the risk of disruption from government interference and geopolitical disruption. It also contributes to energy security domestically, and those benefits can be carried abroad if trade is unencumbered.

This report begins by providing a historical frame of reference around the evolution of U.S. natural gas demand, supply, and trade. This establishes the basis for understanding the recent rapid growth of U.S. LNG exports, and why studies aimed at analyzing the "public interest" are foundational for political discourse around LNG exports. Then, the report explores the findings of past studies commissioned by DOE with an emphasis on the similarities and differences, offering explanations for both. This discussion is then expanded to consider what is included in the concept of "public interest" and how it might be considered. Throughout, some basic economic fundamentals are highlighted to provide a structural underpinning that is vital for any discussion about U.S. LNG exports and natural gas markets in the current context.

US Natural Gas Market Evolution: A Change With Global Impacts

Historical Context

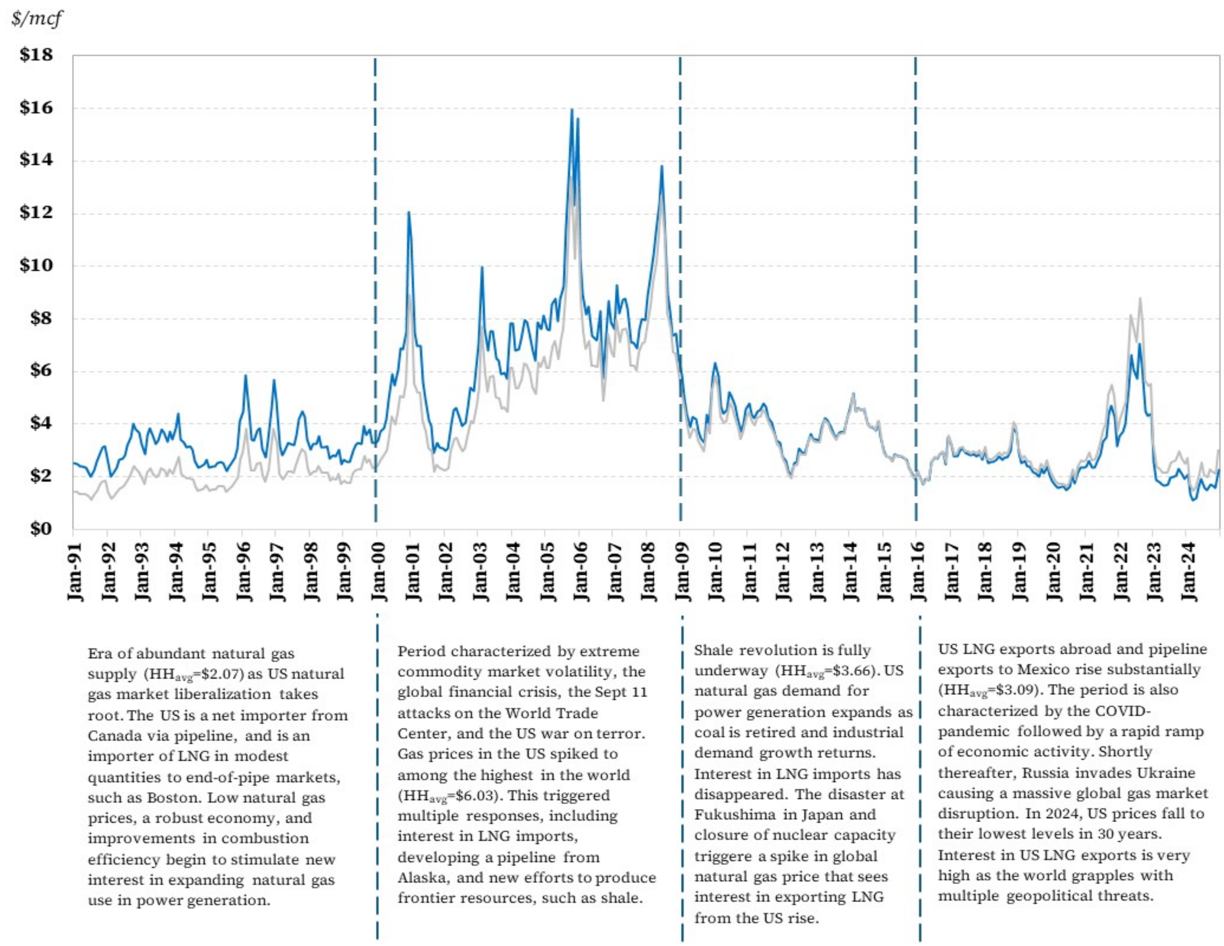
The evolution of the U.S. natural gas industry over the last five decades is a story of policy and regulatory shifts that have unleashed market forces. The Natural Gas Policy Act (NGPA) of 1978 set in motion a series of changes that resulted in the U.S. natural gas market becoming the most liquid, efficient natural gas market in the world.[15] This, in turn, unlocked pathways for production growth, pipeline capacity investment, and demand growth, largely because price could be determined in a transparent, competitive market.

Prior to the NGPA, natural gas sales prices on interstate pipelines were controlled. Thus, producers often chose to sell to intrastate buyers first, which subsequently contributed to shortages in states that did not have robust natural gas production. Price controls also reduced the incentive to develop new production as well as capacity to deliver it. Price controls were ultimately eliminated so that prices could adjust to reflect a market-clearing supply-demand balance.[16] The NGPA also assigned authority to the Federal Energy Regulatory Commission (FERC) to regulate interstate natural gas movement. Over the next two decades, a series of FERC orders, culminating with Order 636, completed the process of market restructuring.[17] Capacity rights were unbundled from pipeline ownership, and pipeline information was mandated to be openly published to establish transparency to support open market function.

Since market competition was codified, the U.S. natural gas market has continued to evolve, undergoing multiple changes. Figure 1 presents a very brief exposition of how the U.S. natural gas market changed from 1991 to 2024. In general, there have been several seismic-level economic, geopolitical, and technological developments that have triggered substantial changes in the overall energy market landscape. Natural gas, due to its importance across multiple sectors — from power generation to process heat and feedstock uses in industry to heating and cooking applications in the residential and commercial sectors — has been shaped by all these factors to some extent.

The 1990s were viewed as the “gas bubble” era and were characterized by abundant domestic supply, low prices, and a vibrant market. The U.S. saw strong economic growth during this period characterized by low commodity price and price volatility. North American market linkages deepened, and the U.S. was an importer of natural gas via pipeline, largely from Canada, as well as LNG from destinations, such as Trinidad and Tobago and Algeria. LNG imports largely served end-of-pipe markets in places such as Boston where demand often exceeds domestic delivery capability in winter months.

Figure 1 — A Brief History of US Natural Gas Prices, January 1991–January 2024



Data Sources: International Monetary Fund (IMF) Commodity Price Service, the U.S. Energy Information Administration (EIA), and the U.S. Federal Reserve Database (FRED). **Notes:** The blue series is in real, or inflation-adjusted, 2015$, the gray series is nominal, and mcf refers to thousand cubic feet.

The early 2000s saw rapidly rising and volatile prices, which were largely interpreted to mean the era of abundance was over. This triggered efforts to develop domestic natural gas resources from frontier plays, such as those of George Mitchell in the Barnett Shale located in the northeast Texas' Fort Worth Basin.[18] High prices also drove significant interest in proposals to build a pipeline from Alaska to the lower 48 states along two different proposed paths — either through the Mackenzie Delta region of Canada or the Alaska Highway route. The period also saw the emergence of enormous interest in importing LNG to the U.S., with many firms applying for and receiving licenses to import LNG. Economics ultimately won the day as Alaska gas remains in Alaska, and innovations unlocked massive investments in previously uneconomic gas deposits in shale, which has driven the interest in developing liquefaction export capacity. In addition, the over 45 LNG import licenses that were granted remain unutilized.

This highlights a critical point in the LNG export licensing discussions. Licenses are options, not guarantees. Projects do not move forward if they are unable to find commercial footing. This very basic point is often neglected in most discussions about the future of U.S. LNG exports. Moreover, if a project is commercially viable, it will, by definition, generate gains from trade because in the competitive U.S. market, full value chain support requires that returns be sufficient along every point in the supply chain. This, in turn, means there are rents distributed to labor, capital providers, and landowners at every step. If returns are not sufficient at any point in the value chain, the supply chain breaks down, and the project will not move forward. If an LNG export terminal is built, but later turns out to be uneconomic, the terminal owner(s) bears the cost, not the U.S. government or U.S. taxpayer. This, in fact, happened with Sabine Pass, for example, which was originally designed to be an import terminal, and later converted to an export terminal.

As noted above, the first steps of the shale revolution were taken in the early 2000s, which set the stage for the next phase of the evolution of the U.S. natural gas market.[19] By 2010, the U.S. shale revolution had begun. Gas supplies were becoming abundant, and producers began to shift focus toward developing oil from shale plays. Their success in developing these light tight oil resources generated a significant interest in changing policy to allow export of crude oil.[20]

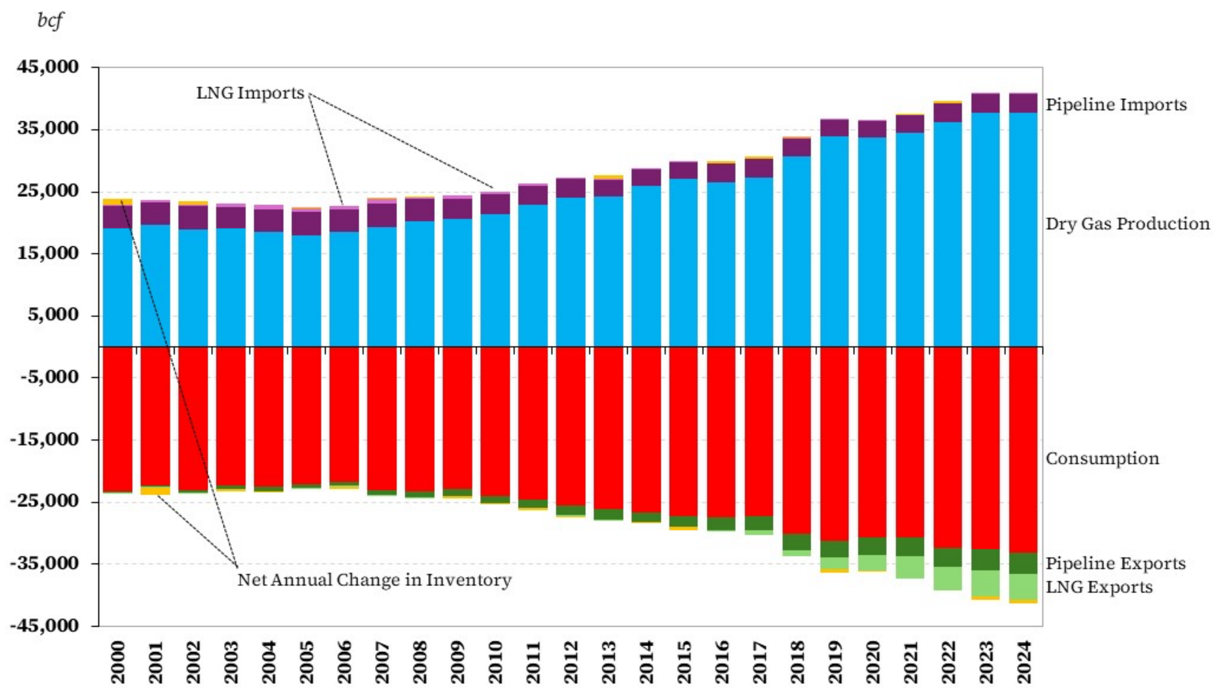
Prior to this, however, interest in exporting LNG had been growing. When the disaster at Fukushima occurred in 2012, the closure of nuclear power generation capacity in Japan and the resulting demand surge for LNG triggered market tightness in a contract-dominated inflexible market that saw international prices climb substantially. Given the widening differential between U.S. price and international price, interest in exporting U.S. natural gas grew significantly, and applications to do so were filed with the DOE. Several years later, after multiple studies to evaluate the public interest in exporting LNG had been conducted and filed into the Federal Register, LNG exports from the lower 48 U.S. states commenced with the opening of Cheniere's liquefaction plant in Sabine Pass in 2016, marking a new era for U.S. natural gas.

Since early 2016, U.S. LNG exports have grown substantially, and so have exports via pipeline, especially to Mexico. The new abundance of U.S. natural gas has also facilitated continued displacement of coal-fired generation from the domestic power grid, provided grid-level back-up support for the adoption of intermittent renewable resources, and delivered supplies to the global market. The latter point has had significant ramifications for the global natural gas market and brought energy security benefits for gas-importing nations around the world. The expansion of U.S. LNG exports, which are loaded FOB thus allowing flexibility to the global market, has facilitated greater ability for global gas supplies to respond to market disruptions. This occurred with tremendous success in the aftermath of Russia's invasion of Ukraine, as U.S. LNG was redirected to Europe, not by government edict but by market response. The energy security benefits of U.S. LNG exports are tangible as the absence of U.S. LNG would have resulted in a very different outcome for Europe.[21]

The Evolution of US Natural Gas Market Balance

The majority of U.S. natural gas production serves the domestic market. At the same time, the U.S. market is also deeply interconnected with Canada and Mexico, meaning it is best viewed as part of the North American natural gas market. The U.S. imports gas via pipeline from Canada, and exports gas via pipeline to Canada and Mexico. The U.S. also has emerged as a significant exporter of LNG since 2016. Altogether, this paints an interesting picture of the market balance in the U.S. as indicated in Figure 2. The importance to domestic supply-demand balance of our neighbors to the north and south cannot be overstated. Indeed, U.S. connectivity to Canada, which has abundant natural gas resources, provides an important backstop for the U.S. market balance.

Figure 2 — Natural Gas Market Balance, 2000–24



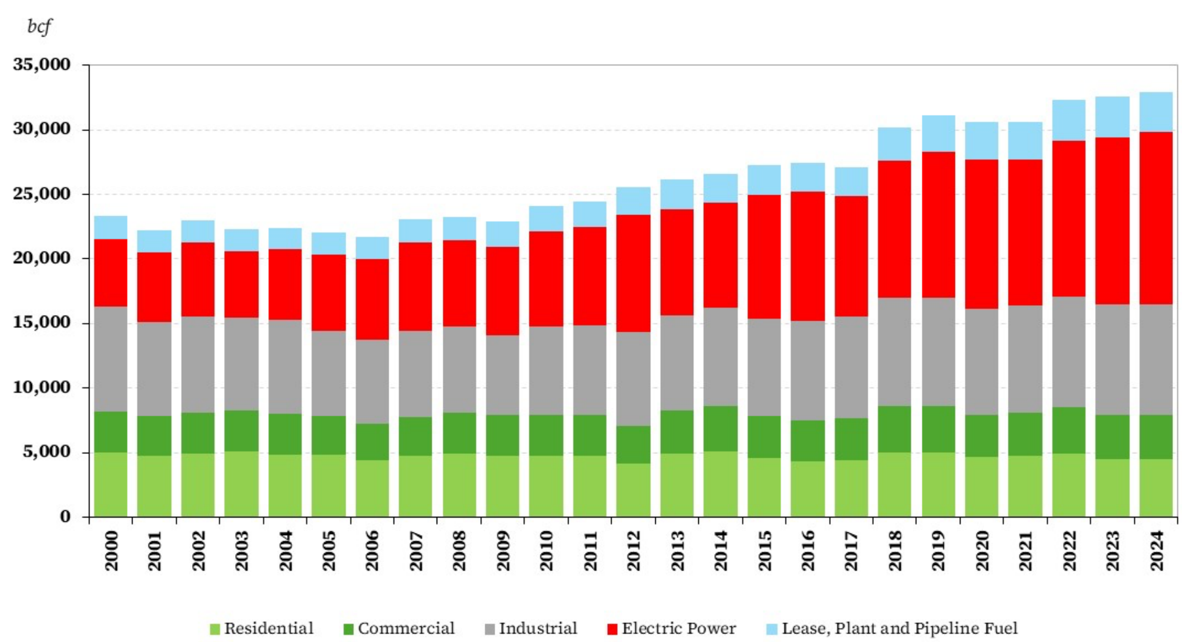
Data Source: EIA
Note: BCF refers to billion cubic feet.

It is interesting to note that the U.S. also imports LNG. This is because demand in the New England area often exceeds available domestic supply when regional bottlenecks manifest due to insufficient pipeline capacity and a lack of local storage during peak demand periods. While LNG exports have risen rapidly in recent years due to the expansion of production from shale and the expansion of liquefaction capacity in the U.S. Gulf Coast, the Merchant Marine Act of 1920 — also known as the Jones Act — prevents waterborne vessel movement of LNG from ports in the U.S. into New England. This is the case because there are no U.S. built and flagged LNG tankers, meaning imports to the region must be sourced from abroad or by pipeline.[22] However, pipeline capacity into the New England area can become scarce during high demand periods, which means foreign-sourced LNG is the only viable option.

The Evolution of US Natural Gas Demand

Since 2000, demand for natural gas has increased by about 41%, rising at an average annual rate of 1.45% (Figure 3). Demand has grown in every sector, except the residential sector where demand has remained relatively flat with year-on-year fluctuations, which are largely due to seasonal changes in winter heating demands. Commercial sector natural gas use has grown modestly, at an average annual rate of 0.2%. Industrial gas demand fell by about 25% from 2000 to 2009 when prices increased, but it has since recovered and surpassed levels not seen since the late 1990s. Since 2009 when industrial gas demand bottomed, it has grown at an average annual rate of 2.2%. In the industrial complex, natural gas is used as a feedstock and a source of process heat; thus, expansion in use is symptomatic of low natural gas prices and international competitiveness. The most notable shift in demand has occurred in the power generation sector, where demand has more than doubled since 2000, rising at an average annual rate of 3.7%.[23]

Figure 3 — Natural Gas Consumption, 2000–24

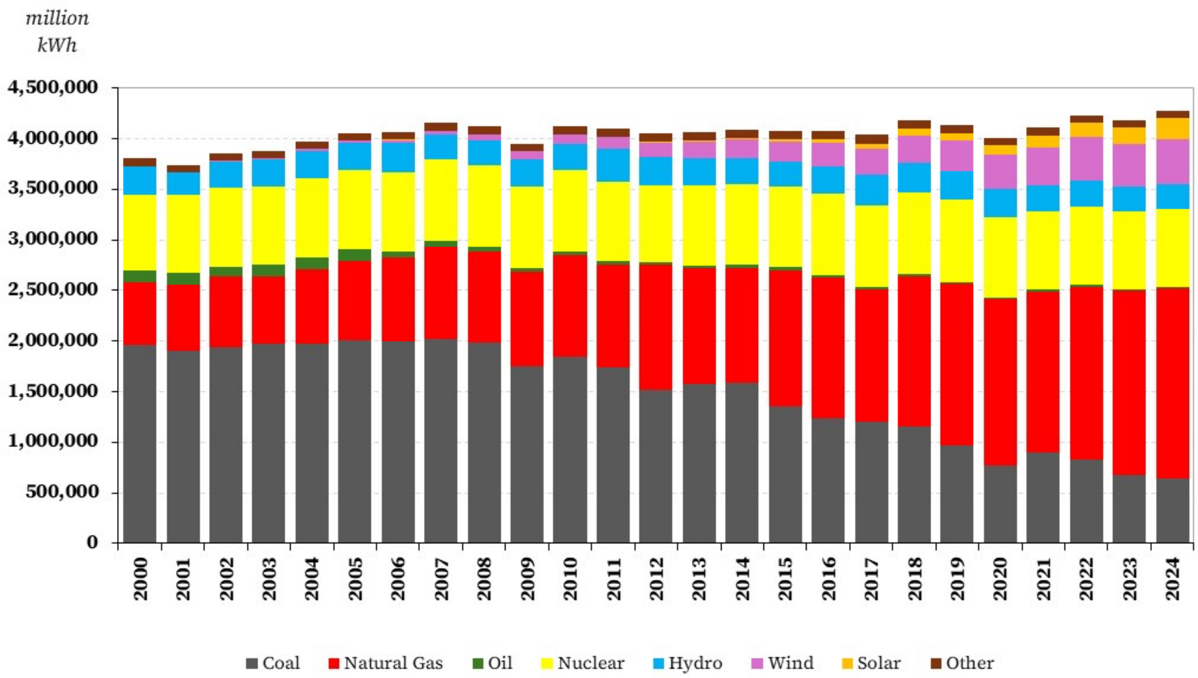


Data Source: EIA.
Note: The “commercial” category includes vehicle fuel.

The growth in natural gas demand for power generation has facilitated significant retirement of coal generation capacity since 2007 while accommodating the rapid expansion of intermittent renewable generation sources such as wind and solar (Figure 4). Since 2000, gas demand in power generation has increased at an average annual rate of 4.7%, meaning it has more than tripled. This growth has been driven by the following factors:

- Low-cost natural gas.
- Improved combustion efficiencies in natural gas generation facilities due to combined-cycle technologies.
- Aging coal generation fleet.
- Growing regional electricity demands.

Figure 4 — Electricity Generation by Source in the US, 2000–24)



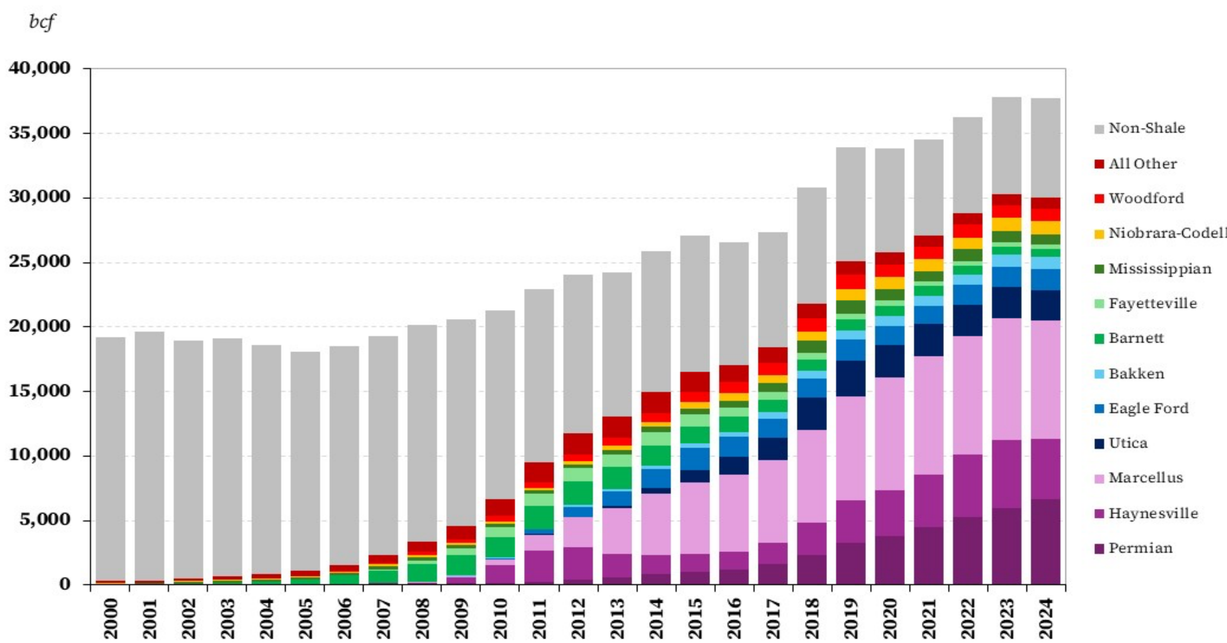
Data Source: EIA.
Note: kWh refers to kilowatt-hour.

Moreover, as can be gathered from the data in Figure 4, the increase in electricity generation from natural gas has accounted for 95.5% of the reduction in power generation from coal since 2000. Overall, power generation in the U.S. in 2024 was approximately 12.5% greater than in 2000. So, other sources have contributed to the margin of overall growth in power generation. Indeed, the amount of power generated by natural gas has increased by 1,265 billion kilowatt-hours (kWh), while all wind and solar combined have accounted for an increase of 652 billion kWh, or about half of the increase in gas generation. Nuclear has also increased, despite recent closures, by about 20 billion kWh, while coal, hydro, and all other sources have declined by 1,324 billion kWh, 37 billion kWh, and 6 billion kWh, respectively. Suffice it to say, the power sector’s evolution over the last 24 years is a natural gas story as much as, if not more so, it is a story about renewables.

The Evolution of Domestic Natural Gas Supply

The rapid expansion of natural gas demand in the U.S. has occurred lockstep with growth in domestic supply. Production of gas from shale has been perhaps the most transformational development in global energy markets over the last two decades, and it has been largely confined to the lower 48 U.S. states (Figure 5). The technical and economically recoverable shale gas resource in the U.S. is massive. However, while this geologic endowment provides a necessary condition for what has happened in the U.S. upstream space, it is not sufficient. This is made clearer when recognizing that shale resources also exist in many other locations around the world, but increased production from shale remains largely a U.S. phenomenon. While overall global development has lagged, Argentina and Canada have begun to see expansion.[24]

Figure 5 — Natural Gas Supply's Growth Driven by Shale, 2000–24



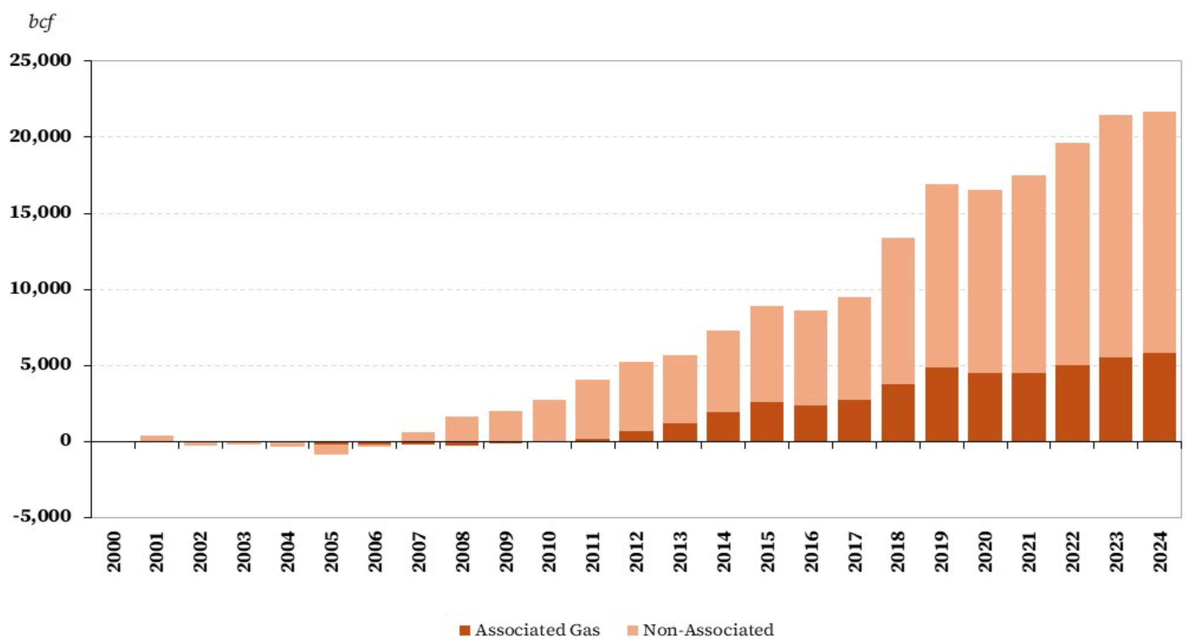
Data Source: EIA, 2007–24. Production estimates from 2000–06 are collected from various sources by author and are available upon request.
Note: Monthly data for 2024 are incomplete; the last three months are estimated based on historical production and rig counts.

Sufficiency for full scale shale development requires a host of above-ground factors to be appropriately aligned to achieve commercial viability. These include a variety of market institutions and regulatory frameworks — private property rights, infrastructure and access to it, a well-established and coordinated set of actors along a deep supply chain, etc. — across the energy value chain, as well as an ability to develop infrastructure to ensure that supply can meet demand under favorable conditions.[25]

As indicated in Figure 5, shale gas production has become the dominant source of natural gas in the U.S. While the innovations of horizontal drilling and hydraulic fracturing had their beginnings decades prior to the early 2000s, their combined application in the Barnett shale in northeast Texas resulted in the launch of a new production horizon in the U.S. Since 2010, expansion in the Marcellus, Haynesville, and Permian Basins have been the primary drivers of growth for domestic production.

The growth in shale gas production over the last 15 years is not the only transformational aspect of the U.S. natural gas supply picture. Growth in associated gas production has also been quite robust (Figure 6). Associated gas is natural gas that is produced from wells that are oil-directed where oil is the primary output and gas is a coproduct. Hence, the rapid growth in oil production, which is primarily from tight oil in shale plays, that has occurred in the U.S. since 2010, is also increasingly contributing to the natural gas supply portfolio in the country.[26] In fact, associated gas has accounted for roughly 27% of the increase in total U.S. gas production since 2000, or about 5,500 billion cubic feet (bcf) of the 21,600 bcf increase in production.

Figure 6 — Change in Associated and Non-Associated Gas, 2000–24



Data Source: EIA, 2000–23. Production estimates from 2024 are collected from various sources by author and are available upon request.

This matters because the increase in associated production since 2010 exceeds total U.S. LNG exports by about 1,500 bcf. Moreover, evidence suggests that the gas-to-oil ratio in many oil producing regions is rising, which means the amount of natural gas that is produced per barrel of oil is increasing. Thus, this net supply situation is unlikely to abate soon, unless there is a collapse in domestic oil production.

It is worth noting that associated gas can also be reinjected, flared, or vented. None of those outcomes is positive for the net supply picture for the U.S. Hence, steps to mitigate flaring and venting, in particular, can increase the supply of marketed gas production, while also providing an environmental benefit. This is a very important point when considering the net supply-demand balance in the U.S. with expanded LNG exports. Impediments to developing domestic natural gas pipeline infrastructure, all else equal, will likely incentivize flaring and venting of associated gas when oil production is commercially viable. This, in turn, would mitigate the extent to which natural gas is available in the domestic market or for export via pipeline or LNG.

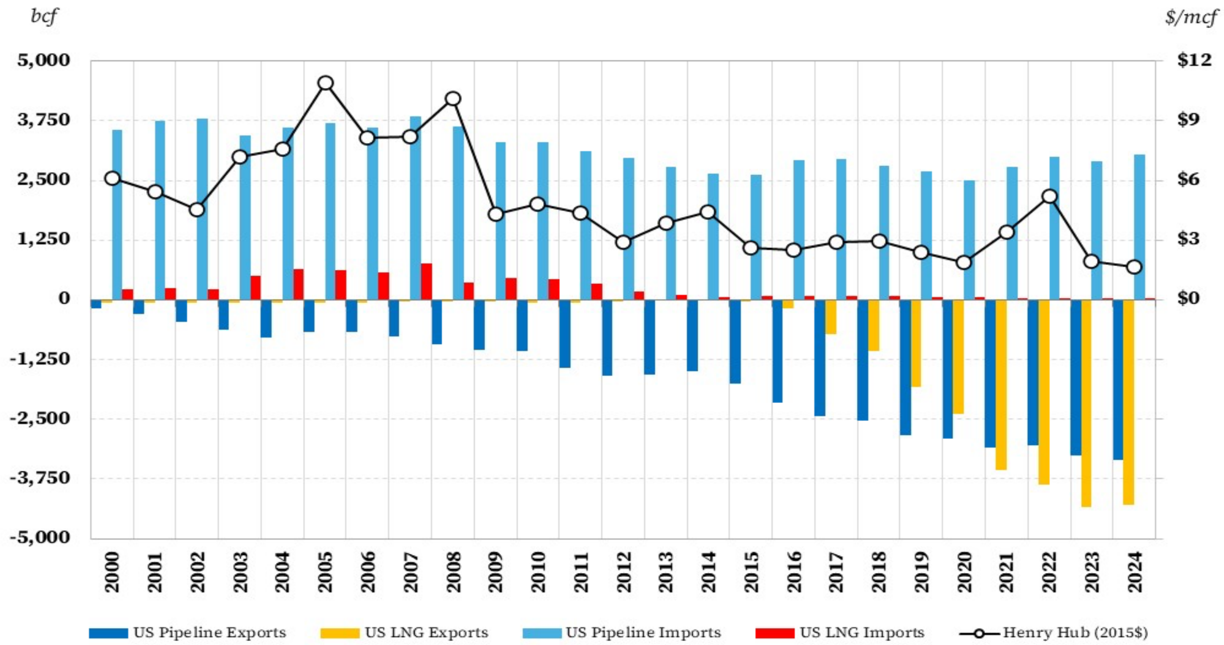
Given the displacement of coal by natural gas in the U.S. over the last two decades, it is reasonable to assess that an increase in the amount of natural gas to the international market would mitigate the expansion of coal use in coal-intensive economies, such as India, Indonesia, and China (Figure 4). Displacement of any energy source by gas is cost-based. If gas provides an energy service at the lowest cost, then it will capture market share. If, however, coal or renewables are less expensive, then gas will not likely displace them.

The Evolution of Natural Gas Trade

The expansion of domestic supply has fueled growth in domestic demand and incentivized a shift to greater exports. As indicated in Figure 7, exports by pipeline and LNG have both expanded. Since 2010, natural gas exports by pipeline have more than tripled, rising to over 9 billion cubic feet per day (bcf/d). Since 2016, when the first liquefaction terminal opened in Sabine Pass, LNG exports have increased 66-fold, rising to over 11.3 bcf/d. As this has occurred, the average annual Henry Hub price has declined from $4.37 per thousand cubic feet (mcf) in 2010 to $2.19 per mcf in 2024. Short-lived increases occurred in 2021 and 2022 as supply chains adjusted in the wake of rapid upstream contraction followed by expansion due to the COVID-19 pandemic.

The patterns observed with regard to price and exports beget an interesting question of causality. Do high net exports drive price increases, or do low prices drive high net exports? Figure 8 graphs the Henry Hub price, the weighted average price of LNG in Europe and Asia, the spread between the two, and LNG exports. The weighted average price of LNG in Europe and Asia is simply an LNG import weighted average price of Asia's Japan Korea Marker (JKM) and Europe's Title Transfer Facility (TTF), gathered from monthly data from Cedigaz and the International Monetary Fund (IMF). This measure is typically heavily weighted toward JKM, although the last couple of years have seen the weight shift toward Europe. The spread between the Henry Hub price and the LNG import weighted average price is an indicator of the arbitrage opportunity that exists to sell U.S. natural gas abroad. Hence, when this spread increases, the opportunity for U.S. LNG, and all LNG for that matter, increases.

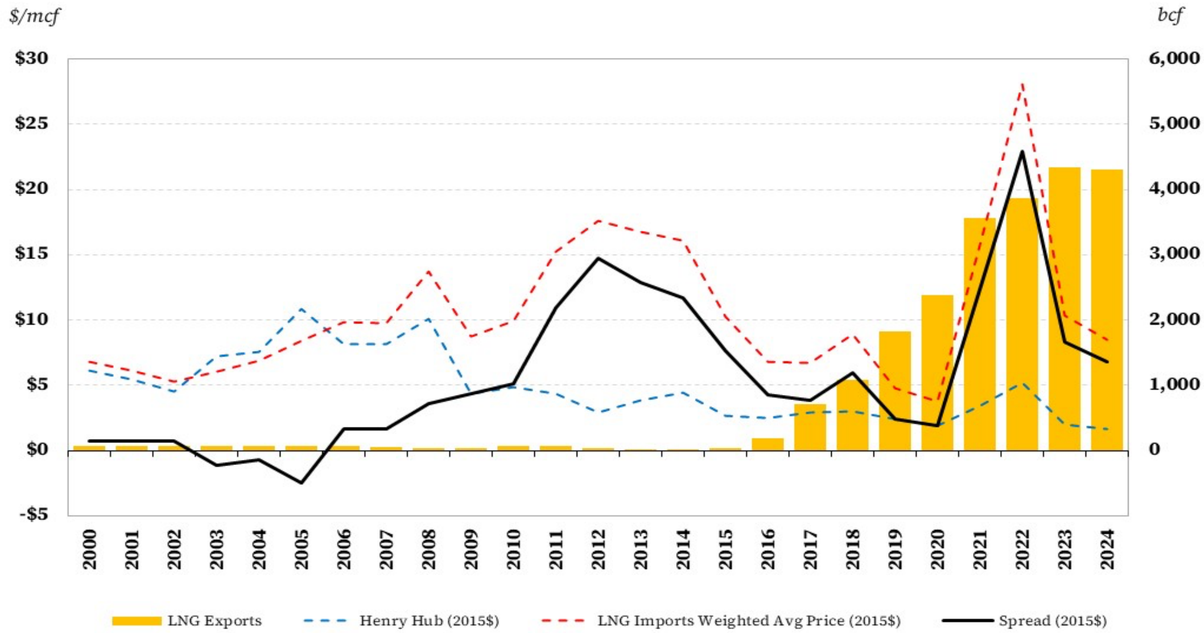
Figure 7 — Shifting Patterns of Trade in the US, 2000–24



Data Source: EIA.

As indicated in Figure 8, the spread has been consistently above zero on an annual basis since 2006. It widened substantially in 2011 and 2012, before settling back from 2016–20. As the world's economies emerged from the COVID-19-induced shutdowns in 2021, global prices spiked, triggering a reinvigoration of interest in LNG. In the U.S., the average time for new LNG export capacity to move from export license approval to first cargo has been increasing.[27] This will generally mean, assuming no new LNG export entrants outside the U.S., that the time between a widening spread and commencement of new LNG exports from the U.S. should increase as well. If the spread ever collapses, or reverts to pre-2006 levels, LNG exports will be out-of-the-money and should wind back until the spread widens. Importantly, this is dynamic. If a new U.S. LNG terminal opens and the spread collapses, all LNG export terminals will likely reduce output at the margin until the international price rises to a point where it once again supports commercial trade.

Figure 8 — Framing the Price-LNG Export Relationship, 2000–24



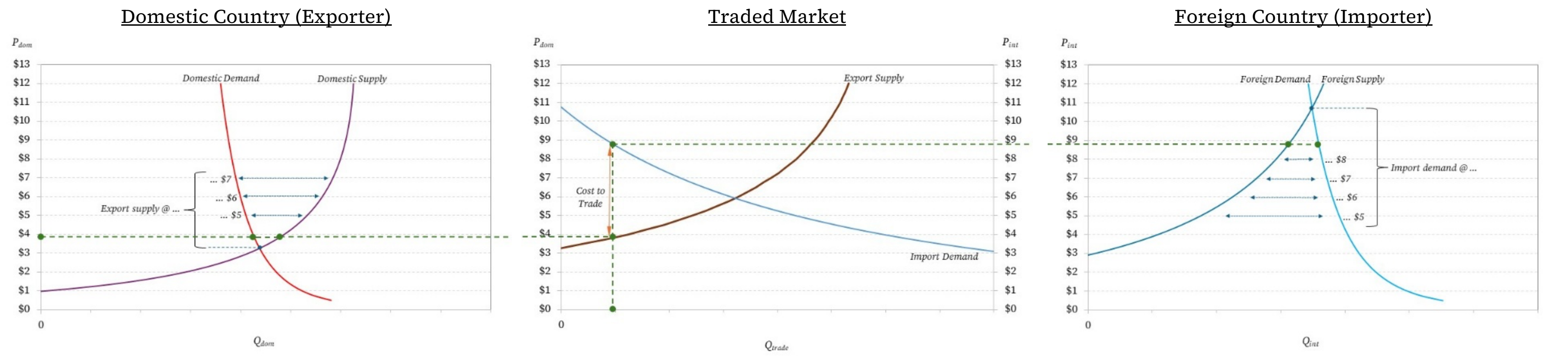
Data Sources: EIA; Energy Institute (EI), "Statistical Review of World Energy," 2024; and International Monetary Fund (IMF).

To better understand this dynamic, consider Figure 9. It illustrates a simple partial equilibrium framework for trade between two countries or regions. The "Initial Equilibrium" graphs illustrate a case where supply in the domestic country is sufficient to begin to export at a domestic price above $3.20 to a foreign country because domestic supply will exceed domestic demand. In the foreign country, supply is not sufficient to meet demand at a price below $10.80; thus, it will need to import if it wishes to increase demand while lowering price. In this case, if the full cost — i.e., the fixed plus operating cost developing all necessary infrastructure to trade — is $5, then a long run equilibrium will emerge where the domestic country exports the indicated quantity to the foreign country. There are net gains from trade to both countries, and the equilibrium, which is determined in the "Traded Market" graph, occurs at a price of $3.90 in the domestic market and $8.90 in the foreign market. For clarity, Figure 9 is for illustrative purposes and is not meant to represent U.S. or foreign markets.

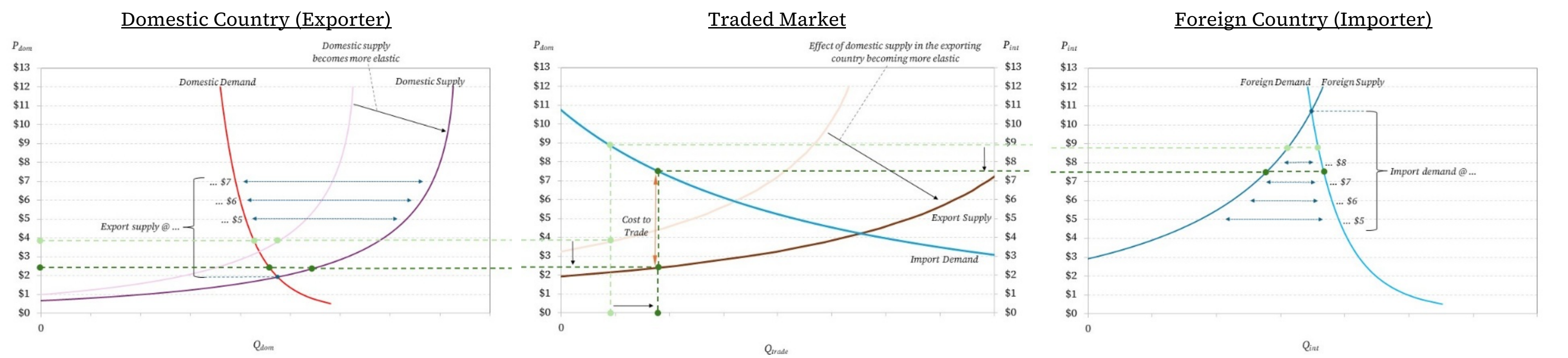
The middle panel defines how market clearing occurs in the "Traded Market" graph. The export supply curve is simply the amount of supply that the domestic country can produce minus domestic demand at every given price above the equilibrium where no exports occur. So, export supply is excess supply in the domestic country at any price. Similarly, the import demand curve is the amount of demand minus supply at every price below where no trade occurs. Thus, import demand is excess demand at any price in the foreign country.

Figure 9 — Trade Equilibrium and Ways Prices Can Decline With Growing Exports

Initial Equilibrium



New Equilibrlium After Domestic Supply Expands in the Exporting Country



Source: Author's calculations.

If there is an intersection in the "Traded Market" between import demand and export supply, trade can theoretically occur. However, trade will only occur if the full cost of trading is not excessive. An excessive cost in the model presented in Figure 9 would be about $7.60, which is the difference of the two no trade equilibria in the domestic and foreign markets, or $3.20 and $10.80, respectively.

The second set of panels in Figure 9 illustrates what happens if supply in the domestic economy shifts out and becomes more elastic at current prices. The export supply curve becomes more elastic, which raises the equilibrium quantity of exports at every price. It also means that the equilibrium quantity of exports in the "Traded Market" graph is now higher at a lower price. This is, of course, attractive to producers in the domestic economy and to consumers in the foreign economy; domestic producers see lower production costs and have access to an expanded market, while foreign consumers have access to more supply at a lower price. The new long-run equilibrium sees expanded exports and lower prices in both markets.

It is also worth noting that trade can also expand if the full cost of trading decreases or demand in the foreign country expands, perhaps due to income growth or policies that promote substitution toward the imported product. In these cases, there are still positive gains from trade, but the domestic price will rise. The extent to which domestic price rises, however, is entirely dependent on how elastic domestic supply is. More elastic domestic supply — i.e., a flatter supply curve — equates to lower price increases.

It bears mentioning that the impact of U.S. LNG exports is also influenced Canadian gas supply. In the case of the U.S., abundant resources in Canada act as a backstop to domestic supply. The rich history of natural gas trade between the U.S. and Canada stands as evidence.[28] Given the significant natural gas resources in Canada, if the U.S. domestic price increases with growing U.S. LNG exports, the gains from trade between the U.S. and Canada will increase. This, absent any political interference, should increase Canadian exports to the U.S. via pipeline, mitigating the extent to which price rises. Hence, the international trade question of domestic price impact is more complex than only examining the quantity of U.S. LNG exports.

The 'Public Interest' and a Brief History of LNG Export Studies

Past Studies: Findings

Several studies utilizing different approaches have been conducted to determine the public interest in licensing LNG exports to non-free trade agreement (FTA) countries. Since 2012, the DOE's Office of Fossil Energy has commissioned six studies to evaluate the macroeconomic effects of LNG exports.

- "Effect of Increased Natural Gas Exports on Domestic Energy Markets" was prepared by the EIA and published in January 2012.[29]

- “Macroeconomic Impacts of LNG Exports from the United States” was prepared by NERA Economic Consulting and published in December 2012.[30]
- “Effect of Increased Levels of Liquefied Natural Gas Exports on U.S. Energy Markets” was prepared by the EIA and published in October 2014.[31]
- “The Macroeconomic Impact of Increasing U.S. LNG Exports” was prepared by CES and Oxford Economics and published in October 2015.[32]
- “Macroeconomic Outcomes of Market Determined Levels of U.S. LNG Exports” was performed by NERA Economic Consulting and published in June 2018.[33]
- “Energy, Economic, and Environmental Assessment of U.S. LNG Exports” was prepared by OnLocation, Inc. with support from Industrial Economics, Incorporated, National Energy Technology Laboratory, and Pacific Northwest National Laboratory and published in December 2024.[34]

Each study took a different approach to modeling the implications of expanded LNG exports. The EIA studies in 2012 and 2014 and the DOE 2024 study utilized the National Energy Modeling System (NEMS) to evaluate the impact of different rates of change in different levels of exports. The DOE 2024 study also used the Global Change Analysis Model (GCAM) to evaluate the implications for energy mix and carbon dioxide ($CO2$) emissions. These studies found that natural gas prices rise as export volumes increase, and they rise faster when exports increase more quickly. Given the nature of the NEMS model, these results are not surprising as exports effectively act as demand shocks of different proportions. The price implications are that natural gas use in power generation declines in favor of coal and renewables. The 2012 and 2014 EIA studies utilized the then-most recent EIA’s “Annual Energy Outlook” as the baseline, but the 2014 EIA study also considered each scenario with different resource base assumptions, finding that a larger resource base reduces the price impact of greater exports. The 2014 EIA study also explicitly evaluated the macroeconomic impact of exports, finding that GDP increases with exports.

The DOE 2024 study had a similar finding but tended to focus on the outcome in 2050, rather than the path in its summary findings. Moreover, the 2024 study focuses on projected outcomes for consumer expenditures in 2050, noting that higher prices drive them up, although it does not highlight how this may be mitigated through consumer choice. It also diminishes the role of GDP as a welfare measure.

The first NERA study, published in 2012, utilized NERA’s Global Natural Gas Model and NewERA macroeconomic model to evaluate the impact of LNG exports under different scenarios. The study found that the net macroeconomic benefits associated with greater LNG exports, which were evaluated up to 12 bcf/d for the study, are positive, meaning there are net welfare gains from trade.

As export license applications continued to come in, the DOE was required to make a public interest determination for LNG export volumes that exceed 12 bcf/d. The study performed by CES and Oxford Economics that was published in 2015 examined several different scenarios utilizing the Rice World Gas Trade Model (RWGTM) and Oxford

Economics' Global Economic Model (GEM) and Global Industry Model (GIM). The gas market scenarios were constructed in the RWGTM, so that international market demand would stimulate greater levels of U.S. LNG exports under different U.S. resource base assumptions. Domestic prices increase in every case, but they are motivated by demand from abroad where prices are even higher. Additionally, the price increases are lower under scenarios with a greater domestic supply elasticity. The GEM and GIM models indicate that the net gains from trade for the U.S. are positive in every case examined, although the benefits vary by scenario. Scenarios with greater resource availability result in greater gains from trade.

The second NERA study, published in 2018, utilized the same models as NERA's 2012 study. It was the broadest in terms of scenario analysis of all studies as noted in this report. Utilizing baseline information from the EIA's 2017 "Annual Energy Outlook" and "International Energy Outlook," scenarios were constructed to evaluate a wide range of scenarios to capture a wider range of potential uncertainties, including those that eventually phase out all fossil fuels. The analysis finds that the most significant factor affecting consumer welfare and U.S. GDP is oil and gas resource availability and technology development, and that greater exports within a single domestic supply scenario are associated with greater welfare gains and higher GDP.

All the studies commissioned by DOE to evaluate the public interest in LNG exports identify a net positive U.S., macroeconomic benefit associated with trade. This is true despite the various constraints that some studies appear to place on the competitiveness of international resources, pipeline trade, and other critical factors for determining international trade equilibrium.[35] Of course, the interpretation of that benefit varies across studies.

Moreover, the net benefits are greater when resource availability is greater, which seems to be an overlooked aspect across these analyses. While this point is often framed in context of a larger resource base with more elastic cost-of-supply, it is also informative of the implications of policies that inhibit development. If policies or lack of regulatory action impede the development of infrastructure that market signals support, the net gains from trade are reduced, and domestic price increases are greater. This is consistent with the trade example outlined in Figure 9.

The CES and Oxford Economics 2015 and NERA 2018 studies also reveal another very important point. Namely, each considered scenarios with LNG export volumes above current levels, and each of those studies demonstrated that market conditions, not licenses to export, will dictate exported volumes. It is certainly true that too few licenses can present a constraint, but too many licenses will not guarantee exceedingly high export volumes.

We have, in fact, already seen this with LNG imports to the U.S., where a significant number of licenses were issued but never resulted in imported volumes. Even in cases where developers constructed regasification capacity, the shift in market conditions in the late 2000s rendered that capacity to be of little consequence, so much so that much of it remained idled until it was later converted to export capacity. In other words, the options that import licenses presented were not exercised because market conditions rendered them out of the money.

In general, a license simply avails market participants of the ability to trade, nothing more. If there are no constraints on licenses to export, market considerations will ultimately bind, particularly those that inhibit the ability to achieve financing — such as market uncertainties, an inability to secure sufficient contracted offtake, legal challenges, and concerns related to policy and regulatory changes. Exports will only occur if there is an associated economic value, which is especially the case if they originate from an open and competitive market, such as the U.S. natural gas market. DOE does not make this decision; the market does.

It is important to recognize that the gains from trade are net and are not absolute. This arises because some consumers of natural gas are negatively impacted by higher prices. However, the gains elsewhere outweigh the losses. The CES and Oxford Economics 2015 study thoroughly identified where the gains and losses occurred across the U.S. economy. Moreover, the losses are lower and net gains higher when more low-cost resources are available. Consistent with Figure 9, this follows from a flatter, longer domestic supply curve, i.e., more elastic supply; the increase in demand for domestic resources that results from greater exports has a smaller impact on domestic prices when domestic supply is more elastic. Constraints that either raise development costs or limit the ability to develop infrastructure tend to make domestic supply less elastic. Ironically, this has the impact of limiting exports and raising domestic prices. In such an outcome, both exports and any net gains from trade are lower.

Until the DOE 2024 study, none of the previous analyses accounted for potential environmental costs or commented on the impacts of resource and infrastructure development. Previously, DOE recognized past studies of environmental costs in its review of LNG export licenses, although those studies were not considered in the determination of public interest when a decision to issue a license was made. Indeed, this has generated some debate about what should, and should not, be included in the assessment of public interest. For every LNG export project, FERC oversees an environmental analysis in accordance with National Environmental Policy Act (NEPA) prior to awarding its approval, so a license application should demonstrate some degree of environmental competence if it is to be approved. The evaluation of local environmental impacts is well established through the NEPA review process. However, the impact on greenhouse gas emissions from increased domestic production for exports, as well as the implication for energy mix abroad, had not been undertaken until the DOE 2024 study. The difficulties inherent in such an analysis are discussed below. The DOE 2024 study acknowledges these caveats as well, although the approach taken does not fully internalize them. In any case, valid concerns related to environmental costs could offset, at least to some extent, any net macroeconomic gains from trade. As such, it is incumbent upon the industry to adequately address environmental concerns.

It should also be noted that none of the studies noted above has fully evaluated the energy and national security implications of U.S. LNG exports. In fact, even though some of the studies recognize the importance of trade for energy security, energy security has not been emphasized in any public interest consideration in the studies that have been commissioned by the DOE. Prior to February 2022, when Russia invaded Ukraine, it may have been understandable to not take this under consideration. Following the invasion, its radical impact on the European energy mix, European gas market balance, and global LNG trade, energy security should be a central consideration. That event has highlighted the fact that U.S. allies in Europe and the Asia-Pacific region have a vested interest in greater volumes of flexible U.S. LNG supplies.

Past Studies: Data and Analysis

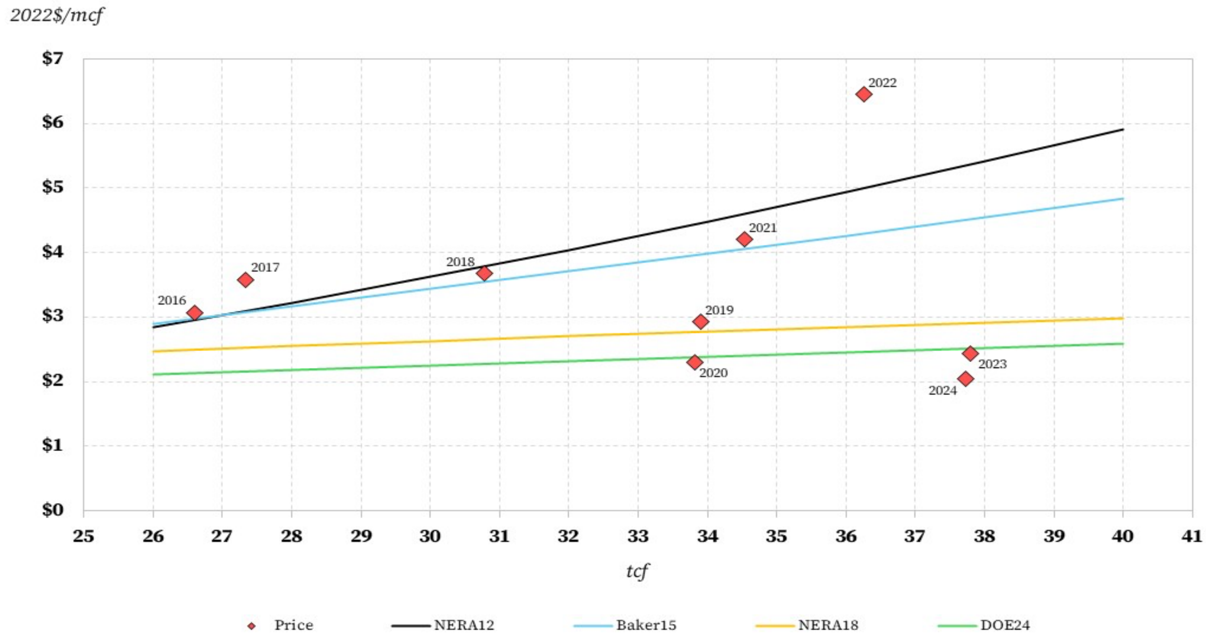
It is worthwhile to examine previous studies' findings alongside recent history to determine how accurate the input assumptions were and understand how various errors made may impact outcomes. Since the most recent DOE 2024 study has been calibrated to recent history, it should be accurate in this respect. Nevertheless, it is included in this report's analysis to maintain consistency.

Figure 10 indicates actual annual production and Henry Hub price from 2016 through 2024. It also indicates a set of modeled results — i.e., econometrically fitted supply curves — for the NERA 2012, CES and Oxford Economics 2015, NERA 2018, and DOE 2024 studies. The fitted supply curves for each of the studies are graphed between 26 trillion cubic feet (tcf) and 40 tcf in order to compare the outcomes to recent history.

Different base years were used for inflation adjustment across the different studies. For instance, the NERA 2012 study reported results in real 2010$, the CES and Oxford Economics study reported in 2015$, the NERA 2018 study reported in 2016$, and the DOE 2024 reported in 2022$. So, to make comparisons possible, this report normalizes all data through to real 2022$ using the consumer price index.

Figure 10 and Table 1 indicate that each of the studies assumes a relatively flat supply curve. Moreover, each successive study used a supply curve that is shifted down and/or flatter relative to the previous studies. This has direct implications for the estimated price impacts of expanded production, which is required for greater LNG exports. As noted in Figure 9, greater exports can be supported through increased production with either higher prices or a more elastic/lower marginal cost supply curve.

Figure 10 — Actual Versus Predicted Model Outcomes for High US Supply Scenarios



Data Sources: NERA 2012, CES and Oxford Economics 2015, NERA 2018, and DOE 2024 studies, and EIA.
Note: High supply scenario outcomes are determined by estimating the price-production relationship using a panel of the high supply scenarios in each of the studies. The results are discussed in the text.

Consider the production outcome in the DOE 2024's "Defined Policies Model Resolved High US Supply Case," which was 56.9 tcf in 2050. The results in Table 1 and Figure 10 indicate that the Henry Hub price would rise to $10.78 per mcf in the NERA 2012 model, $7.35 per mcf in the CES and Oxford Economics 2015 model, $3.48 per mcf in the NERA 2018 model, and $3.31 per mcf in the DOE 2024 model.[36] These values are all derived from the estimated equations in Table 1 and are adjusted to real 2022$. Of course, in each model the international price would have to rise commensurately to support export volumes at those production and price levels.

The modeled results from each of the studies are found by fitting a log-log specification to the price and production outputs for a panel of the high domestic supply/resource cases for each of the studies. Table 1 reveals the outcomes for each of these exercises. Notably, the goodness of fit measures decline, which may be an indicator of the assumptions made in building the expanded range of high supply cases considered in later studies.

Table 1 — Estimation Results Used to Derive Data in Figure 10

Study	Estimated Equation	Overall Fit
NERA 2012	$\ln p_t = \underset{(0.1329)}{-4.2487} + \underset{(0.0396)}{1.7046} \ln q_t$	$R^2 = 0.947$
CES and Oxford Economics 2015	$\ln p_t = \underset{(0.3337)}{-2.5963} + \underset{(0.0952)}{1.1881} \ln q_t$	$R^2 = 0.631$
NERA 2018	$\ln p_t = \underset{(0.1372)}{-0.3710} + \underset{(0.0366)}{0.4357} \ln q_t$	$R^2 = 0.500$
DOE 2024	$\ln p_t = \underset{(0.7511)}{-1.5386} + \underset{(0.2002)}{0.6759} \ln q_t$	$R^2 = 0.487$

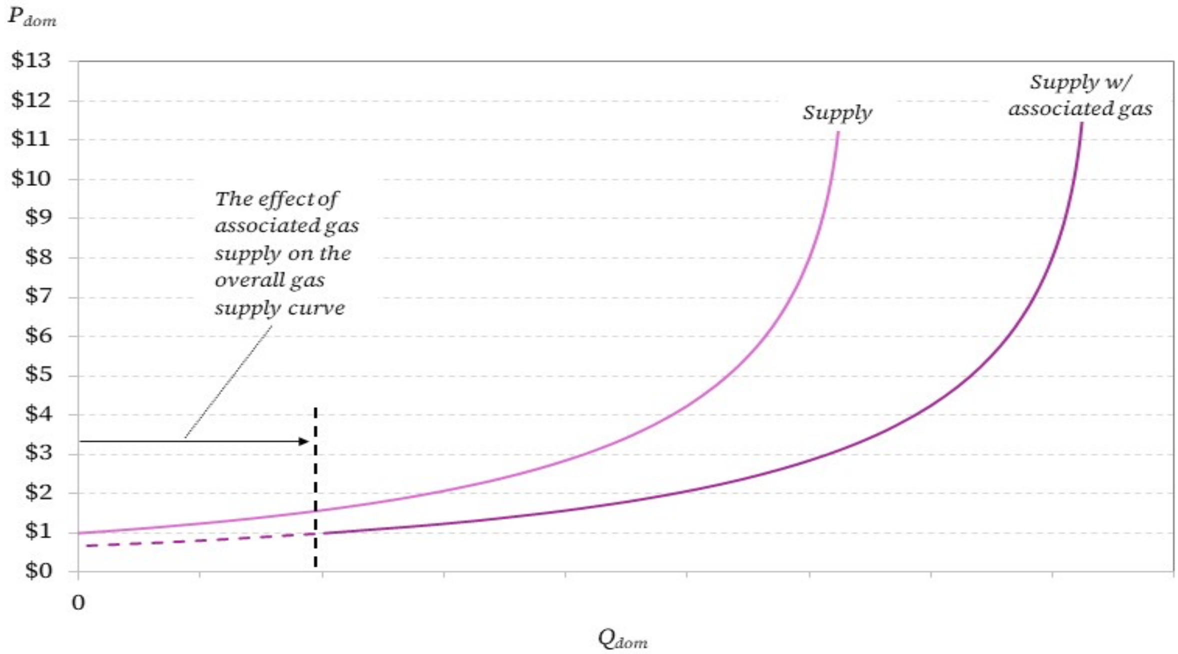
Source: Author's calculations.
Note: All equations were estimated using STATA. The panel specification is random effects, according to the Breusch and Pagan Lagrange multiplier test. Focusing only on the high supply cases rendered a random effect specification appropriate.

Why do more recent studies appear to do better at fitting recent history? For one, recent history today was an unknown future in 2012 and 2015. Given the evolving state of information about shale and the gas resource base, more recent studies can incorporate information learned since 2012. With the benefit of more recent data, the models can be calibrated to better match what is known. However, it should not be assumed that calibrating a model to match recent history will produce a more accurate prediction.

Nevertheless, the studies performed from 2012 to 2024 indicate a systematic downward shift and flattening of the domestic supply curve. Some of this can be explained with different perspectives regarding the outlook for associated gas production. Figure 11 illustrates two gas supply curves: one where there is no or very little associated gas production, and one where there is an abundance. As noted above, the commercial decision to produce oil is generally a function of the price of oil, and any associated gas is a coproduct that can be flared, reinjected, or sold into a market. The marginal cost of the coproduct to the producer, if the coproduct is sold into a market, is effectively the cost of separation and gathering, so it is very low. This means associated gas is a low-cost source of supply that shifts the domestic gas supply curve down and to the right, making it much more elastic. Therefore, associated gas production, which was discussed in Figure 6, is a very important feature of domestic market balance.

Hence, future studies should recognize the role of growing associated gas production. It is an inframarginal source of supply that stretches the domestic gas supply curve. Notably, this also connects the domestic gas supply situation in the U.S. directly to oil-directed upstream activities and highlights the importance of infrastructure for ensuring market stability and minimal environmental impacts from flaring and venting.[37] It also highlights the importance of distinguishing associated gas from unassociated gas because oil prices drive the former, while domestic gas prices drive the latter.

Figure 11 — The Effect of Associated Gas Production on a Gas Supply Curve



Source: Author's construction.

Any future study will be hard-pressed to not find positive macroeconomic benefits or net gains from trade from commercially viable U.S. LNG exports. In fact, as noted previously, all past studies found net positive gains from trade and net positive macroeconomic benefits associated with greater export volume, regardless of the scenario or its estimated domestic price impacts. Moreover, as more supply was made available in each study, the domestic price impacts were smaller, and the gains from trade were larger.

Will demand for U.S. LNG continue to grow? This appears likely, but regional supply-demand balances will ultimately determine regional price differentials, which will significantly shape the volume of trade. While markets will dictate flow, the same pattern does not hold for permits. A lack of permits can restrict flow, but too many permits will not result in uneconomic trade.

Another factor that raises the attractiveness of U.S. LNG is its flexibility. The depth of LNG trade has increased substantially with the emergence of the U.S. as an LNG exporter since 2016, representing a game-changing shift in the global gas market.[38] Flexible U.S. LNG supply presents an option value to LNG importers that was previously unavailable. This, in turn, serves to increase the demand for U.S. LNG relative to other sources, all else equal. This outcome is reinforced with a higher elasticity of supply in the U.S.

Finally, it is important to note that all past studies commissioned by DOE have aimed to understand the long-run, structural implications of expanded U.S. LNG exports. As such, they do not capture short-term variations in demand and the resulting impacts on price. This is not what they were built to do. Analysis that claims overly negative domestic price impacts due to exports tend to miss the distinction between short-run and long-run elasticity. This is a subtle, but very important point in the policy context.

Short- Versus Long-Term Impacts: Understanding Price Variability

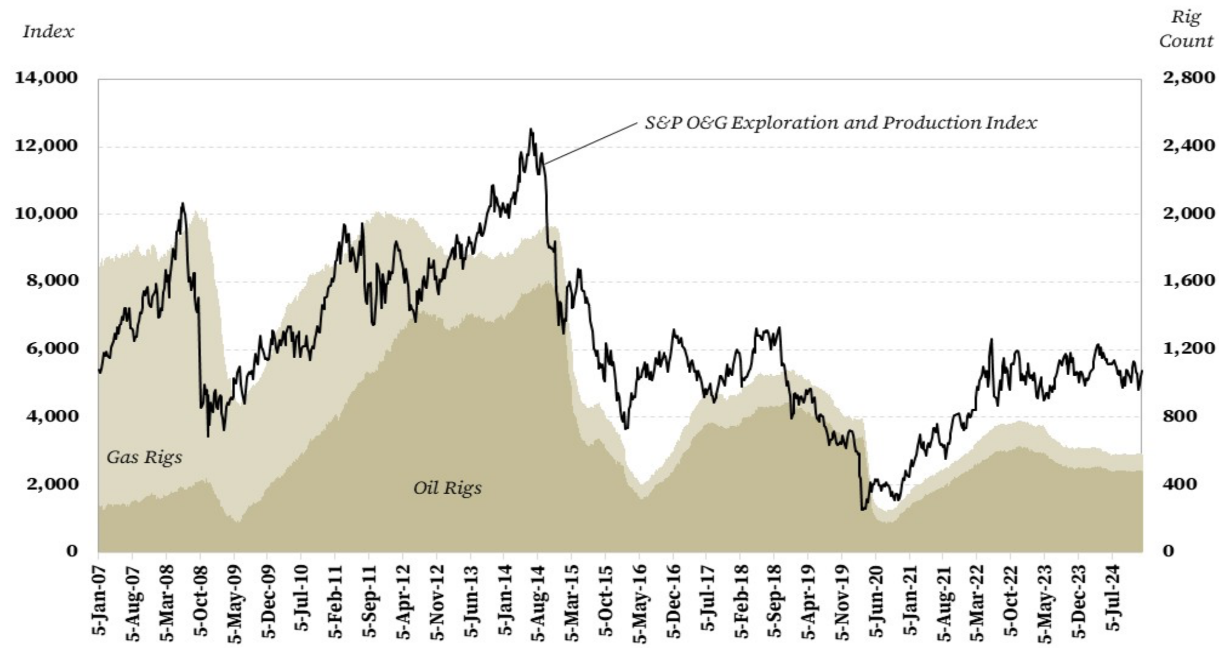
There are often attempts made to explain short-run price movements in a long-run context. The DOE 2024 study is no different. It presents "background on the complex relationship between U.S. natural gas price volatility and global LNG market dynamics."[39] It then references various consultant and think tank reports that attribute a lack of export-induced price movement to the long lead times for new export capacity and the ability ramp production domestically with foresight to accommodate the opening of new capacity. However, this is only part of the story.

It is true that prices would rise if new facilities opened without new supplies being made available. Yet, the fact that new supplies are available speaks to the elasticity of supply, not long-term offtake agreements to ship LNG abroad and the predictability of associated terminals opening. If, for example, offtake agreements were in place and terminal construction commenced, but new domestic supply was not commercially available, prices would rise anyway, even without the terminal operating. So, attribution to long-term contractual arrangements ignores the flexibility that highly elastic domestic supply provides and the extent to which it mitigates price movements, even with new export capacity coming online.

In the short term, price variability is always driven by short-term constraints. How and when constraints manifest matters. It is why economists and seasoned commodity traders focus on understanding physical market developments that can present transitory constraints that drive price volatility. For example, the northeast U.S. can experience periods of short-lived extreme price volatility with cold weather conditions. The demand for natural gas climbs, but pipeline delivery capacity to the region is limited. As a result, the wholesale market prices at Tennessee Gas Pipeline (TGP) Zone 6 and Algonquin City Gate will rise rapidly, which is a regional phenomenon that reveals a scarcity premium for deliverability of natural gas and highlights a period of intense price volatility. This happens even though there are long-term offtake contracts in place for buyers of pipeline gas in the region. In fact, some of the buyers, to the extent possible, may release their firm capacity into the secondary market, allowing other consumers to purchase the gas. Absent that, price would become even more volatile.

It is important to note that even with highly elastic long run supply, there are short-term market rigidities that affect market response and contribute to transitory price increases. This situation occurred in the wake of the COVID-19 pandemic when global economies began to reawaken. When the global economy shut down in the spring of 2020, demand for oil and natural gas waned. This was most pronounced in April 2020 when West Texas Intermediate (WTI) futures closed in negative territory for a day.[40] During that period, rig counts declined as producers were forced to rationalize a sudden drop in demand. Moreover, equity values of oil and gas producers declined radically. As indicated in Figure 12, equity performance and rig counts are closely linked.[41] In fact, analysis indicates that the S&P Oil & Gas Exploration & Production Index is a leading indicator of rig counts by about 13 weeks.[42]

Figure 12 — Weekly Oil and Gas Rig Counts and Equity Performance, January 2007–January 2025



Data Sources: Investing.com and Baker Hughes.

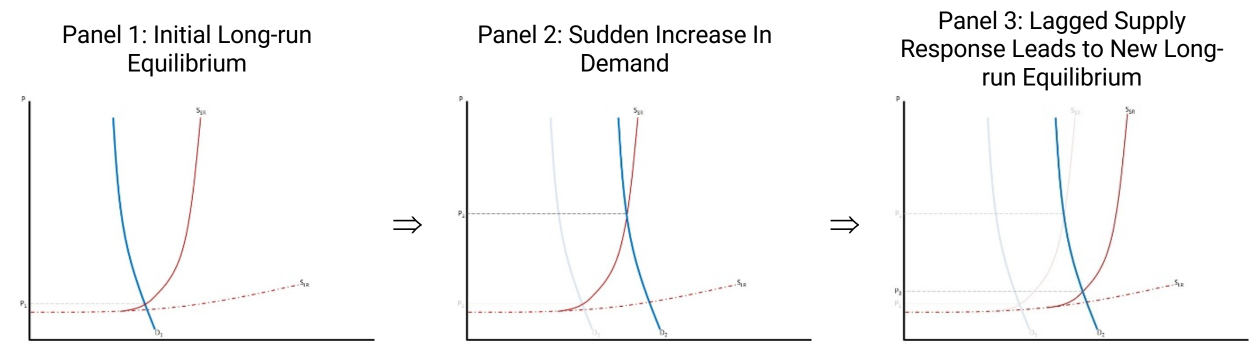
Altogether, the financial performance of the oil and gas industry has direct bearing on rig counts, which, in turn, has direct bearing on production. Notably, the value lost in the months prior to and during the period of the COVID-19 pandemic was not recovered until the second quarter of 2022. Total rig counts followed suit, peaking in the fourth quarter of 2022. Demand in the U.S., coupled with the spike in demand in Europe driven by mandated storage fill due to lost pipeline flows from Russia, exerted upward pressure on price, which contributed to improved equity valuations. In turn, this supported a continued increase in drilling. Not surprisingly, the price at Henry Hub peaked in the third quarter, declining afterward as new drilling commenced, and supplies were brought forth.

The issues outlined in Figure 12 provide an example of how short-term deliverability constraints can emerge due to the lag response of rig counts to reported firm profitability. Such constraints are transitory since shareholders and management generally need to see improved financial performance to support increased spending.

Moreover, this short-term dynamic response should not be used to motivate discussions about long-term, structural market changes.

A more academic explanation is given in Figure 13. Here, a generic difference between the short-run elasticity and long-run elasticity of supply is provided, and what happens when demand increases rapidly in the short run is also illustrated. We begin with an initial market equilibrium in the first panel of Figure 13. Then, in the second panel, a sudden increase in demand drives price up along the short-run supply curve. But the increase in price generates supranormal profits, thereby driving an expansion of drilling. As capital is deployed to increase production – i.e., rigs are deployed to increase drilling – the market shifts toward a new long-run equilibrium, as indicated in the third panel. Thus, Figure 13 indicates how a sudden shift in demand can generate a short-run change in price due to a lagged response in supply.

Figure 13 — The Price Implications of Short-Run and Long-Run Elasticity of Supply



Source: Author's construction.

Expanding the 'Public Interest' Focus: Greenhouse Gases

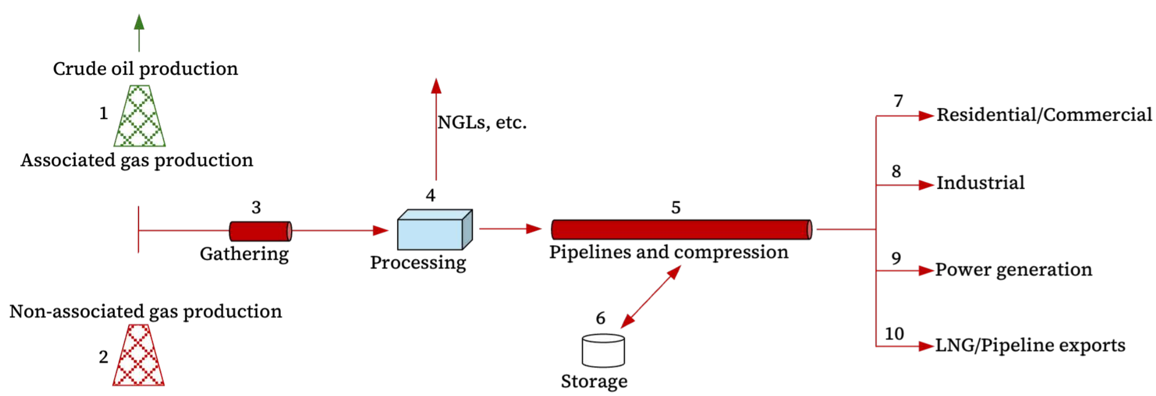
Domestic

Natural gas has already facilitated the displacement of a significant amount of coal in power generation in the U.S. and Europe, and it has the potential to do so in developing nations, such as China and India, where coal is a domestic staple. However, the greenhouse gas footprint of natural gas supply chains is increasingly called into question, and this should be adequately addressed if the future of natural gas in the energy mix is to remain robust.

Flaring and venting are a central concern to the future of natural gas, however neither is a practice deployed during gas-directed upstream activities. Such practices are typically used in oil-directed upstream activities with associated natural gas production, particularly when there is either inadequate takeaway capacity from the production site or the local market cannot make use of natural gas volumes. While this points to some relatively straight-forward solutions — such as more pipeline takeaway capacity and/or greater local demand through power generation — the economic incentive is not always sufficient, which can be motivation for local regulators to allow flaring to occur. Flaring and venting can also occur for safety and operational reasons to protect personnel and equipment. While a deeper treatise on flaring and venting is beyond the scope of this report, it is worth noting that flaring and venting is addressed differently in different jurisdictions.[43]

Methane leakage along pipeline transportation and delivery systems is a concern regardless of the upstream source of natural gas. Once produced, either as a primary commodity or associated with oil, natural gas comingles in the intrastate and interstate pipeline network. From there, it moves to a power generator, an industrial customer, a city gate where a local utility then takes custody of the gas for distribution to a variety of customer types, or to an export facility (Figure 14). Because methane is a much more potent GHG than CO2, if methane leakage along the pipeline network is high enough, then the purported benefits of using natural gas instead of other hydrocarbons, such as coal, disappear.

Figure 14 — Simplified Natural Gas Supply Chain



Source: Author's construction.

Prior to the war in Ukraine, LNG buyers in Europe had pulled back from supporting LNG imports from certain regions due to concerns about flaring and methane emissions. However, the disruption of Russian natural gas supplies coupled with production declines in the EU drove a renewed demand for LNG as energy security concerns mounted. This realization of a need for balancing environmental and energy security objectives will likely continue. But, given broad EU environmental priorities, emphasis on natural gas supply chains that have a low GHG footprint is growing.

Government action is already evident. For example, in September 2021, U.S. and EU leadership invited countries to participate in the Global Methane Pledge and formally launched the initiative at 26th United Nations Climate Change Conference of the Parties (COP26).[44] Regardless of different proposed interventions or initiatives, greater transparency brought by different measurement efforts will likely eventually harden methane reduction targets.

Industry and regional government action is also evident. For instance, the industry led Oil and Gas Climate Initiative announced a global average methane emission target as a share of marketed natural gas of 0.25% by 2025.[45] At more regional levels, similar steps are being taken. For example, the Texas Oil and Gas Association and other members of the Texas Methane & Flaring Coalition have announced a commitment to end routine flaring.[46]

The National Petroleum Council (NPC) recently completed a study at the request of Jennifer Granholm, Secretary of Energy under the Biden Administration, to examine options for reducing GHG emissions along the natural gas supply chain. NPC identified the Technology, Innovation, and Policy (TIP) pathway for reducing methane by 70% and CO2 by 33% in production and transmission relative to EIA's Reference Case in the 2023 "Annual Energy Outlook" through 2050.[47] Some key points included:

- Lack of infrastructure worsens GHGs, and permitting is important for expanding pipeline takeaway and accelerating deployment of emissions reduction technologies.
- Accurate, steady measurement is critical for identifying and addressing emissions.

These points are made even more salient if domestic natural gas supply is more elastic, and associated gas production continues to grow. Given the continuing interest in U.S. oil production and a tendency for gas-oil ratios to increase over time in tight oil plays, infrastructure and measurement appear to be the simplest pathways to address emissions while preserving gains from trade. A more extreme measure would be to shut in production, but that eliminates the gains from trade and prevents natural gas exports from displacing more carbon-intensive fuels abroad, such as natural gas has done in the U.S. since 2007.

International

Another important question to consider is: What will U.S. LNG exports displace? This is a very difficult question to answer. The DOE 2024 study attempts to do so by evaluating various export scenarios under different assumptions about domestic and international demand under different emission reduction scenarios. However, such an exercise runs the risk of engineering scenarios that violate basic economic principles to induce particular impacts.

For example, in a standard international natural gas trade setting, natural gas prices are not equal across markets, with price differentials determined by the cost of trade, as noted in Figure 9. As such, natural gas prices are always higher in importing regions, and they are always lower in exporting regions, which we see in intrastate trade in the lower 48 U.S. states. Accordingly, if a new technology presents a cost-competitive alternative to natural gas, it should be adopted most rapidly in the importing region. In turn, this will result in the destruction of demand for LNG in the importing region. As this happens, it will push LNG supplies back to the open water, reducing prices everywhere. All else equal, this should mean the adoption of the new technology, on a cost-competitive basis, will occur last in the exporting region where natural gas prices will remain the lowest. This is what leads to the ‘last man standing’ phenomenon where the exporting region with the largest natural gas resource endowment will be the last region to consume natural gas.

If, however, a scenario is constructed where the new technology that serves as an alternative to natural gas is forcibly adopted in the exporting regions — perhaps through an assumed policy intervention — but it is not yet cost-competitive in the importing regions, then more natural gas supply would be available for export because natural gas price and demand in the domestic market would be lower. This increases the attractiveness of LNG or pipeline gas imports to the importer, which will expand exports of natural gas from the exporting region where demand is falling. However, this outcome is engineered in the sense that it ignores the economic incentives of price-induced substitution in the exporting region, but not the importing region. In turn, the GHG impacts associated with the use of the exported commodity are higher in the importing region because the commodity is less expensive. This outcome is predictable in a scenario engineered as such, and the DOE 2024 study appears to have done this.

By no means is assessing the GHG emission implications of LNG exports an easy task. In the case of U.S. LNG exports, it requires knowing the destination markets, and understanding what those markets would use in the absence of U.S. LNG.

Regarding destination markets, U.S. LNG is loaded FOB, so portfolio LNG shippers can shift LNG exports to pursue the highest price. Globally, gas prices change often, unexpectedly, and differently across regions. This can be seen with the distribution of prices, and price spreads, over the last decade. In turn, predicting the destination of LNG exports from any given terminal at any given time — much less how that might change over time — is difficult at best. Nevertheless, statistical approaches are possible with such a problem, which could then be used to perform Monte Carlo simulations to yield a probability of trade destinations. Even then, only the limited historical information about prices in a global market with expanding trade is available, which would force the use of Bayesian priors to parameterize distributions of price in different markets. Accordingly, these priors, while informed by international trade theory, are subjective, which opens a door for the introduction of bias into the analysis.

Even if a way to probabilistically assess the destination of U.S. LNG exports is provided, the question of what markets would deploy if U.S. LNG were not available remains. As recent history demonstrates, this will vary by region and is heavily contingent on native resource endowments, government policies, technology deployment options, native energy supply chains, etc. A detailed assessment, country by country and region by region, that captures intraregional constraints is necessary for this work. Moreover, it is not as simple as allowing technologies to compete based on price. The fixed cost of adopting alternatives also matters, not only the cost of using them. This steps into understanding siting and regulatory issues, region by region, as well as the previously sunk costs of incumbent resources and what premature retirement would yield in term of stranded costs. Stranded costs present a barrier to entry for new assets because they are unrecoverable capital costs that are typically avoided.

Nevertheless, if postulating what markets would use in the absence of U.S. LNG is accomplished, then determining the destination markets can be examined using a Bayesian approach. At the same time, one analyst's priors may differ from another's for a variety of reasons. This situation is already playing itself out now in broader discussions around the divergence of forecasts across agencies.

One such approach could be as follows:

- Develop a probability tree for export destinations that captures one export location to *N* possible import destinations. This means every LNG export location would be evaluated independently given differences in costs.
- Evaluate the impact on overall GHG emissions in each possible destination market. This will be determined by the energy mix and relative energy prices in that market, which will differ across markets. A frequent assumption is to assume energy resources can compete based on a standard set of technology options, but this ignores regional heterogeneities that impact the fixed costs of deploying those options, such as land availability and cost as well as the cost of supporting infrastructure — ports, pipelines, rails, transmission, etc.
- Run multiple scenarios that generate outcomes, and then probability-weight those scenarios yielding an expected outcome within a distribution of possible outcomes.

To make matters even more complex, if one wishes to incorporate this into a public interest determination, it must be recognized that an analysis constructed as such would be different for every proposed export terminal. Accordingly, such an analysis must be conducted for each terminal, not at a broad macro level. Thus, it is distinctly different from the approach taken to assess public interest used by DOE-commissioned studies in the past. For example, a broad brush puts a facility on the West Coast in the same light as a facility on the Gulf Coast. The cost to destination markets is distinctly different, which matters when determining where LNG exports from a specific port of origin might land and what the energy mix will be in the destination country.

Expanding the 'Public Interest' Focus: Energy Security

Should energy security across the global natural gas landscape matter? Yes. U.S. interests are paramount when discussing security of supply abroad, and U.S. LNG exports play a role. The recent experience in Europe in the wake of Russia's invasion of Ukraine stands as evidence and highlights the importance of a fungible global market for mitigating the costs of any supply disruption.[48] Any public interest determination that focuses on GHG emissions at end use, giving no bearing to energy security, is incomplete at best. As demonstrated by U.S. LNG exports to Europe following Russia's invasion of Ukraine, the energy security benefit of U.S. LNG exports is tangible.

To better understand how U.S. LNG supply impacts energy security three questions should be addressed:

- How did LNG trade shift from 2021 to 2022?
- What role did U.S. LNG exports play?
- What does the expansion of U.S. LNG exports mean going forward?

Prior to Feb. 24, 2022, EU natural gas was predominantly provided by Russian pipeline flows. However, Russia's invasion of Ukraine and the ensuing reduction of gas flows from Russia to Europe prefaced a radical shift in global gas flows. Is this shift structural or transitory? Notably, U.S. LNG had already shifted toward Europe due to wind deficits and ensuing gas storage drawdowns for use in power generation in the fall of 2021, but this was in response to a transitory, weather-related event. The answer regarding the fallout of the Russia-Ukraine war is likely not transitory, and its long-term implications are connected to the North American gas market.

Russia's role in the EU gas market will likely remain structurally lower, and in any event, global gas flows are set to change.

- Qatar is significantly expanding its LNG export capacity.[49]
- U.S. LNG export capacity is set to expand considerably.[50]
- Projects in the Mediterranean and Africa portend global LNG supply growth.
- Russia is likely to increase its LNG export footprint as well as deepen its pipeline connectivity to China.[51]
- Asian LNG demand will likely grow, as will Latin American demand.[52]

Qatari LNG exports have long been recognized as inframarginal as gas production costs are among the lowest costs in the world, and Qatar is situated in a geographically advantageous position with an ability to serve both European and Asian markets. Nevertheless, U.S. LNG exports have been a global game-changer for the overall global supply picture as well as the depth and liquidity of the global market. The flexibility of U.S. LNG exports makes them well-suited to capture arbitrage opportunities when market conditions shift.

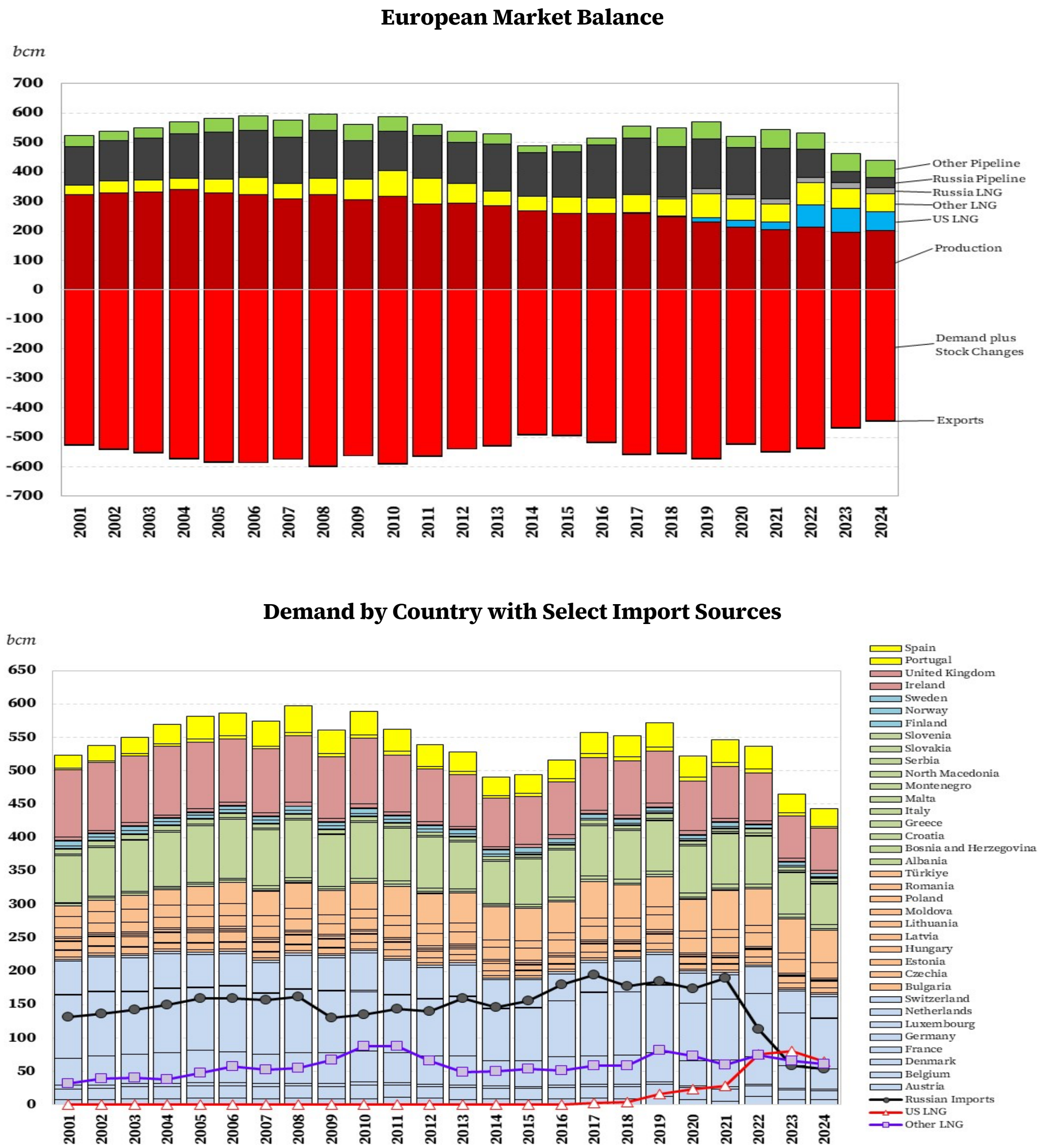
As can be seen in Figure 15, Russian natural gas exports to Europe were on an upward trend from 2001 through 2021, but European natural gas demand was trending downward. This resulted in an increase in Russian market share, which expanded from 22.8% in 2010 to 34.8% in 2021. Notably, this occurred despite pricing disputes with Ukraine that resulted in pressure reductions on transit systems in 2005–06 and 2008–09.[53] This demonstrates the historical importance of natural gas for the European economy and energy system, as well as the dominant first-mover advantage that Russia historically held in Europe through a significant pipeline network with roots in the former Soviet Union.

Since the Russian invasion of Ukraine, Russian natural gas exports to Europe have declined due to sizeable disruptions in pipeline flows. However, Russian LNG exports into Europe have increased, partially offsetting the precipitous decline in pipeline exports. U.S. LNG exports to Europe have also risen dramatically since 2021, and U.S. market share in Europe now rivals Russian market share. This highlights the uncertainty inherent with geopolitically motivated commodity market disruptions, as well as the tremendous value that flexible supplies have in mitigating the market impacts. It also highlights the difficulty in predicting where LNG exports will land in 25 years.

of course, the energy security benefits of U.S. LNG exports extend beyond geopolitical disruptions. During the fall of 2021 prior to Russia's invasion of Ukraine, electricity generation demand for natural gas increased due to a wind drought. This was a weather -related shock that was mitigated by the availability of flexible U.S. LNG supplies. A core strength of an accessible, flexible supply portfolio is that it supports market responsiveness that would not otherwise exist, thus allowing mitigation of disruptions without a need for government intervention.

In the longer term, previous research indicates that the investments triggered in response to a geopolitically motivated disruption of Russian supplies to Europe Russian market share, even if there is a return to the previous state-of-relations between Russia and European gas importing nations.[54] This follows because the sunk costs of entry — e.g., new LNG import pathways as well as alternatives to natural gas — for new energy supply options to replace Russian natural gas will have been borne. This erodes the competitiveness of Russian supplies at the margin, making it more difficult to recapture lost market share. Of course, disruptions that impact the availability of new energy options can reopen the door for Russia. Hence, long-term stability in flexible U.S. LNG supplies, or flexible supplies from any region, bode well for European and global energy supply diversity and security. Mechanisms that mitigate the use of energy as a weapon carries significant national security benefits.[55]

Figure 15 — European Natural Gas at a Glance, 2001–24

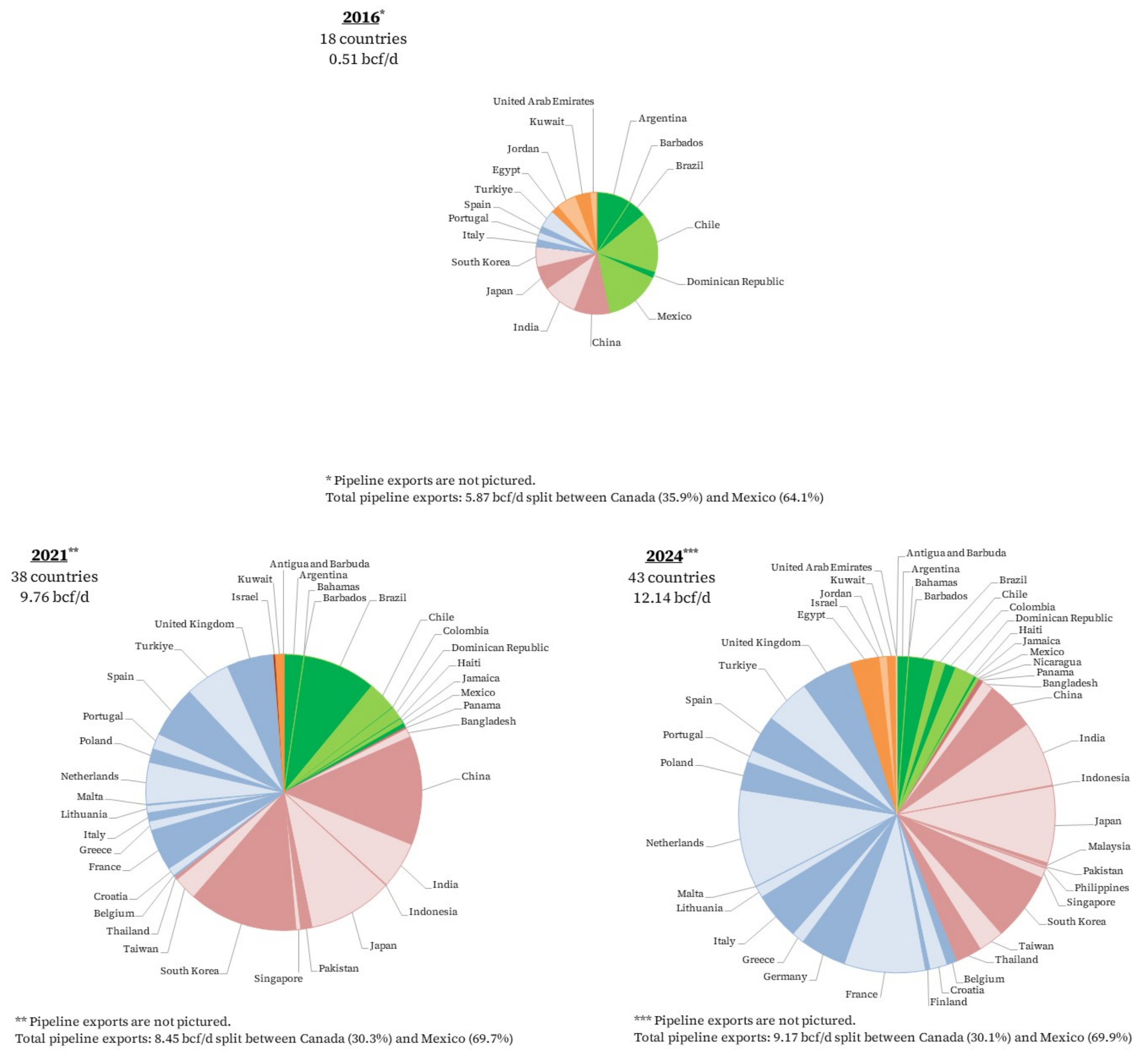


Data Sources: International Energy Agency, European Network of Transmission System Operators for Gas (ENTSOG), and EIA.

Note: Exports include pipeline exports to Ukraine and LNG exports from Norway. Countries included are given in the second panel, where different colors are used to differentiate country groupings, from top to bottom as Iberian Peninsula, U.K. and Ireland, Nordic region, Southern Europe, Eastern Europe, and Northwest Europe mainland. Lines indicated imports to Europe from Russia, U.S. LNG, and other LNG. Other pipeline imports and Russian LNG are not pictured in the second panel.

As illustrated in Figure 16, U.S. LNG exports dramatically shifted toward Europe — illustrated in blue in Figure 16 — in response to market signals after 2021. They also increased substantially after the Sabine Pass liquefaction facility opened commercial operations in 2016. In 2016, U.S. LNG was exported to 18 different countries, over half of which were in the Western Hemisphere. In that same year, Europe only accounted for about 10% of U.S. LNG exports.

Figure 16 – US LNG Exports by Country of Destination, 2016, 2021, and 2024



Data Source: EIA.

By 2021, U.S. LNG exports had increased 19-fold, and they were landing in 38 different countries. Hence, the scale and reach of U.S. LNG had changed significantly, carrying with it tremendous interest abroad in accessing the U.S. supply portfolio. Approximately half of this demand was in Asia, with South Korea, Japan, and China all making significant purchases. About 17% was destined for Western Hemisphere trading partners, which seems like a decline relative to 2016, but, in fact, this represents an 8-

fold increase in LNG flows given the increased size of the U.S. LNG portfolio. Europe accounted for about 34% of U.S. LNG exports.

The year 2022 cemented a seismic reshuffling of global LNG flows. As of 2024, U.S. LNG exports are now reaching 43 different countries. Asia accounted for about 34% of U.S. LNG exports, while Europe received slightly over half. Effectively, Asia and Europe traded shares. U.S. LNG exports also continued to climb, reaching more than 12 bcf per day, which was a 25% increase relative to 2021. Western Hemisphere deliveries declined to under 10% of U.S. LNG shipments, with the Middle East and Africa accounting for the remainder.

In summary, the distribution of U.S. LNG continues to evolve, driven by shifts in the relative supply-demand balances across regions that manifest in changing prices. Meanwhile, as discussed above, the U.S. natural gas price has not increased, despite a rapid expansion of LNG exports over the last eight years. This price stability emerges from a highly elastic domestic supply, which contributes to increased demand for U.S. LNG in the international market.

The nature of U.S. LNG, which is highly flexible by design, enhances its appeal for LNG supply portfolio holders around the world. In turn, this carries significant energy security benefits because this flexibility acts as a buffer against regional market shocks. Absent U.S. LNG, it is highly probable that the stresses seen in Europe since 2021 would have manifested very differently. Where and when the next shock occurs is unknown, but flexibility in the supply portfolio is critical to mitigating its impacts.

Conclusion

This paper has sought to elevate a conversation about the future of U.S. LNG exports. Broad goals for economic development, the environment, and energy security will define the global future of natural gas and many other energy sources, and some regions will inevitably chart different courses than others. The future of U.S. LNG exports will be heavily influenced by outcomes beyond U.S. borders, but domestic policies will also have influence.

The U.S. natural gas market is not starting from zero. It is a well-established industry whose domestic evolution over the last 50 years has witnessed concerns regarding scarcity, a period of plentiful supply sparked by new market design, interest in ramping LNG imports, and innovations that unlocked shale resources. This history has left the U.S. natural gas industry with a legacy and scale that is largely unrivaled across the globe. It benefits from mostly unparalleled depth and liquidity that is rooted in a regulatory architecture that promotes transparency and competition. The U.S. has already begun to transform global gas trade, and it stands to play a prominent role in the future of natural gas worldwide.

The U.S. market structure is a distinct advantage. Consumers do not need to connect their purchases all the way along the value chain back to the wellhead. Instead, buyers can access supplies indexed to regional market hubs and through trading arrangements that generally dictate the consumer with the highest marginal value receives supply. For LNG liquefaction projects, this reduces the upfront capital commitment, allowing a focus on liquefaction, and it facilitates a range of risk mitigation tools that are not available when investments from the wellhead to the terminal in a fixed-point relationship are required to support an LNG project.

The decision to export LNG is commercial, and periods of significant differences between international and domestic prices have driven interest in developing export projects. Historically, applications for export licenses increased when regional price differentials were higher.[56] The process of applying for and receiving an export license to non-FTA countries is important for bankability, but it is also arduous and often lengthy. This can present challenges to the prospects for infrastructure development, particularly as market conditions change during the process. Nevertheless, the rapid growth in LNG exports since 2016 clearly indicates the desirability of U.S. LNG supplies to buyers around the world.

Capturing gains from trade are contingent on lower barriers to entry. When infrastructure impediments exist, the ability to trade is limited. Such capacity constraints prevent buyers from accessing low-cost supplies and sellers from capturing the rents associated with development and sale. Importantly, in a competitive, unbundled market, such as the U.S., the rents will be distributed throughout the entire supply chain, or investors in any unprofitable part of the endeavor will exit. This, in turn, results in coordination failure that limits the scale and scope of the transaction, potentially eliminating it. Thus, when a decision is made to develop that is commercially supported by all parties involved, gains from trade will be positive. If at any point that support breaks down, the gains from trade dissipate, and the project will not move forward. Due to this, export licenses are simply options. They provide the holder with the ability to evaluate a commercial prospect. If that evaluation is not positive, then no export project will be developed, despite a license in-hand. This is why the international trade models that have been used to evaluate the public interest of U.S. LNG exports have, correctly so, consistently found positive economic gains from trade across the wide range of scenarios they have considered. In fact, the CES and Oxford Economics 2015 and NERA 2018 studies reveal that market conditions will dictate traded volumes, not licenses to export, because simulated market conditions dictate the volume of trade independently from assumptions about licenses, unless there are too few licenses.

The consistency across the DOE-commissioned studies' finding of positive gains from trade is notable. The gains from trade are also higher, across every study, when available resources are more abundant. This is often framed as a larger resource base that supports more elastic domestic supply. However, if the barriers to accessing and developing domestic resources are removed, domestic supply also becomes more elastic. Hence the studies have built-in assessments about what political obstacles to resource development mean for the U.S. economy — fewer impediments to development are expected to lead to higher macroeconomic growth. In other words, impediments to the development of infrastructure will reduce the net gains from trade.

The rapid growth of associated gas in the U.S. is a significant opportunity. Oil production, particularly from shale formations, has been rising rapidly. The so-called light tight oil has been transformative for the global oil market, which is typically the focus of investors and analysts. Yet, the natural gas production that is associated with these oil-producing assets has risen substantially, and it stands to continue increasing even if domestic oil production plateaus because gas-oil ratios are rising. Without the requisite pipeline takeaway capacity, this gas will not be marketed; instead, it will be flared, vented, or used for field production activities. However, this is largely an infrastructure issue that can be addressed directly. Moreover, adding those gas supplies to the domestic portfolio helps to keep prices from rising, even with increases in domestic demand and exports via pipeline and LNG. Associated gas production in the Gulf Coast region, such as the Permian Basin, is sufficient to meet local power generation and industrial demands as well as support LNG exports.

In general, it is important to maintain a deeply interconnected North American natural gas market to ensure regional price dislocations are minimized. Pipelines ensure regional gains from trade are accessible across the U.S. and North America. Just as the U.S. is now exporting substantial volumes of natural gas to Mexico, Canadian gas supplies play an important role in balancing the U.S. market. If a disruption occurs within the seamless flow of natural gas via pipeline across North American borders, it could have significant consequences for the long-term commercial viability of U.S. LNG exports by disrupting market balance. This, in turn, could sacrifice the geopolitical gains associated with U.S. energy exports that support security of energy supply objectives around the world.

Environmental concerns should be addressed. The NEPA process managed by FERC brings the environment squarely into the decision-making paradigm. This should not be ignored. Honoring a duty to manage natural resources in ways that minimize potential negative externalities can facilitate a more robust capture of net macroeconomic benefits. For instance, infrastructure that damages an offshore ecosystem that supports a local fishing industry can bring devastating costs to a local community. This will diminish the net macroeconomic gains from trade and potentially, at a microeconomic level, lead to legal costs and regulatory interventions that are avoidable.

This argument can be extended across the full value chain supporting an export project — from wellhead to pipeline to shipper to end user. Doing so requires a micro-level analysis of the project because the geographic dispersion of feed-gas supplies and LNG export cargo destinations introduces substantial heterogeneity into the process. It is not possible to paint with broad brush strokes. Significant work has been done to address steps that can be taken to mitigate methane emissions and natural gas flaring and venting, each of which represents a significant source of GHG emissions and wasted gas resources. Reducing flaring, venting, and methane leaks can ensure significant opportunities for LNG to be a decarbonization vehicle.

The U.S. stands as evidence of what natural gas displacement of coal in power generation means for CO2 emissions reduction. Since 2007, expanded production coupled with the depth and liquidity of the U.S. gas market has engendered substantial shifts away from coal, proving that adequate, low-cost gas supplies can be a buttress against the continued expansion of environmental cost from using coal in power generation. In addition, gas has also been a significant facilitator, due to its flexibility, in supporting reliability services in electric power markets with increasing deployment of intermittent wind and solar resources. The U.S. has the resource base, if developed responsibly, to see that this extends beyond its borders.

Currently, coal-fired power generation continues to rise in China, India, and elsewhere in Asia. To reduce emissions over the next several decades, flexible LNG supplies to diversify away from coal use in those countries will grow in importance. A mix of approaches will be needed to ensure reliability with an expansion of intermittent renewables, but dispatchability remains key.[57] Constraining U.S. LNG exports will likely mean those Asian countries will continue to turn to coal for power system balance.

Finally, the energy security benefits of flexible U.S. LNG exports are tangible. This has been seen since 2022 through the role that U.S. LNG has played in mitigating the economic damage from the Russian invasion of Ukraine and associated disruption of supply. It bears repeating; if the events of February 2022 occurred in 2015, when U.S. LNG was not available, the situation in Europe would have played out very differently.

The prospects for U.S. LNG exports are strong, but only to the extent that market forces work without impediment. Infrastructure to support regional and international gains from trade is paramount. This does not imply regulations should be lax. Rather, regulation should encourage transparency and competition, so that value propositions are identifiable. Sources of energy supply that are competitive, accessible, and environmentally favorable will ultimately thrive, and U.S. natural gas has a significant role to play.

Notes

[1] Kenneth B. Medlock III, "U.S. LNG Exports: Truth and Consequence," Rice University's Baker Institute for Public Policy, August 10, 2012, https://www.bakerinstitute.org/research/us-lng-exports-truth-and-consequence.
[2] Medlock, "US LNG Exports: Supply, Siting and Bottlenecks," Rice University's Baker Institute for Public Policy, May 16, 2023, https://www.bakerinstitute.org/research/us-lng-exports-supply-siting-and-bottlenecks.
[3] National Economics Research Associates (NERA) Economic Consulting, *Macroeconomic Impacts of LNG Exports from the United States*, 2012, https://www.energy.gov/sites/prod/files/2013/04/f0/nera_lng_report.pdf. Subsequent references to NERA Economic Consulting's *Macroeconomic Impacts of LNG Exports from the United States* will appear as NERA 2012 in notes.

[4] The Baker Institute for Public Policy Center for Energy Studies (CES) and Oxford Economics, *The Macroeconomic Impact of Increasing U.S. LNG Exports*, October 2015, https://www.energy.gov/sites/prod/files/2015/12/f27/20151113_macro_impact_of_lng_exports_0.pdf. Subsequent references to CES and Oxford Economics' *The Macroeconomic Impact of Increasing U.S. LNG Exports* will appear as CES and Oxford Economics 2015 in notes.

[5] NERA Economic Consulting, *Macroeconomic Outcomes of Market Determined Levels of U.S. LNG Exports*, June 7, 2018, https://www.energy.gov/sites/prod/files/2018/06/f52/Macroeconomic%20LNG%20Export%20Study%202018.pdf. Subsequent references to NERA Economic Consulting's *Macroeconomic Outcomes of Market Determined Levels of U.S. LNG Exports* will appear as NERA 2018 in notes.

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[7] U.S. Department of Energy (DOE), "DOE to Update Public Interest Analysis to Enhance National Security, Achieve Clean Energy Goals and Continue Support for Global," January 26, 2024, https://www.energy.gov/articles/doe-update-public-interest-analysis-enhance-national-security-achieve-clean-energy-goals.

[8] DOE 2024.

[9] Medlock, "The Land of Opportunity? Policy, Constraints, and Energy Security in North America," Rice University's Baker Institute for Public Policy, June 2, 2014, https://www.bakerinstitute.org/research/land-opportunity-policy-constraints-and-energy-security-north-america.

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[13] One can think of this through the lens of real options. Investing in infrastructure is a real option. One only exercises the option when profitable. In the absence of market liquidity, a liquidity premium exists that renders the option value lower, thus reducing investment. Liquidity increases scale.
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[15] "H.R.5289 — Natural Gas Policy Act of 1978," congress.gov, accessed January 31, 2025, https://www.congress.gov/bill/95th-congress/house-bill/5289.
[16] The process of allowing market forces to dictate prices was not completed until the passage of the Natural Gas Wellhead Decontrol Act in 1989 ("H.R.1722 — Natural Gas Wellhead Decontrol Act of 1989," congress.gov, accessed January 31, 2025, https://www.congress.gov/bill/95th-congress/house-bill/5289). By 1993, all price regulations under the Natural Gas Policy Act (NGPA) were eliminated.
[17] Federal Energy Regulatory Commission (FERC), "Order No. 636 — Restructuring of Pipeline Services," last modified June 11, 2020, https://www.ferc.gov/order-no-636-restructuring-pipeline-services. This process began with FERC Order 436 (1985), which allowed pipelines to voluntarily offer "open access" transportation services on a competitive basis within a minimum and maximum tariff range. Customers realized a cost savings relative to "take-or-pay" contracted volumes, so customers switched. As take-or-pay contracts were unwound, netback pricing evolved ("Natural Gas Regulation: Pipeline Transportation Under FERC Order 436," United States General Accounting Office, 1987, https://www.gao.gov/assets/rced-87-133br.pdf).
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[23] Natural gas demand for vehicle fuel has increased at 7.2% per year since 2000, but still only comprises 0.18% or total consumption.
[24] Gabe Collins et al., "Shale Renders the 'Obsolescing Bargain' Obsolete: Political Risk and Foreign Investment in Argentina's Vaca Muerta," *Resources Policy*, 74 (December 2021), https://doi.org/10.1016/j.resourpol.2021.102269; Medlock, "North American Resources and Gas Supply to the State of California," Institute of Transportation Studies, University of California, Davis, February 18, 2015, https://escholarship.org/uc/item/56r577b2.
[25] Medlock, "The Land of Opportunity?"
[26] The U.S. Energy Information Administration (EIA) highlighted associated gas production in its Nov. 13, 2024 edition "Today in Energy" ("U.S. Associated Natural Gas Production Increased Nearly 8% in 2023," November 13, 2024, https://www.eia.gov/todayinenergy/detail.php?id=63704). It is worth noting that most of the gas flaring and venting that has been a source of ongoing concern is the result of associated gas production that is not marketed. This can be due to a lack of infrastructure or a lack of commercial incentive, which can arise because oil — not gas — is the primary source of revenue. It can be addressed through different technological or regulatory interventions. However, production activities that specifically target natural gas do not generally flare or vent, unless there is an operational safety consideration, because the primary source of revenue is the gas molecule. Fugitive methane — which can be due to leaks in valves, for example — is a different concern that applies to both associated and non-associated natural gas production. For more on the opportunity of gas capture in oil field activities, see Gabriel Collins, "Reducing Oilfield Methane Emissions Can Create New US Gas Export Opportunities," Rice University's Baker Institute for Public Policy, November 19, 2019, https://www.bakerinstitute.org/research/reducing-oilfield-methane-emissions-can-create-new-us-gas-export-opportunities.
[27] Medlock, "US LNG Exports: Supply, Siting and Bottlenecks."
[28] EIA, "Natural Gas Explained: Natural Gas Imports and Exports," last modified June 30, 2023, https://www.eia.gov/energyexplained/natural-gas/imports-and-exports.php.
[29] EIA, *Effect of Increased Natural Gas Exports on Domestic Energy Markets*, January 2012, www.energy.gov/sites/prod/files/2013/04/f0/fe_eia_lng.pdf.
[30] NERA 2012.
[31] EIA, *Effect of Increased Levels of Liquefied Natural Gas Exports on U.S. Energy Markets*, October 2014, www.eia.gov/analysis/requests/fe/pdf/lng.pdf.
[32] CES and Oxford Economics 2015.
[33] NERA 2018.
[34] DOE 2024.
[35] The DOE 2024 study, for example, calibrates resource development costs to current market conditions, which can overstate long-run costs in some markets and explain the outcomes of some of the scenarios considered. There also appears to be an arbitrary restriction on U.S. pipeline exports and some unexplained features of trade flows in North America. Altogether, the outcomes for international trade flows appear to follow

by construction, which has the appearance of engineering a solution. As one example, if a new technology becomes cost-competitive with natural gas at, say $5 per thousand cubic feet (mcf), it will begin to displace gas from the energy mix as appropriate investments are made to use the alternative resource. To this end, capital constraints would limit the pace at which the new technology option is adopted. In turn, this would push back on import demand in higher cost foreign markets, thereby reducing natural gas prices everywhere. As this occurs increasingly, the regions that will still consume natural gas demand will be exporting nations, precisely because they have the lowest cost gas. This means exports will decline, but domestic demand will remain robust, fueled by low-cost domestic supply that drives an increase in demand concomitant with the size of demand elasticity in different sectors. This does not appear to occur in the DOE 2024 study.

[36] It is important to note that the results of the DOE 2024 study's section, "Defined Policies Model Resolved High US Supply Case," report a price of $3.41 per mcf with production at 56.9 trillion cubic feet (tcf) in 2050. Thus, the econometric results in Table 1 are slightly lower.

[37] Medlock, "U.S. LNG Exports: Supply, Siting, and Bottlenecks."

[38] Hartley and Medlock, "Debt and Optionality in U.S. LNG Export Projects," *The Energy Journal* 4, no. 2 (2023): 1–28, https://doi.org/10.5547/01956574.44.2.phar.

[39] DOE 2024, S-36.

[40] Medlock, "April 20: WTI At -$37, Brent at $26! What Happened? What Comes Next? The Stories That Will Be Told… ," Forbes, April 21, 2020, https://www.forbes.com/sites/thebakersinstitute/2020/04/21/april-20-wti-at37-brent-at-26-what-happened-what-comes-next-the-stories-that-will-be-told/?sh=4665d62e4d4b.

[41] Not pictured, taking a weighted average of Henry Hub and West Texas Intermediate (WTI) futures in U.S. dollars per metric million British thermal units (MMBtu), where the weights are based on oil and gas rig counts, yields a similar result. This is not surprising because price is an indicator of value in the industry.

[42] A very simple rolling correlation analysis reveals the 13th lag of the S&P Oil and Gas Exploration & Production Index has the strongest correlation with total rig count at 0.8184. Notably, this is one-quarter, which supports the idea that drilling programs are generally adjusted on a quarterly basis.

[43] The DOE's publication, "Natural Gas Flaring and Venting: State and Federal Regulatory Overview, Trends, and Impacts," from June 2019, provides a good summary of differences in regulation and technologies to reduce flaring (www.energy.gov/sites/prod/files/2019/08/f65/Natural%20Gas%20Flaring%20and%20Venting%20Report.pdf).

[44] Global Methane Pledge, "About the Global Methane Pledge," accessed February 2025, https://www.globalmethanepledge.org/#about.

[45] Oil and Gas Climate Initiative, "Oil and Gas Climate Initiative Sets First Collective Methane Target for Member Companies," September 24, 2018, https://www.ogci.com/news/oil-and-gas-climate-initiative-sets-first-collective-methane-target-for-member-companies.

[46] Texas Oil and Gas Association (TXOGA), "TXOGA Statement on Railroad Commission Actions to End Routine Flaring," August 5, 2020, https://www.txoga.org/txoga-statement-on-railroad-commission-actions-to-end-routine-flaring/; Medlock, "The Future

of Houston as Energy Transitions," Rice University's Baker Institute for Public Policy, May 13, 2021, https://www.bakerinstitute.org/research/future-houston-energy-transitions.

[47] National Petroleum Council (NPC), "Charting the Course: Reducing GHG Emissions from the U.S. Natural Gas Supply Chain," April 2024, https://chartingthecourse.npc.org/.

[48] Medlock et al., "The Global Gas Market, LNG Exports, and the Shifting U.S. Geopolitical Presence."

[49] Christina Boufarah et al., "Global Energy: Qatar's LNG Expansion," Rice University's Baker Institute for Public Policy, May 10, 2024, https://doi.org/10.25613/ZHCN-RE19.

[50] EIA, "North America's LNG Export Capacity Is on Track to More Than Double by 2028," December 30, 2024, https://www.eia.gov/todayinenergy/detail.php?id=64128.

[51] Michael Ratner, *Power of Siberia 2: Another Russia-China Pipeline*, IF12748, Congressional Research Service, August 28, 2024, https://crsreports.congress.gov/product/pdf/IF/IF12748.

[52] Wood Mackenzie, "Asia LNG Demand Assessment: Executive Summary," Asia Natural Gas and Energy Association, November 12, 2024, https://angeassociation.com/wp-content/uploads/2024/12/Wood-Mackenzie-LNG-Demand-Study-Executive-Summary-Brief.pdf.

[53] Medlock et al., "Natural Gas Balance in Europe: Germany as a Case Study," Rice University's Baker Institute for Public Policy, December 7, 2022, https://doi.org/10.25613/8SKH-J217.

[54] For a previous analysis examining the long-term implications of reductions in Russian gas flows to Europe, see Hartley and Medlock, "Potential Futures for Russian Natural Gas," in "World Natural Gas Markets and Trade: A Multi-Modeling Perspective," ed. Hillard G. Huntington, special issue, *The Energy Journal* 30 (2019): 73–95, https://doi.org/10.5547/ISSN0195-6574-EJ-Vol30-NoSI-6.

[55] Medlock and Miller, "A 'Credible Threat' Approach."

[56] Medlock, "US LNG Exports: Supply, Siting, and Bottlenecks."

[57] Hartley et al., "ERCOT and the Future of Reliability in Texas," Rice University's Baker Institute for Public Policy, February 7, 2024, https://doi.org/10.25613/EP4G-KW61. This report outlines the importance of dispatchability in the Electric Reliability Council of Texas (ERCOT) market, and this lesson is transferable to other power markets.

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