Energy Security and Climate Initiative
at BROOKINGS

Natural gas in the United States in 2016

Problem child and poster child

Tim Boersma

July 2016 • Policy Brief 16-02

What do Americans think about U.S. natural gas? It depends on who you ask. Presidential candidates, Washington think tank analysts, and ordinary citizens all give widely different answers to that question. This policy brief provides an overview of those various sentiments and gives data supporting or refuting these varied points of view. It observes that in recent years, the image of natural gas has deteriorated, in particular within the environmental community. This, even though natural gas will surely play an important role in the U.S. energy mix for the foreseeable future and has yielded several major economic, environmental, and health benefits in the short- and medium-term. Finally, assuming that natural gas can play a role as bridge fuel to a low-carbon economy, this brief provides a policy and research agenda for the utilization of gas going forward. Evidently, natural gas production and consumption have their warts—but they are, as discussed below, increasingly better managed. For the moment, very competitive natural gas prices have created a bridge to a gas-rich world. The jury is still out on whether this gas-rich world can also be reconciled with long-term ambitions of deep de-carbonization.

Domestic natural gas production – Unconventional has become conventional

Both supporters and opponents of natural gas can agree that natural gas production has really taken flight in the United States. This is particularly due to a combination of hydraulic fracturing and horizontal drilling, often referred to in popular lexicon as unconventional gas production, or "fracking." In 2000, hydraulically fractured wells produced 3.6 billion cubic per day (Bcf/d) of marketed gas in the United States, making up less than 7 percent of the national total. By 2015, production from those wells had grown to more than

The Author

Dr. Tim Boersma is a fellow in the Energy Security and Climate Initiative, part of the Foreign Policy Program at Brookings. His research focuses on energy policy coordination, energy security, gas infrastructure and regulation, and unconventional natural gas extraction.

53 Bcf/d, making up about 67 percent of the country's total natural gas output.[1]

We have increasing certainty that the United States has a resource base that can supply the country at current annual consumption levels for several decades (and possibly much more). In 2016, consulting company IHS CERA estimated that 38 major oil and gas plays in North America contain up to 1900 trillion cubic feet (Tcf) of commercially recoverable natural gas. It estimated that around 800 Tcf of this natural gas can be produced at Henry Hub (HH) prices of $3/million British Thermal Units (mmBtu), and an additional 600 Tcf can be produced commercially at HH prices of $4/mmBtu. Furthermore, significant quantities of associated gas (gas essentially produced as a by-product) from areas with more oil or gas liquids actually have negative break-even prices, according to the report.

Impressive and intimidating as these numbers may be, it is worth keeping in mind that today's spot market prices (HH being the most frequently used reference, though many different trading hubs exist in the United States) are substantially lower than that. As an example, in the spring of 2016, HH prices hovered around and even below $2/mmBtu, following a mild winter, record storage levels, and continued production growth despite the decline in rigs targeting natural gas production. Even without new wells being drilled, production can continue to grow because wells that had already been drilled previously—but had not been put in production—can now be put to work with relatively little additional capital. By some accounts, there are currently over 5,500 wells nationwide that can be brought online and/or have production increased at a cost roughly 30 percent less than drilling and completing a new well, with 1,500 of them in the Marcellus and Utica shale alone.[2] However, gas prices fluctuate around $1/mmBtu in the northeast of the country, and there is limited short-term opportunity for relief as a result of access to the market pipeline constraints.[3] Thus, it has become evident that in the coming months even the most productive areas in the United States (in particular the Marcellus shale, stretching from Pennsylvania, Ohio, West Virginia, into New York, though in the latter hydraulic fracturing has been banned, and natural gas production is thus fairly minimal) will witness a substantial decline in natural gas production.[4] Furthermore, in the current price environment, we have reached a point where in some cases shutting in wells (ceasing production) is happening because it is becoming cash-flow negative to produce. In other words, revenues cannot cover the costs of production, gathering and transportation, and capital borrowed to fund the operation.[5] This in turn affects not just producers in the region, but also midstream operators and service companies, among other actors. In short, current price levels are not sustainable in most places for the industry, and most stakeholders on the production side would probably welcome a recovery in prices. In addition, it is worth noting that for some consuming sectors, low prices that discourage associated natural gas liquids (e.g. ethane) production can also be a negative thing. As I discuss later, there is some indication of a modest upward price effect on the horizon, for instance increased seasonal demand due to an

[1] U.S. Energy Information Administration, "Hydraulically fractured wells provide two-thirds of U.S. natural gas production," last updated 5 May 2016, http://www.eia.gov/todayinenergy/detail.cfm?id=26112.

[2] Note that these are drilled but uncompleted wells (ducs), completed wells on backlog (cobs), and wells choked to hold back production.

[3] We base this on March index prices published by Platts, for price points like Transco Leidy, Millennium East, and Dominion South Point.

[4] In its February 2016 news release and teleconference to investors (transcript publicly available), Southwestern Energy for instance indicated that it, as a result of the low price environment, had decided to drill zero new wells in 2016. Produced volumes stay substantial by bringing previously drilled wells on stream, but without those the decline in production would have been approximately 20 percent.

[5] If we assume $0.75/ mmBtu costs for production, gathering and transportation as a rule of thumb, and then add the costs on borrowed capital, then we estimate the $1/ mmBtu threshold as a boundary where shutting in wells becomes more attractive than producing natural gas.

expected warm summer, but overall the short term is likely to still be painful.

Despite that sobering outlook for the near-term future, it is important to keep an eye on the underlying fundamentals. As described, the United States is awash in natural gas that can be produced at low cost. However, current prices challenge the entire industry, and an upward effect due to increased consumption and exports is not expected before 2017, according to the Energy Information Administration (EIA). In April 2016, the industry witnessed a price rally of 30 percent, as signs of declining production boosted the belief that the worst glut might be over—though that may prove to be more speculative than based on a better balance between supply and demand. The EIA expects that throughout 2016, natural gas production will grow relatively modestly as low prices and low rig activity start to affect production. However, by the end of the year and into 2017, production is expected to recover somewhat, as a result of slightly increased prices, industrial demand, and increased exports of liquefied natural gas (LNG). I will now take a closer look at domestic natural gas consumption.

Domestic natural gas consumption – Steady growth

In the United States, natural gas is consumed in the residential and commercial sectors for heating and cooking, used to produce electricity, and used for industrial activity. In 2016, the EIA anticipates U.S. natural gas consumption will average 76.2 Bcf/d, while continuing to grow to 77.6 Bcf/d in 2017, compared with 75.3 Bcf/d in 2015. As with most of the OECD countries, residential and commercial consumption levels stay roughly flat or may even decline somewhat, with increased efficiency offsetting moderate growth. In 2016, total consumption rises predominantly as a result of increased electricity sector usage of natural gas as a feedstock. Forecast electric power sector use of natural gas increases by 3.9 percent in 2016, but then declines by 1.3 percent in 2017 in the current forecast, as natural gas prices rise and some coal-fired electricity plants (which were retrofitted for compliance with U.S. Environmental Protection Agency's (EPA) Mercury and Air Toxics Standards rule) can compete with gas-fired plants. Finally, we should consider demand fluctuations because of seasonal influences, like 2016's relatively mild winter and the expected relatively warm summer.

Next to being an attractive feedstock for electricity generation, competitive natural gas also continues to attract industrial activity, such as fertilizer and major chemical producers. It is expected that annual industrial natural gas consumption will grow by 2.6 percent in 2016, and another 2.2 percent in 2017. Going forward, more natural gas consumption is also expected in parts of the transportation sector, including marine shipping, long-distance and heavy duty trucking, and city buses (for instance in the Los Angeles Metro, which has over 2,200 vehicles that drive on compressed natural gas, or CNG). It is worth keeping in mind that higher oil prices (and subsequent more expensive oil products like gasoline and diesel) are necessary to spur large-scale demand growth in the transportation sector. Another substantial growth sector is exports of natural gas, discussed below.

Natural gas exports – Significant growth

Since the early 2000s, with the advent of enhanced natural gas production, we have seen natural gas exports increase steadily. Until February 2016, these were exclusively exports of natural gas by pipeline, even though virtually all of the public debate focused on exports of natural gas in the form of LNG. I will return to U.S. LNG shortly, but first I will outline how significant the expansion of cross-border infrastructure into Mexico has been. Today, three major pipelines carry natural gas into Mexico, i.e. Sierrita (1.9 Bcf/d capacity), Tejas 300 million cubic feet per day (Mcf/d), and Mier-Monterrey (375 Mcf/d). Furthermore, six new pipelines have been proposed and/or are under construction. They are the Nueva Era pipeline (600 Mcf/d), South Texas-Tuxpan facility (2.6 Bcf/d), the Houston pipeline (140 Mcf/d), Trans Pecos (1.4 Bcf/d), Comanche (1.1 Bcf/d), and Roadrunner (which is operating, but will have eventual capacity in 2019 of 640 Mcf/d). In total, by the decade's end, there will be nine operating pipelines, with a combined capacity in excess of 6.5 Bcf/d. These pipelines fuel growing Mexican demand for electricity and in some cases connect directly to large scale energy intensive manufacturing. A topic that deserves further study is what effect this uptick in U.S. natural gas imports will have on long anticipated domestic energy market reforms, which Mexico started in December 2013.[6]

Natural gas imports from Canada have persistently eroded, and in most scenarios, imports from the north will continue to decline. In 2007, Canada exported 10.6 Bcf/d of natural gas to the United States. However, by 2014 exports had decreased to 7.4 Bcf/d. Most experts believe that we will see a further erosion of Canadian imports going forward, although in parts of the country—like New England—this is expected to take time, as local resistance has greatly complicated pipeline construction.[7] Some of the bottlenecks may not ever be resolved. Constructing additional infrastructure in this part of the country is generally challenging, as witnessed by occasional import of cargoes of LNG into the Boston Harbor during winter peak demand and New England generators' reliance on dual-fueled generation capacity and middle distillates for short-term shortfalls. In the medium term, Canada's National Energy Board predicts that imports of natural gas into the United States will continue to decline, reaching a level of 2.5 Bcf/d by 2025, as additional infrastructure comes online that can bring natural gas from the Marcellus and Utica shales to the market.

After several years of public discussion, February 2016 marked a historic moment as, for the first time in many decades, a cargo of natural gas in the form of LNG set sail from Louisiana. From that same state, the Methane Pioneer had been the first LNG tanker in the world to set sail for international waters (on January 25, 1959), arriving in Great Britain 27 days later. In the decades after, as gas production declined and consumption increased, so did imports. Although maybe just symbolic at this early stage, recent events in Louisiana mark the advent of unconventional gas production in this country. Ironically, after the endless talk whether cargoes of U.S. LNG would be sold in Asia or Europe, the first tanker to leave the Sabine Pass terminal in Louisiana was destined for Brazil. Next to Sabine Pass (2.76 Bcf/d at full capacity), several other projects have received all the permits required to begin construction. These are Cameron LNG (2.1 Bcf/d), Freeport LNG (1.8 Bcf/d), Cove Point (0.82 Bcf/d), Corpus Christi (2.14 Bcf/d), and an extension of Sabine Pass (1.4 Bcf/d). Once constructed and in operation, these projects together are expected to make the United States the country with the third-largest export capacity of LNG, after

[6] Adrian Lajous, "Mexican Energy Reform," Center on Global Energy Policy, Columbia University, prepared for Goldman Sachs, June 2014, http://www.goldmansachs.com/our-thinking/pages/north-american-energy-summit/reports/cgep-mexican-energy-reform.pdf.

[7] See for instance recent delays with the Constitution Pipeline in New York: Jon Hurdle, "New York State denies permit to Constitution Pipeline, halting construction," *StateImpact Pennsylvania*, 22 April 2016, https://stateimpact.npr.org/pennsylvania/2016/04/22/new-york-state-denies-permit-to-constitution-pipeline-halting-construction/.

Australia and Qatar. Next to the projects that are currently under construction, a substantial amount of projects have been proposed and/or are in the permitting process. As we discussed last year, it seems increasingly unlikely that new projects will be financed in the next couple of years, as the global market for natural gas is significantly oversupplied.[8]

With significant new volumes coming into the market in the next five years, not just from the United States but also from Australia, combined with disappointing demand, analysts increasingly agree that the overhang will last to the end of the decade—according to some, even way into the next decade.[9] A more optimistic school of thought assumes that with increasingly competitive prices for natural gas, demand will also be incentivized. We see some evidence of this, with investments in smaller-scale and relatively new technologies, like floating LNG (FLNG) and LNG bunkering, in places as diverse as Lithuania, Pakistan, Egypt, and Jordan, with several other countries also considering similar options. However, in the aggregate, these investments seem insufficient to bring supply and demand back into balance in the near future. Less sanguine forecasters expect that in the next few years, the major Asian economies will continue to struggle to find a right price balance in what continue to be mostly regulated markets. They therefore predict that natural gas will continue to have a hard time competing in the electricity sector against coal and possibly fuel oil. We should also keep in mind that these countries are embarking on sometimes very ambitious renewables programs, further eroding potential demand for natural gas. These trends suggest a very competitive environment for U.S. LNG projects and that in the coming years, we will see where these projects fit in the marketplace. Some have argued that because of their flexibility and unique pricing structure (based on spot-market prices rather than oil-indexation), U.S. LNG is very well-positioned to take significant market share. Our modeling work suggests that U.S. LNG may indeed become fairly competitive in the more liquid parts of Northwestern Europe in the coming years.[10] Other analysts suggest that surely in a low oil-price environment—and with other projects still under long-term, oil-indexed, take-or-pay contracts, and considering the supply overhang—that U.S. projects might, in the short term, be relatively uncompetitive. The truth of the matter seems to be that with so many moving parts (shifting demand, competing fuels, fluctuating prices, changing regulations, and fallout from the Paris climate accord from December 2015), it is almost impossible to predict with certainty where exactly U.S. projects will fit in the global market space. To give an example, following the Paris summit, a more accurate assessment and more effective containment of fugitive methane emissions may determine whether the Paris accord results in a boon for global gas demand or does the opposite. What is evident is that not only are major additional supplies coming to the market in the coming years, but the amount of LNG cargoes that do not have a final destination yet is also significant, estimated by some in the range between 4.6-9.3 Bcf/d.[11] This surplus likely will increase further as the result of (spot market) trading contributing further to the liquidity of the sector.

[8] Tim Boersma, Charles K. Ebinger, and Heather L Greenley, "An Assessment of U.S. Natural Gas Exports," Brookings Institution, July 2015, http://www.brookings.edu/~/media/research/files/papers/2015/07/us-natural-gas-exports/lng_markets.pdf.

[9] William Powell, "IEA Sees Tighter Markets Next Decade," *Natural Gas Europe*, 9 June 2016, http://www.naturalgaseurope.com/iea-sees-tighter-markets-next-decade-30021.

[10] Tatiana Mitrova, Tim Boersma, and Anna Galkina, "Some future scenarios of Russian natural gas in Europe," *Energy Strategy Reviews*, vol. 11-12, June 2016, pp. 19-28, http://www.sciencedirect.com/science/article/pii/S2211467X16300141.

[11] Dr. Fereidun Fesharaki, "The Global LNG Market Outlook: Too Many Sellers, Not Enough Buyers," Presentation at the Center for Strategic and International Studies, Washington, DC, September 2015, https://www.csis.org/events/global-lng-market-outlook-too-many-sellers-not-enough-buyers.

The domestic debate about LNG exports essentially has two dimensions. First, opponents like to focus on the potential consequences of exports on domestic natural gas prices. Usual suspects in this argument have been energy-intensive industries who want to continue to reap the benefits of low commodity prices. However, studies commissioned by U.S. Department of Energy (DOE) suggest fairly moderate upward price effects of exports up to 20 Bcf/d (a first study looked only at 6 and 12 Bcf/d, but when project announcements kept emerging, DOE hastily commissioned a second study looking at 20 Bcf/d instead).[12] Also, one should keep in mind the potential size of exported volumes, and note that the vast majority of natural gas produced in the United States will stay in this country. One under-appreciated element of an upward effect in gas prices is the effects they could have in the electricity market where—under the rules of merit order dispatch—coal might, in the absence of a carbon price, undercut gas, leading to enhanced carbon emissions. The other debate has focused on the geopolitical consequences of increased exports of natural gas.[13] In many parts of the world, this notion is ill-understood because public and private actors are so clearly separated. In the United States, the White House does not sell natural gas. In essence, the geopolitical argument revolves around the notion that there are significant ripple effects of additional availability of supplies in the global market, and supporters and opponents will have to adjust to those new realities. This is a valid argument, and one confirmation hereof has been the fairly rapid erosion of oil-indexation in the more liquid parts of the European market as a result of an oversupplied market in mid-2008 and 2009 (to which increased U.S. production contributed).[14] More broadly speaking, increased natural gas production and trade, including in and from the United States, continues to contribute to natural gas slowly but surely becoming more of a global commodity.

All this assumes, of course, that domestic natural gas production will continue to expand as forecasted, something that outside observers of the current election cycle may start to doubt on occasion. In particular, Democratic candidates have been critical about shale gas production, with Senator Bernie Sanders (D-VT) promising an outright ban on fracking, and Secretary Hillary Clinton, possibly forced to the left by Sanders, following suit. Clinton called for increasingly stringent regulations on fracking. Under her leadership, there would likely be, in her own words, "very few places in the United States" where the industry would still be interested in producing natural gas from shale rock layers. In addition, one can wonder whether the industry will be able to grow production in the future to meet aforementioned forecasts, or whether access to capital and labor become a challenge at some point. These long-term forecasts generally assume factors like these will stay equal, something that rarely happens in reality.

The next section turns briefly to the most prevailing debates regarding environmental concerns that have been linked to U.S. natural gas production.

[12] For references to these studies, see U.S. Department of Energy, "2012 LNG Export Study," accessed 11 July 2016, http://energy.gov/fe/services/natural-gas-regulation/lng-export-study; and Adrian Cooper, Michael Kleiman, Scott Livermore, and Kenneth B. Medlock III, "The Macroeconomic Impact of Increasing U.S. LNG Exports," National Energy Technology Laboratory, 29 October 2015, http://energy.gov/sites/prod/files/2015/12/f27/20151113_macro_impact_of_lng_exports_0.pdf.

[13] See Robert D. Blackwill and Meghan L. O'Sullivan, "America's Energy Edge: The Geopolitical Consequences of the Shale Revolution," *Foreign Affairs*, March/April 2014, https://www.foreignaffairs.com/articles/united-states/2014-02-12/americas-energy-edge; and Jason Bordoff and Akos Losz, "The United States Turns On the Gas: The Benign Energy Superpower?" *Foreign Affairs*, 4 March 2016, https://www.foreignaffairs.com/articles/2016-03-04/united-states-turns-gas.

[14] Tim Boersma, *Energy Security and Natural Gas Markets in Europe: Lessons from the EU and the United States*, Routledge Studies in Energy Policy, (Abingdon, United Kingdom: Routledge, 2015).

Environmental debates related to natural gas – Can natural gas be a bridge fuel?

Several environmental debates continue to be linked—rightly or not—to unconventional gas production. In particular, some people link unconventional gas production with water contamination, methane emissions and reduced air quality, and induced seismicity, among other concerns. Several years ago, the gas industry began to argue that gas is an ideal "bridge fuel" to a low-carbon economy, contending that natural gas is an abundant and relatively clean fossil fuel.[15] In addition, gas-fired electricity plants—such as combined cycle plants—can relatively easily be switched on and off, making them complementary to renewable sources like solar and wind that have intermittency challenges.[16] Opponents of this narrative posit that natural gas, like coal and oil, is just a fossil fuel and should be treated as such. They point to aforementioned environmental claims and argue that natural gas is best left in the ground. This argument has gained prominence in recent years, and a now-significant grassroots movement has spurred local and even state-level moves (including in New York) to ban hydraulic fracturing. As the image of natural gas has deteriorated in recent years, we can expect to see more of these sentiments and policy decisions going forward.

A 2011 study out of Cornell University brought new attention to methane (CH_4) emissions related to shale gas extraction. That study concluded that because of fugitive methane emissions, the overall carbon footprint of shale gas is as bad as or even worse than coal.[17] Some studies have suggested that at 3.2 percent leakage rates or higher, natural gas would be as damaging as coal.[18] Many other studies have since questioned the data used in the Cornell study, with most concluding to various degrees that in terms of greenhouse gas emissions, natural gas is not as bad as coal.[19] In April 2016, EPA released its 1990-2014 greenhouse gas inventory. Its data suggest that natural gas systems were the largest anthropogenic source of methane emissions in the United States in 2014, with 176 million metric tons (MMT) of carbon dioxide equivalent (CO_2 eq.) of emissions. However, since 1990, these emissions have decreased 14.8 percent, chiefly due to the decrease of emissions from transmission, storage, and distribution of natural gas. These, in turn, are largely due to reduced compressor station emissions, and increased use of plastic piping and station upgrades at metering and regulation stations.[20] Importantly, though, CH_4 emissions from petroleum systems increased by 76 percent to 29 MMT CO_2 eq. over the same timeframe, largely due to increases in emissions from production equipment. Although EPA data indeed suggest that natural gas does not have the same footprint as coal, recent studies in turn have concluded that EPA estimates of methane emissions throughout the production cycle have been too optimistic.[21]

[15] It is worth reminding that in the past, several major studies have warned that if these environmental issues were not addressed properly, this would jeopardize the position of natural gas as a fuel source, see for instance: MIT Energy Initiative, *The Future of Natural Gas: An Interdisciplinary MIT Study*, 2011, http://energy.mit.edu/research/future-natural-gas/.

[16] It is also worth noting that newer coal-fired electricity plants are increasingly flexible, and so the carbon argument seems to the most important one in the bridge fuel narrative.

[17] Robert W. Howarth, Renee Santoro, and Anthony Ingraffea, "Methane and the Greenhouse-gas Footprint of Natural Gas from Shale Formations," *Climatic Change*, vol. 106, no. 4, 2011.

[18] Ramon A. Alvarez, et al., "Greater focus needed on methane emissions leakage from natural gas infrastructure," PNAS, vol. 109, no. 17, 13 February 2012, http://www.pnas.org/content/109/17/6435.

[19] For a comprehensive and recent overview, see Michael Levi, "Fracking and the Climate Debate," *Democracy*, no. 37, Summer 2015, http://democracyjournal.org/magazine/37/fracking-and-the-climate-debate/.

[20] U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks," 15 April 2016, https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2016-Main-Text.pdf.

[21] See for instance David R. Lyon, "Methane Emissions from the Natural Gas Supply Chain," Chapter 3, in *Environmental and Health Issues in Unconventional Oil and Gas Development*, (Elsevier: 2016), http://www.sciencedirect.com/science/article/pii/B9780128041116000030.

It is worth adding that fugitive methane emissions can occur throughout the production cycle, with leaks particularly occurring at the wellhead, at compressor stations (upstream), during transportation (midstream), and at the local distribution level (downstream). In recent years, much attention has been focused on reducing upstream emissions, because that is where the EPA estimates 58 percent of methane leaks occur.[22] In some cases, companies have deployed technologies such as "green completions" to capture methane (the prime element of natural gas) to gain additional revenue. In addition, in 2014, after preparatory discussions in the Interagency Task Force on Natural Gas, the Obama administration started regulating methane emissions under the Strategy to Reduce Methane Emissions. The chief reason for this initiative was the expectation that without any form of regulation—and with domestic oil and gas production on the rise—U.S. methane emissions were going to rise substantially.[23] In May 2016, EPA regulations that were first proposed in August 2015 came into effect, further regulating upstream methane emissions from oil and gas production. New rules for existing wells are expected in the future. In February 2016, the Interior Department proposed rules to cut methane emissions from oil and gas operations on federal and Indian lands.[24]

Similar to upstream emissions, addressing midstream and downstream emissions has proven difficult. One reason may be that leaks are complicated to measure, and data can therefore be incomplete.[25] However, detailed studies at the municipal level provide worrisome data, with methane emissions often substantially higher than local authorities believed.[26] There can be several reasons for this, such as inadequate access to emissions, inadequate measuring, and higher than expected leak levels from aging pipeline systems, especially in major urban areas.[27] But none of these arguments should prevent serious thinking and action about how to reduce methane emissions from midstream and downstream gas systems. In many cases, this will require major investments in new pipeline systems. Logically, it would in turn push up household costs—but someone is already paying for the fugitive methane releases now, and that has been (rightly or not) the customer. Cost arguments come on top of arguments over air quality (ozone formation), climate change, jobs creation, and overall safety.[28] Midstream and downstream challenges have significantly changed the image of natural gas in the United States in recent years. For example, a major gas leak at a storage well in Aliso County (near Los Angeles) in October 2015 made headlines around the country. It took several months to control the leak. In the meantime, over 97,000 metric tons of methane are estimated to have been leaked into the atmosphere. Better maintenance of aging infrastructure and more stringent

[22] U.S. Environmental Protection Agency, "U.S. Greenhouse Gas Inventory Report: 1990-2014," last updated on 10 June 2016, https://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

[23] The White House, "Climate Action Plan: Strategy to Reduce Methane Emissions," March 2014, https://www.whitehouse.gov/sites/default/files/strategy_to_reduce_methane_emissions_2014-03-28_final.pdf.

[24] Department of the Interior, "Proposed Rules," Federal Register, vol. 81, no. 25, 8 February 2016, http://www.blm.gov/style/medialib/blm/wo/Communications_Directorate/public_affairs/news_release_attachments.Par.15043.File.dat/VF%20Proposed%20Rule%20Waste%20Prevention.pdf.

[25] Tim Boersma and Charles K. Ebinger, "Prevailing Debates Related to Natural Gas Infrastructure: Investments and Emissions," Brookings Institution, January 2014, http://www.brookings.edu/~/media/research/files/reports/2014/natural-gas-infrastructure-investments-emissions/debates-natural-gas-infrastructure-investments-emissions-boersma-ebinger.pdf. See also study by Kate Larsen, et al., "Untapped Potential: Reducing Global Methane Emissions from Oil and Natural Gas Systems," Rhodium Group, April 2015, http://rhg.com/wp-content/uploads/2015/04/RHG_UntappedPotential_April2015.pdf for global best estimates of methane leakage, with worrisome initial for other parts of the world, like Russia, and the Caspian Region.

[26] Kathryn McKain, et al., "Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts," PNAS, vol. 112, no. 7, pp. 1941-1946, http://www.pnas.org/content/112/7/1941.abstract.

[27] Rob Jackson, "Lessons from Methane Emissions in Boston and the White House Climate Action Plan," Brookings Institution, 5 February 2015, http://www.brookings.edu/blogs/planetpolicy/posts/2015/02/methane-emissions-boston-white-house-climate-action-plan-jackson.

[28] Professor Robert Jackson, "Shale Gas in Latin America," internal workshop organized by the Brookings Institution at the World Bank, 24-25 June 2014.

federal and state oversight are necessary to prevent such blow-outs in the future. In sum, despite many studies on methane emissions throughout the production cycle, the jury is still out on what the exact overall footprint of shale gas is. More measuring, better monitoring, and (where necessary) increased regulation and enforcement are required to further reduce greenhouse gas emissions throughout the natural gas production cycle.

On a more positive note, natural gas consumption over the last fifteen years has reduced carbon dioxide (CO_2) emissions in the electricity sector, as well as emissions of nitrogen oxide (NO_x) and sulfur dioxide (SO_2). EPA data suggest that between 2005 and 2014, CO_2 emissions from electricity generation have been reduced from 2,400 MMT CO_2 eq. to an estimated 2,039 MMT CO_2 eq. At the same time, EPA measured slight increases in carbon emissions from industrial, commercial, and residential consumption, partly offsetting the benefits from the electricity production sector.[29] In addition, substantial coal exports suggest that some of the emissions may have been displaced, rather than prevented, even though U.S. coal exports are in decline.[30] Still, that drop in overall U.S. carbon emissions is largely attributed to fuel switching (electricity generators preferring natural gas over coal), and increased efficiency. Although we do not have a counterfactual to prove that, it is possible that without the significant drop in U.S. national carbon emissions due to the rise in natural gas production and consumption, the Obama administration could not have taken the leadership role that it did in Paris.

Critics are quick to point out that the benefit of fuel switching is one-off, and that is true. But fuel-switching continues to bring benefits, including in states that have historically been coal-intensive.[31] At the same time, natural gas at some point may out-compete rival energy sources, including zero-carbon options like nuclear. In deregulated markets with fierce competition—partly induced by competitive natural gas—nuclear energy is losing ground. From a carbon reduction point of view, it would be problematic if zero-carbon options were shut out by natural gas, since nuclear power currently provides close to 60 percent of non-carbon electricity in the United States. Some studies have suggested, however, this seems to be only a matter of time.[32]

Natural gas is not just cleaner in terms of carbon emissions, but also several other pollutants. Burning natural gas instead of coal results in over 90 percent less SO_2 and mercury, and also less NO_x and particulates. DOE data suggest that every 10,000 U.S. homes powered with natural gas instead of coal reduces annual emissions by 1,900 tons of NO_x, 3,900 tons of SO_2, and 5,200 tons of particulates. As such, fuel switching in the electricity sector has yielded substantial health benefits. One study suggested that if all coal plants in the United States were substituted with gas-fired electricity, this would reduce SO_2 emissions by more than 90 percent, and NO_x emissions by more than 60 percent, reducing total national annual health damages by \$20 to \$50 billion.[33] Even though natural gas is a fossil fuel, and additional solutions will be required to further reduce various emissions, these facts help accurately evaluate the merits of various fuel sources.

[29] U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks," 15 April 2016, https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2016-Main-Text.pdf.
[30] U.S. Energy Information Administration, "Quarterly Coal Report," 15 June 2016, http://www.eia.gov/coal/production/quarterly/.
[31] U.S. Energy Information Administration, "Natural Gas Weekly Update," 14 April 2016, http://www.eia.gov/naturalgas/weekly/archive/2016/04_14/index.cfm.
[32] See Trevor Houser and Shashank Mohan, *Fueling Up: The Economic Implications of America's Oil and Gas Boom*, Peterson Institute for International Economics (Washington, DC: January 2014).
[33] Roger Lueken et al., "The climate and health effects of a USA switch from coal to gas electricity generation," *Energy*, vol. 109, 15 August 2016, pp. 1160-1166, http://www.sciencedirect.com/science/article/pii/S036054421630322X.

Following a congressional request in 2009, in June 2015 the EPA released a long-awaited study on the impacts of hydraulic fracturing operations on drinking water resources. Though the debate continues and the science advisory board of the EPA has requested additional research on several accounts, the overall conclusion is that there is no evidence of widespread water contamination by the oil and gas industry.[34] Other studies also concluded that even though accidental surface spills with diesel do occur, widespread subsurface contamination has not been confirmed.[35] In recent years, there have been a couple of widely reported cases where drinking water was indeed contaminated—for example in Dimock, Pennsylvania. Fortunately, these have turned out to be anomalies so far. At a minimum, no more of these cases have been reported, though it is possible that this is chiefly because no systematic studies have been conducted.

The risk of water contamination can be mitigated by proper drilling, increasing well bore integrity, improving casing design, and other best practices. Large operators have generally applied these best practices, though more can be done to improve overall industry performance. As an example, one recent study of over 900 water wells in Colorado, concluded that the main cause of stray gas migration were inadequate surface casing and leaks in production casing and wellhead seals in older, vertical oil and gas wells, not high-volume hydraulic fracturing in horizontal wells.[36] On aggregate, we have seen sustained progress regarding water use in hydraulic fracturing operations: for instance, increased reuse of water (at industry initiative), increased use of saline or brackish water in parts of the country where water rights are costly, and greater disclosure rules for chemicals used, both quality and quantity (partly at industry initiative, and also as a result of more stringent state regulations in Colorado, Texas, Wyoming, and other states).

Wastewater produced during hydraulic fracturing operations includes flowback water, which returns to the surface immediately after fracturing the well, and produced water, which is brought to the surface during oil and gas production. The balance of flowback and produced water across the Marcellus in Pennsylvania in 2011 was 43 percent flowback and 45 percent produced water.[37] Rough estimates show that each unconventional shale gas well produces between 3,500 and 7,200 cubic meters of wastewater during its lifetime. In most states, wastewater is injected in deep saline aquifers after treatment. In states where injection in aquifers is not possible, such as Pennsylvania, wastewater is increasingly recycled and then reused, or in some instances treated in brine treatment facilities, and then discharged. Risks in terms of wastewater management remain, particularly from spills, and inadequate treatment. Adequate treatment of wastewater, and tight controls on discharging and leak prevention, is particularly important in countries where deep-well injection is not allowed, such as China and member states of the European Union.

Increased seismic activity continues to be linked to disposal of water from hydraulic fracturing operations. To be clear, most scientists suggest that hydraulic fracturing does not create earth tremors, but it is increasingly

[34] U.S. Environmental Protection Agency, "Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources: Executive Summary," External Review Draft, June 2015, https://www.epa.gov/sites/production/files/2015-07/documents/hf_es_erd_jun2015.pdf.

[35] Brian D. Drollette, et al., "Elevated levels of diesel range organic compounds in groundwater near Marcellus gas operations are derived from surface activities," PNAS, vol. 112, no.43, 27 October 2015, pp. 13184-13189, http://www.pnas.org/content/112/43/13184.full.pdf.

[36] Owen A. Sherwood et al., "Groundwater methane in relation to oil and gas development and shallow coal seams in the Denver-Julesburg Basin of Colorado," PNAS Early Edition, pp. 1-6, http://www.pnas.org/content/early/2016/07/05/1523267113.full.pdf.

[37] For a detailed overview on environmental concerns linked to hydraulic fracturing, including wastewater treatment, see Robert B. Jackson, et al., "The Environmental Costs and Benefits of Fracking," Annual Review of Environment and Resources, vol. 39, 2014, pp. 327-362, http://www.annualreviews.org/doi/pdf/10.1146/annurev-environ-031113-144051.

believed that the reinjection of flow back water into the well can create tremors, under certain circumstances. The epicenter of these concerns has been in Oklahoma, which experienced over 900 magnitude 3+ earthquakes in 2015, 585 of the same kind in 2014, and 109 in 2013. The official stance of the state authorities is that even though historically Oklahoma has experienced some level of seismicity, the recent rise in earthquakes cannot be entirely attributed to natural causes. The Oklahoma Geological Survey has determined that the majority of recent earthquakes in central and north-central Oklahoma are very likely triggered by the injection of produced water in disposal wells.[38] In response to increased concerns about seismic activity in the state, the state regulator Oklahoma Corporation Commission (OCC) implemented a traffic light system in 2013. Under the rules, disposal well operators in areas of interest must report daily on well pressure and volume of disposal wells to the authorities.[39] Industry, OCC, and the Oklahoma Geological Survey cooperate under this system to monitor and—if necessary—take precautionary measures, the ultimate possibility that injection operations would be halted.[40] This monitoring system is not static, and state regulators, scientists and companies continue to learn and adopt best practices to deal with the risks of seismic activity. Overall, cases of seismic activity that are attributable to hydraulic fracturing and/or wastewater injection are small in comparison to other anthropogenic triggers such as mining and dam impoundment.[41] However, important questions related to seismicity and energy extraction remain unanswered, and a major earthquake could have substantial impacts on shale resource extraction going forward.[42]

Discussion

As noted, the image of natural gas has substantially deteriorated in recent years. This is most profoundly evidenced by the ban on hydraulic fracturing in New York State, after lengthy discussion, and strong negative feedback from citizens. In addition, recent discussions about shale gas and tight oil in the pre-election campaign of the Democratic Party have displayed significant opposition to the shale industry. Although those concerns cannot and should not be dismissed, the broader picture is rosier than some recent commentaries suggest. On a macro level, we have to appreciate the significant benefits—for the economy, environment, public health, and geopolitics—that the fracking boom has brought the United States. At the same time, there are ongoing debates about air and water quality, as well as increased seismicity. Yet the critics too easily dismiss the substantial progress that has been made on all these issues, mostly at the state level. While it would be unwise to be complacent, it would also be foolish to throw out the baby with the bathwater. Moreover, it is worth keeping in mind that currently almost two-thirds of domestically produced natural gas comes from shale rock layers, which brings into question the sheer practicality of suggestions to ban fracking altogether.

Looking beyond the United States, we see that other developed countries are struggling with transitioning to a low carbon economy, as well. In Germany, the share of renewable energy has significantly increased; however, due to a fairly dysfunctional European emissions trading scheme—and with the phase-out

[38] Office of the Secretary of Energy and Environment, "What We Know," Earthquakes in Oklahoma, accessed 11 July 2016, http://earthquakes.ok.gov/what-we-know/.

[39] Office of the Secretary of Energy and Environment, "Oklahoma Corporation Commission," Earthquakes in Oklahoma, accessed 11 July 2016, http://earthquakes.ok.gov/what-we-are-doing/oklahoma-corporation-commission/.

[40] Oklahoma Corporation Commission, "The Oklahoma Corporation Commission (OCC) continues its proactive approach to the issue of seismic activity in Oklahoma," 28 March 2014, https://www.occeweb.com/OCC_SESMICITY5.pdf.

[41] See for instance Jackson, et al., "The Environmental Costs and Benefits of Fracking."

[42] It is worth noting that in the Netherlands, which for decades has had large scale conventional gas extraction, increased seismic activity has largely eroded public and political support for extraction of the resource, hereby fundamentally altering the production out

of nuclear energy on the horizon—national carbon emissions have not decreased as anticipated as coal consumption has flourished. As a result, Germany is unlikely to meet its self-imposed carbon-reduction targets in the near future. In Japan, nuclear energy has become highly controversial for obvious reasons, and price spikes for natural gas have led some to believe that investments in new coal-fired electricity are the way to go. These two examples alone help demonstrate that the current U.S. trajectory is not all that negative. In fact, it seems that with abundant and very cost-competitive natural gas, the United States has an excellent opportunity to sustain carbon reduction in the electricity sector, while simultaneously ramping up the share of renewable electricity. This is happening in many states already.

At the same time, and maybe because of the increasingly toxic debate related to the fracking industry, some of the longer term issues related to natural gas as a bridge fuel are not getting the attention they deserve. Primarily, we need a serious assessment on what role natural gas can play in scenarios of deep de-carbonization. This includes a much more inclusive assessment of greenhouse gas emissions throughout the production cycle, with better measuring, monitoring, and (where necessary) regulating and enforcing. In addition, we must consider what investments we need to make today that prevent the United States from getting locked into carbon levels that will be too high in 2030 and beyond. My colleagues and I have studied carbon capture and sequestration technology (CCS), for instance. We believe that in the long term, CCS can play a vital role amid a wider portfolio of carbon mitigation technologies. We have also concluded that despite the admirable efforts by DOE, current efforts may be insufficient to get the required number of large-scale commercial projects online in the coming years. These are critical for bringing down the costs of the technology further, in order to make CCS available in the long-term—not just for coal-fired electricity plants, but (possibly in particular) for gas-fired plants and several industrial processes. We should also pay close attention to revitalizing old pipeline systems, in an effort to reduce methane leaks as much as possible. Raising consumer rates, however, will pose challenges. For the natural gas industry to flourish it is important to proactively and continuously address environmental concerns, which to date has not always happened. The natural gas industry should learn from its peers in the coal industry—or from German utilities for that matter—and accept that sticking your head in the sand is not a wise strategy for the long term.

At the moment, the United States has an opportunity to have a gradual but clear transition towards a low-carbon economy, with major economic benefits on the way. This opportunity is almost unprecedented globally and will likely have positive geopolitical ripple effects (consider, for instance, how an abundance of natural gas in the form of LNG, essentially puts a ceiling on prices in the EU for the coming years). These geopolitical bonuses may be harder to quantify but are just as important. Yet, as I have described, the U.S. natural gas industry will have to continue to earn a license to operate, over and over again.

Acknowledgements

The author would like to thank Charles K. Ebinger, David G. Victor, Avner Vengosh, Ryan Savage, and Kevin Book for their careful reviews and suggestions; Heather Greenley and George Ward for their excellent research assistance; and Anna Newby and the Brookings Foreign Policy communications team for their editorial assistance. All errors are my own.

About the Brookings Energy Security and Climate Initiative

The Energy Security and Climate Initiative (ESCI) at Brookings is designed to encourage the development, discussion, and dissemination of high-caliber energy security and climate research. ESCI, through its research and convening efforts, seeks to examine three key substantive aspects of energy security: the geopolitics of energy; the economics of energy; and the growing environmental imperative of balancing increasing global economic prosperity in a carbon-constrained context.

Contact for ESCI:
Jennifer Potvin
Senior Project Coordinator
(202) 797-4389
jpotvin@brookings.edu