Questioning the Future of Natural Gas

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Executive Summary

Significant benefits from natural gas

The U.S. natural gas industry has enjoyed a great run over the past eight years. It has contributed to the economy by creating new jobs and significantly reducing households' and businesses' energy bills. This was particularly important during the Great Recession when a boost from a major industry prevented further downward spiral of the economy.

Natural gas also benefited the environment by accelerating the retirement of coals plants. The shift from coal to natural gas was a major factor in lowering U.S. energy-related CO_2 emissions by 12 percent between 2005 and 2015. Even after accounting for methane emissions, the most credible studies show that switching from coal to natural gas has mitigated global warming. Besides, natural gas emits less air pollutants, like sulfur-dioxide, mercury and nitrogen oxide, than coal.

Because of its abundance of shale gas, the U.S. expects to be a net exporter of natural gas. Until this decade, the worry was that the country would be importing increasing amounts of natural gas from vulnerable areas of the world.

Overall, because of environmentally prudent development of natural gas resources highlighted by advanced technology for hydrocarbon extraction, especially 3D seismic, horizontal drilling and hydraulic-fracturing stimulation, natural gas appears to have a bright future. About 50 percent of U.S. natural gas production comes from "fracking" techniques applied in shale formations, whereas just 10 years ago this percentage was virtually zero.

Recent opposition to natural gas has little merit

Up until the last two or so years, most environmental groups viewed natural gas favorably in facilitating the transition to a low-carbon environment. Today, these groups as well as others have radically altered their perspective of natural gas. They now see natural gas as a barrier to achieving climate-change targets that, in their minds, will help assure against catastrophes. They propose to phase-out, as quickly as possible, the use of natural gas in electricity generation and to include in the dialogue the idea of residential and business customers switching their consumption of natural gas and other fossil fuels for space heating, water heating, and other end-uses to electricity (hereafter called "electrification").

Natural gas should continue as a bridge fuel

Natural gas-fired electricity generation constitutes about 30 percent of total generation, a sharp increase from 17 percent in 2003. Phasing-out natural gas for electricity generation in the next 10 years to be replaced by renewable energy does not seem feasible, let alone economical. The most rational policy, at this time, is to continue relying on natural gas for electric generation for the next two decades and probably even longer. During that time, the U.S. can also grow the penetration of zero-carbon technologies, like renewable energy and nuclear power, to meet increased demand for electricity and replace coal-fired power plants.

In fact, a reasonable argument is that U.S. and state energy policy should encourage the expansion of natural gas for different uses rather than its suppression. A proper balancing of economic and environmental considerations would likely reach that conclusion. Those who advocate less natural-gas usage generally skew their finding by giving little if any weight to the economic effects. Their obsession centers on the urgency of controlling climate change, no matter the cost. Climate change concerns should certainly be a factor in developing energy policy, but not the sole or even overriding factor.

Challenges ahead for natural gas

There is one caveat about the long-term future of natural gas: Natural gas without carbon capture and sequestration is not a deep decarbonization option when compared with energy efficiency, nuclear power and renewable energy. If the world continues its current path toward decarbonization, probably around 2050 if not before, natural gas would cease to be a major source of fuel for electricity generation or even for household and business use.

It is beyond dispute that natural gas for electricity generation has contributed to a decline in carbon emissions over the past several years by substituting for coal-fired generation. Most studies have shown, however, that over the next two or so decades natural gas can increase carbon emissions by deferring the use of renewable energy and nuclear power in the generation of electricity. The net outcome boils down to an empirical question of the extent to which natural gas will affect the economics of zero-carbon technologies, in addition to the growth in energy consumption and economic growth resulting from continued low natural-gas prices.

Electrification, where customers switch from natural gas and other fossil fuels to electricity for direct use (e.g., transportation, water and space heating), does not seem to be a major threat for the natural gas industry in the near future. Electrification is a hard sell as long as natural gas is cheap and electricity generation still requires fossil fuels. Electrification will likely receive only a lukewarm reaction from policymakers. (Appendix A provides some basic information on electrification.)

Although electrification may have little effect on natural gas over the next several years, it is a topic of growing interest, as the U.S. electric power system moves toward zero-carbon technologies. At the point when decarbonization takes hold, the natural gas sector will have to rationalize why a world with zero-carbon electricity generation should not favor households and businesses switching from natural gas and other fossil fuels.

In the interim, it will be ill-advised for the natural gas industry to underestimate the importance of R&D for making natural gas more carbon friendly. The electric industry will surely push hard for electrification if only to bolster its stagnant sales, just as at the beginning of this decade the natural gas industry lobbied hard for customers to switch from electricity to natural gas for space and water heating, and other end-uses.

To wit, while the abundance of competitively-priced natural gas points to a bright future, it is critical for the industry to spend more on R&D and take other actions that will make natural gas more environmentally and overall socially acceptable. Major technological breakthroughs are a requisite for including natural gas in the long-term energy mix, in addition to extending the "bridge" period for natural gas.

The natural gas sector cannot therefore just sit back on its heels, but needs to aggressively support R&D that will lead to innovations assuring its long-term success. Technology can work either for or against the future of natural gas. The natural gas industry, undoubtedly, would want it to work in its favor. Examples are technologies that will reduce methane leakage throughout the natural-gas system, the environmental damage from "fracking" on local communities, and carbon emissions from electric generating facilities. Natural gas could then have a longer life as a major fuel source serving electric generators, households and businesses.

One role for natural gas in the future is to serve as a cost-effective transitional fuel until zero or lower-carbon energy sources become more economically attractive. A second is to act as a safety net against a *laissez faire* policy on climate change and disappointing performance of renewable energy and other forms of clean energy. Natural gas can buy time before zero-carbon technologies become more economical. If we eliminate natural gas from the mix today, either coal would likely damage public health and contribute to climate change for a longer period, or high-cost renewable energy would lead to higher electricity bills and a less secure and reliable electric power system. Neither outcome would be good for the country.

As a cardinal rule, any public-policy dialogue on the future role of natural gas should steer away from "rhetorical heat" and toward "analytical light", especially when climate change becomes part of the discussion. But, of course, that is easier said than done.

The focus of this paper

This paper will examine the different roles that natural gas can play in the future, especially in electricity generation. The intent is to assist state utility commissions in assessing these alternative roles, as they will likely have to address them in the not-so-distant future if they have not already. This paper lays out questions for policymakers to consider, while attempting to provide answers to some of them.

By design, this paper is comprehensive in covering a wide range of topics relating to the future role of natural gas in the U.S. energy mix. It provides the reader with a basic understanding of these topics without, in most instances, going into a deep discussion. The reader can use the references in gaining in-depth knowledge of individual topics.

Finally, some of the views expressed in this paper comport with the work of Michael Levi, who wrote an influential and thoughtful article on the subject of natural gas as a bridge fuel. (S*ee* Appendix B for the major findings of the article as well as his comments on his blog.) One of his conclusions was that natural gas can serve as a hedge in electricity generation until zero-carbon technologies are ready for prime time. His other conclusions are in line with others who have examined the role of natural gas as a transitional fuel to zero-carbon technologies.

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Questioning the Future of Natural Gas

I. The Social Benefits of Natural Gas

A. Consensus on the economic gains from natural gas

The U.S. natural gas industry has enjoyed a great run over the past eight years. It has contributed to the economy by creating new jobs and significantly reducing households' and businesses' energy bills. This was particularly important during the Great Recession when a boost from a major industry prevented further downward spiral of the economy.

Natural gas also benefited the environment by accelerating the retirement of coals plants. The shift from coal to natural gas was a major factor in lowering U.S. energy-related CO_2 emissions by 12 percent over the period 2005-2015.[1] Even after accounting for methane emissions, the most credible studies conclude that switching from coal to natural gas has mitigated global warming.[2] Besides, natural gas emits less air pollutants, like sulfur-dioxide, mercury and nitrogen oxide, than coal.

Because of its abundance of shale gas, the U.S. expects to be a net exporter of natural gas. Until this decade, the worry was that the country would be importing increasing amounts of natural gas from vulnerable areas of the world.

Many analysts support the expanded use of natural gas over the next two or so decades. As remarked by one research organization:

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[1] According to the U.S. Energy Information Administration:

> Energy-related CO_2 emissions can be reduced by consuming less petroleum, coal, and natural gas, or by switching from more carbon-intensive fuels to less carbon-intensive fuels. Many of the changes in energy-related CO_2 emissions in recent history have occurred in the electric power sector because of the decreased use of coal and the increased use of natural gas for electricity generation. [https://www.eia.gov/todayinenergy/detail.php?id=26152]

[2] Every greenhouse gas (GHG) has a global warming potential (GWP) ─ the measure of its ability to trap heat in the atmosphere relative to carbon dioxide (CO_2). Scientists consider methane as a potent GHG because, according to the EPA, it has a GWP of 34: When integrated over a100 years, methane is over 34 times more effective (per metric ton) than CO_2 at trapping heat in the atmosphere. That is, pound for pound, methane emissions are 34 times more potent in their effect on global warming than CO_2 over the period of 100 years after emission. Methane has a relatively short atmospheric lifetime of 10 to12 years, however. *See*, for example, IHS CERA, "Mismeasuring Methane: Estimating Greenhouse Gas Emissions from Upstream Natural Gas Development," private report, 2011; and The White House, "The President's Climate Action Plan," June 2013.

Natural gas is a versatile energy resource and since it is the fossil fuel with the lowest emissions of carbon dioxide, it is in demand in all sectors of the economy. It has lowered carbon dioxide emissions in the electric generating sector, resulted in the resurgence of the industrial sector in the United States, and remains the major fuel in the residential sector heating homes and providing energy to other appliances in many households. It is being eyed to replace coal in the electric generation sector, to be used to fuel the heavy truck fleet, and to be exported to nations that need more favorably priced natural gas or are dependent on Russian natural gas. Those uses could create a large demand for the fuel that will require huge up front capital costs, large infrastructure changes, and the need to produce much, much more natural gas in the future than our forecasters are predicting.[3]

Overall, because of the prudent development of natural gas resources highlighted by advanced technology for hydrocarbon extraction, especially 3D seismic, horizontal drilling and hydraulic-fracturing stimulation, natural gas appears to have a bright future.[4] Over 50 percent of U.S. natural gas production comes from "fracking" techniques applied in shale formations, whereas just 10 years ago this percentage was virtually zero.[5]

B. Natural gas as a bridge fuel

Up until the past few years, the overwhelming view was that natural gas would play the important role of a bridge fuel in the generation of electricity. One 2013 study describes the wide support for natural gas as a bridge fuel:

> Environmental experts and advocates have long viewed natural gas as a critical driver of the shift from coal toward lower-carbon energy sources. Widely referred to as a "bridge fuel," natural gas proponents argue it is one of the lowest-cost and most easily substitutable alternatives to coal. Because it produces roughly half the CO_2 emissions of coal, natural gas has been embraced as a bridge fuel to zero-carbon energy supplies by Al Gore, the Sierra Club, the Natural Resources Defense Council (NRDC), Resources for

[3] Institute for Energy Research, "Natural Gas: How Much Can We Ask Of 'The Bridge Fuel'?" March 3, 2014 at http://instituteforenergyresearch.org/analysis/natural-gas-how-much-can-we-ask-of-the-bridge-fuel/.

[4] According to a February 2016 study, IHS Energy calculated a 66 percent increase since 2010 in potential natural gas recoverable at a break-even Henry Hub price of $4/MMBTU or less. [http://news.ihsmarkit.com/press-release/north-americas-unconventional-natural-gas-resource-base-continues-expand-volume-and-de.]

[5] See https://www.eia.gov/tools/faqs/faq.php?id=907&t=8.

the Future, former Environmental Protection Agency head and Obama climate chief Carol Browner, and energy experts across the political spectrum.[6]

This paper defines a “bridge fuel” as a fuel source of electricity generation relied on until zero-carbon energy like renewable energy evolves more economically and feasibly (in terms of operability and system reliability) to be the major source of electricity generation. Natural gas accompanies growth in renewable energy for some time (i.e., the “bridge” period) but then declines as renewable energy assumes a more dominant role.

This "bridge" operates in the following way: In the near future, cheap natural gas will push aside coal in the U.S. electricity sector. Since burning natural gas for electricity emits about half the carbon dioxide that burning coal does, this will curtail U.S. emissions, which has already happened on a large scale. That, in turn, buys us some time before making the more radical shift to even cleaner forms of energy, like solar or wind or even nuclear.

Another definition of the word “bridge” depicts a scenario in which natural gas demand rises in the future from current levels before declining. In some analyses, the “bridge” period would extend to 2030 or sooner. As such, natural gas would act as a short-term stop-gap (i.e., bridge) until zero-carbon energy sources begin to dominate.

In sum, the consensus until recently has been that natural gas could serve the beneficial role of a “bridge fuel,” smoothing a transition of the electricity sector from fossil fuels to zero-carbon energy by hastening the decline in coal use. Natural gas would buy time before the country is able to depend on zero-carbon technologies to play a prominent role in fueling the electric supply system.

C. Historical overview of gas-fired generation

During the early 1970s, natural gas began to displace coal in electric generation, but then natural gas shortages (caused by artificially low wellhead gas prices) triggered federal legislation, the Power Plant and Industrial Fuel Use Act of 1978, which prohibited gas usage for electric generation.[7]

Natural gas made a comeback when the federal government repealed the Fuel Use Act in 1987. Natural gas deregulation encouraged new gas supplies to be brought to market, and new environmental regulations disfavored coal.[8]

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[6] Alex Trembath et al., “Coal Killer: How Natural Gas Fuels the Clean Energy Revolution,” paper prepared by the Breakthrough Institute, June 2013, 11.

[7] The Carter Administration actually supported the use of coal for electric generation.

[8] Natural gas production was price regulated from the 1950s to the 1970s, after which time Congress gradually repealed price regulation on the (correct) premise that the market for wellhead

Especially during the 1990s and the early part of this century, natural gas grew dramatically as a fuel source for electricity generation. For example, in 1999 gas-fired generation supplied about 16 percent of New England's total electricity requirements, increasing to around 49 percent by 2016.[9] The surge in gas-fired generating capacity during that period in other parts of the country as well came about because of the combination of different factors. One was the perception of higher risks for other sources of electricity capacity. Gas-fired facilities were particularly compatible with a more competitive electricity market that was evolving: They could be built quickly with relatively low capital costs, even on a small scale, and siting problems were minimal. Relatively low environmental impact, low capital costs, high thermal efficiency, low natural gas prices, the short construction times of natural gas facilities and their modular feature, together, contributed to the attractiveness of natural gas as a new source of electric generation starting in the early 1990s.

Most regional electricity markets, as of today, predict increased use of natural gas, and solar and wind energy in the future.[10] Nuclear power will decline along with coal-fired capacity. States and regions will rely increasingly on natural gas for both base-load electricity generation and as a back up to the fast-growing solar and wind energy.[11] The versatility of natural gas has proven valuable for electric supply systems throughout the U.S.

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production was competitive. *See* Ken Costello, "The Natural Gas Industry at a Glance," NRRI Paper 10-14, October 2010.

[9] Peter T. Brandien, "Managing Gas-Electric Interdependencies in the New England Region," presentation before the NARUC 2017 Winter Committee Meetings, February 14, 2017.

[10] The U.S. government projects an increase in gas-fired generating capacity of 11.2 gigawatts in 2017 and 25.4 gigawatts in 2018. Together these increases will increase total gas-fired capacity by 8 percent. [U.S. Energy Information Administration, "Natural Gas-Fired Generating Capacity Likely to Increase over Next Two Years," *Today in Energy*, January 30, 2017.]

[11] Typical is the expected development in the ERCOT market. According to one study,

> The price of natural gas is driving change in the ERCOT grid, much more than any other factor…Persistently low natural gas prices could cause the retirement of sixty percent (12 GW) of ERCOT's current fleet of coal-powered plants by 2022…By 2035, about 85% of ERCOT power generation will come from natural gas, wind and solar power, with NGCC [natural gas combined cycle] plants providing the lion's share of new generation.

[Ira Shavel et al., "Exploring Natural Gas and Renewables in ERCOT, Part IV," presentation before the Texas Clean Energy Coalition, May 17, 2016, 6.]

See also, Scott Wright, "Gas Fired Generation in MISO: Outlook and Challenges," presentation before the NARUC Committee on Gas, February 14, 2017.

D. Salient facts about natural gas

The following provides some relevant information about natural gas:

1. In 2016, 36 percent of the natural-gas use was for electricity generation, 28 percent for industrial use, 16 percent for residential use, and 11 percent for commercial use; thus, the electricity sector is the largest user of natural gas and has been growing faster than the other sectors.[12]

2. In 2016, natural gas was about 30 percent of the total primary energy consumption in the U.S. (second to petroleum, which was 37 percent).[13]

3. Natural gas-fired electricity generation is about 30 percent of total electricity generation, which has grown almost continuously since the 1990s; natural gas is now the largest fuel source for electricity generation.[14]

4. For most of the country, natural gas is the most economical energy source for homes and businesses.[15]

5. The shift from coal to natural gas was a major factor in lowering U.S. energy-related CO_2 emissions by 12 percent between 2005 and 2015.[16]

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[12] *See* EIA website at https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm. Natural gas is the only source of energy consumed in significant amounts directly by households and businesses, as well as for electricity generation.

[13] *See* EIA website at https://www.eia.gov/totalenergy/data/monthly/pdf/sec1_7.pdf.

[14] In 2003, 51 and 17 percent of U.S. electricity was generated using coal and natural gas, respectively. [https://www.eia.gov/electricity/data/state/.]

[15] The major drivers for the choice of a specific energy source in the U.S., over time, are the relative prices of different energy sources, climate, environmental regulation (e.g., removing coal for home use), and energy-source availability. Rural areas use little natural gas because of the unavailability of gas-distribution lines. This situation stems from the cost-ineffectiveness of extending lines to these areas. Natural gas is the energy choice in most areas where households have access to a gas-distribution main.

[16] *Supra* note 1. According to the Council on Economic Advisers (CEA):

> Both the increase in renewable energy and the shift towards natural gas have lowered emissions in the power sector. CEA analysis shows that 66 percent of the carbon intensity reduction from the power sector since 2008 in the United States is attributable to a shift towards lower-carbon fossil fuels (mostly increased generation from natural gas), and 34 percent is attributable to increased generation from zero-carbon renewable resources.

6. The U.S. has an abundance of relatively low-cost natural gas that the U.S. can depend on for several decades; the size of U.S. recoverable natural gas resource has doubled in the last decade; the U.S. Energy Information Administration (EIA) predicts, in its Reference Case, that natural gas prices will remain below $5 (in 2016 dollars) beyond 2040.[17]

7. Natural gas has been a "coal killer" (a "nuclear power killer" to a lesser extent), largely because of its low price and smaller footprint on the environment.

8. The flexibility of natural gas has increased the value of renewable energy on electricity grids.

9. Natural gas without carbon capture and sequestration (CCS) is not a deep decarbonization option when compared with energy efficiency, nuclear power, and renewable energy; it is a fossil fuel that emits both CO_2 and methane.

10. Nearly one quarter of methane emissions in the U.S. comes from the natural gas supply sector, which is the largest source; [18] this represents a downward trend since 1990 – a 15 percent decline overall with drastic drops in transportation and distribution (in MMT CO_2 Eq.).[19]

11. Shale gas has had a significant effect on bolstering the economy by creating new jobs, adding to disposable income, and reducing households' and businesses' energy burdens.[20]

[Council of Economic Advisers, "The Economic Record of the Obama Administration: Addressing Climate Change," September 2016, 4.]

[17] U.S. Energy Information Administration, *Annual Energy Outlook 2017*, January 5, 2017.

[18] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014*, April 2016. Methane leaks in the natural gas industry largely originate from drilling wellheads, compressors, meters, regulators, valves and pipelines. The 2013 leakage rate for the entire natural gas supply chain was 1.5 percent, according to EPA numbers.

[19] Ibid. Over that period, methane emissions in the gas-distribution sector declined by almost three-quarters.

[20] One study estimated that for 2015, "economic benefits from increased domestic shale gas production and the accompanying lower NG prices include contributions of $190 billion to real gross domestic product (GDP), 1.4 million additional jobs, and $156 billion to real disposable income." The study also estimated that for 2015 the average household saved around $1,300 because of shale gas. [IHS Economics, "The Economic Benefits of Natural Gas Pipeline Development on the Manufacturing Sector," report prepared for the National Association of Manufacturers, May 2016, 4.]

12. Recent studies have concluded that the EPA's estimates of methane emissions throughout the natural gas system have been overly optimistic, but still below the level that would neutralize the effect of coal-to-gas switching on the level of greenhouse gasses (more on this later).

13. Over 50 percent of U.S. natural gas production comes from the combination of "fracking" and horizontal/directional drilling techniques applied in shale formations.[21]

14. Lower natural-gas prices displace the use of coal, but they also boost overall energy consumption and have an adverse effect on nuclear power and renewable energy; as concluded in some studies (to be discussed later), the abundance of natural gas may likely have only a minimal effect on greenhouse gas (GHG) emissions over the next decade or two.[22]

E. The pro-gas stance

Advocates of natural gas can point to a number of positive developments over the past several years that made this fuel source highly beneficial to society. First, cleaner energy sources like natural gas along with zero-emitting sources like renewable energy have increasingly displaced the use of dirtier fossil-fuel sources.[23] The shift from coal to natural gas was a major factor in the 18 percent decline in carbon emissions per dollar of real GDP from 2008 to 2015.[24]

Second, natural gas is abundant and cheap, with expectations that prices will remain low over the next several years. Over the recent past, EIA's *Annual Energy Outlook* has

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[21] *See* the EIA website at https://www.eia.gov/tools/faqs/faq.php?id=907&t=8.

[22] This is the consensus of different studies, some of which this paper identifies in Part IV.

[23] Some observers have labeled natural gas a "coal killer because of its low natural gas price. Over the past few years, the Mercury and Air Toxics rule, the Regional Haze rule, the Cross-State Air Pollution rule, the Effluent Limitation Guidelines, however, have significantly increased the cost of operating coal generation. The coal industry may now be beyond reviving.

The primary argument in support of natural gas is the fact that it is cleaner than coal and can be conveniently and cost effectively substituted for it in power generation. [*See*, for example, MIT Energy Initiative, *The Future of Natural Gas: An Interdisciplinary MIT Study*, June 6, 2011.]

[24] Between 1999 and 2005, the United States had added a significant amount of natural gas-fueled electricity plants, as U.S. coal-fired capacity fell. But by 2007, with natural gas prices rising, the U.S. government predicted a reversal: Over the next two decades, coal-fired power plants would be built at a furious pace, while natural gas would stagnate. This would have shot up U.S. GHG emissions. It is because of shale gas that this scenario did not transpire.

continuously painted a brighter picture of the natural gas sector: Lower natural gas prices, more gas production, more gas consumption, less imports and more exports.

Third, natural gas competes most strongly in the electric power sector, because it has much lower CO_2 emissions than coal. Existing natural gas technology for electricity production is well-known and inexpensive compared with alternatives such as nuclear power or renewable energy. On a level playing field, only with significant cost breakthroughs, very stringent CO_2 reduction targets or carbon pricing, would these alternative sources likely compete successfully with natural gas over the next decade or two.[25]

In the electric generation sector, natural gas has so far served as an economically (measured by levelized costs[26]) and environmentally valuable bridge fuel, providing a cleaner alternative to coal. With continued tightening of CO_2 constraints beyond 2050, however, the CO_2 emissions from gas generation eventually will require the deployment of other, still lower carbon-emitting generation technologies. Overall, shale gas is far from a panacea over the longer term and investment in the development of still lower CO_2 technologies remains an important priority for the U.S. As discussed later, research and development (R&D) is vital for achieving this goal.

Overall, what natural gas has going for it is plenty: Abundant domestic availability, low price for the foreseeable future, relative cleanliness when compared to the other fossil fuels, and flexibility in electric power production (e.g., base load, peaker and back-up to renewable energy). As a bridge fuel, natural gas has served both as a cost-effective option to reduce GHG emissions (as supported by a number of objective studies), and as a supplement to renewable energy in maintaining reliable and well-operating electric systems.[27]

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[25] *See*, for example, Sergey Paltsev et al., "The Future of Natural Gas Production, Use, and Trade," *Energy Policy*, Vol. 39 (2011): 5309-21.

[26] *See* Lazard, *Levelized Cost of Energy Analysis – Version 10.0*, December 15, 2016. One definition of levelized cost of energy is:

> [T]he constant dollar electricity price that would be required over the life of the plant to cover all operating expenses, payment of debt and accrued interest on initial project expenses, and the payment of an acceptable return to investors. Levelized [cost of electricity] is comprised of three components: capital charge, operation and maintenance costs, and fuel costs.
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> [Massachusetts Institute of Technology (MIT), "The Future of Coal: Options for a Carbon-Constrained World," 2007, 127.]

[27] As remarked in one study:

> [I]t 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.

II. Recent Negativity on Natural Gas

We have seen a two-prong attack on natural gas. The first is the opposition to natural gas as a bridge fuel in electricity generation. The second, so far only in preliminary discussions, is what industry observers call "electrification," where customers switch from natural gas and other fossil fuels to electricity for direct use (e.g., transportation, water and space heating). Promoters of electrification contend that it is imperative for meeting stringent GHG-emissions targets.[28]

According to some climate-change activists, the safe level of carbon dioxide in the atmosphere is 350 parts per million. The only path to achieve that goal is to immediately transition the global economy away from fossil fuels. Reaching such a stringent target is effectively already impossible without large-scale carbon removal. Even aggressive scenarios (for example, 1.5° C warming targets) still have over 400 ppm. Reaching a 400-450 ppm target would require the U.S. to reduce its CO_2 emissions by 80 percent between now and 2050, which means an extremely short bridge for natural gas.

The attacks on natural gas are occurring both around the edges and at the core. One example is strong rhetoric coming from climate activists.[29] They view natural gas as a barrier to achieving climate-change targets that, in their minds, will help assure against devastating global warming. They reveal their negativity toward natural gas in the following ways:

1. "A bridge to nowhere"[30]

2. "Natural gas is an exit ramp"[31]

[Tim Boersma, "Natural Gas in the United States in 2016: Problem Child and Poster Child," Energy Security and Climate Initiatives at Brookings, Policy Brief 16-02, July 2016, 4.]

[28] The rationale for reducing the role of natural gas in households, businesses and industries is that, if the U.S. commits to about an 80 percent or higher CO_2 emissions reduction by 2050, it would not only have to reduce natural gas usage for electricity production but also for water and space heating. Unless something dramatic occurs in transportation, little room exists for reducing emissions in other sectors. This means that natural gas consumption would have to drastically decline in the future.

[29] *See*, for example, Conservation Law Foundation, *Comments of Conservation Law Foundation concerning Draft New Source Review Permits 0299, 0300, and 0301 for PSEG Power Connecticut, LLC to Construct and Operate the Unit 5 Combined Cycle Project*, letter to the Connecticut Department of Energy and Environmental Protection," February 28, 2017.

[30] Robert W. Howarth, "A Bridge to Nowhere: Methane Emissions and the Greenhouse Gas Footprint of Natural Gas," *Energy Science & Engineering*, Vol. 2, No. 2 (2014): 47-60; and Mark Boyer, "New Study Shows Natural Gas Is a Bridge (Fuel) to Nowhere," *Inhabitat*, March 19, 2012.

[31] The head of the Environmental Defense Fund, Fred Krupp, once commented that "I don't consider [natural gas] a bridge to clean energy; I consider it an exit ramp off of coal and ultimately off of fossil fuels. We have to switch to clean energy; the debate really is about how long that is going to take.

3. "Natural gas is best left in the ground"[32]

4. "Huge gas leaks add doubt on gas as a bridge fuel"

5. "As a bridge fuel, natural gas could take us to a GHG level of no return"

6. "Natural gas is not a bridge fuel, it's a death sentence"[33]

7. "Natural gas: bridge fuel or fool's gold?"[34]

8. "Natural gas is part of the problem, not the solution"[35]

9. "Natural gas is more of a gamble than a hedge"[36]

I think natural gas is going to be around for a while. I think natural gas is going to have a longer useful life to our country if it cleans itself up." He implied that staying with natural gas too long would compromise decarbonization targets that would almost guarantee climate-change catastrophe. [Fred Krupp, "The Times They Are a Changing," Keynote Speech at the 5th Natural Gas Symposium, Colorado State University's Energy Institute and the Center for the New Energy Economy, October 2015.]

32 One can make a more valid case that coal should be left in the ground, because of how we consume it. As remarked by one energy expert:

> [T]he way we use coal today is irresponsible. New coal technologies may yet give us better use options, and we should sustain support for such research, given the magnitude of a potential payoff. Until then, the resource will be safe in the ground. Getting off dirty coal is not a simple or easy transition for the country, but it is one that can be made in a fair way, given the numerous net benefits in doing so – a transition substantially enabled by our newfound natural gas supplies.

[Thomas F. Stephenson, "A More Balanced Approach to Climate Change Policy," *An Energy Policy Essay*, Hoover Institution, Stanford University, 2014, 4.]

33 The implication is that we should move straight from coal to renewable energy and skip over natural gas as a transitional fuel.

34 *See* http://www.cchange.net/2013/08/13/richard-heinberg-on-natural-gas-bridge-fuel-or-fools-gold/.

35 What critics imply here is that extending the use of natural gas for too long would delay the time for renewable energy to penetrate the market to help assure climate stabilization. As some analysts have expressed it, the "dash for gas" may compromise decarbonization targets, especially in the absence of CCS. *See*, for example, Joel B. Stronberg, "Natural Gas: Bridge or Barrier to a Clean Energy Future," *Renewable Energy World*, June 24, 2016.

36 *See*, for example, Jeff Deyette, "The Natural Gas Gamble: A Risk Bet on America's Clean Energy Future," prepared for the Union of Concerned Scientists, March 2015. The paper favors the use

Opponents of natural gas have tried to block the building of new gas-infrastructure projects (LNG export terminals, new gas pipeline construction) and discouraging gas usage and supply.[37] They include homeowners, other NIMBY folks (who are generally anti-development), and environmentalists.[38]

With the Trump administration's promise to help the coal industry, the natural gas industry may have a new rival that could jeopardize its future. How the Administration is going to revive the coal industry and create additional jobs remains to be seen. The odds are that the effort to offer a lifeline to the coal industry will not succeed, as retirements of old coal plants, the growing citizen-backed movement to clean energy and climate-change mitigation will probably only intensify in the future, making the coal industry's revival less probable.

A. Natural gas is a fossil fuel

Critics of natural gas point to four reasons why natural gas may not be acceptable environmentally. The first is the negative environmental effects of fracking on the local community and the environment.[39] The second is methane leakage throughout the natural gas supply system.[40] The third is natural gas (with its low price) delaying the market penetration of

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of natural gas as an "enabler of grid flexibility in support of renewable technologies," rather than as a replacement for coal (at 33).

[37] Actually, it's not a bad strategy, given the reality that natural gas in the U.S. is so abundant and much of it is inexpensive to drill. On the surface, with normal market forces it seems that natural gas should play a prominent role in the U.S. energy sector for several decades. [The highly respected firm IHS Markit estimated that we have over 50 years of domestic natural gas resources available at $4 per Mcf or less.] One goal is to prevent natural gas from reaching its intended destination for consumption.

[38] Local opposition to new natural-gas infrastructures falls under the label Not-In-My-Backyard (NIMBY). The local population may see an environmental or safety threat from a facility. Frequently, the fears are irrational. Nevertheless, the political reality remains that if the public is wary of a new facility in their locality, the owner will need to address those fears or face strong opposition. One problem is that an active minority of opponents to a facility can dominate the preference of a more passive majority at town meetings or in referenda. This intervention can lead to a decision not representative of the majority preferences in the community. The vocal group may be most affected by a facility or have ideological or self-interest reasons for opposing it. They may perceive no benefits, for example, but only environmental or safety threats from the facility.

[39] About 50 percent of U.S. natural gas production today comes from "fracking" techniques applied in shale formations.

[40] The argument is that methane leakage in the natural gas system poses climate risks and erodes the climate benefits of replacing coal with natural gas. *See*, for example, Bill McKibben, "Bad News for Obama: Fracking May Be Worse Than Burning Coal," blog on *Mother Jones*, September 8, 2014.

carbon-free technologies like nuclear,[41] solar and wind. Some environmentalists and analysts have argued that a shift to a zero-carbon energy future is imminent and can occur at little cost. Fourth, natural gas emits enough CO_2 to risk catastrophic climate change sometime in the future.[42]

Critics also argue that natural gas without CCS is not a deep decarbonization option when compared with energy efficiency, nuclear power and renewable energy.[43] Although its carbon intensity is significantly lower than coal, natural gas still emits a substantial amount of carbon.

From a climate perspective, the consensus is that natural gas can act as a bridge in displacing coal on a large scale if the carbon target is 500 or 550 ppm; but if society adopts a more stringent target of 450 ppm or lower, it would be hard pressed to justify natural gas as part of the energy mix for too long. Many scientists believe that we need such a target to avoid catastrophic climate change.[44]

The "policy" argument of those opposed to natural gas is that we should leapfrog over natural gas in favor of clean, zero-carbon energy technologies. We should therefore find ways to use less natural gas, rather than trying to expand its use.

Methane emissions in the natural-gas supply system originate from two major sources: (a) venting (intentional releasing of excess gas), and (b) leaks (the top source of methane emissions, which mostly occur on the pipeline and distribution components).

[41] Nuclear power faces several major challenges that predated the shale gas revolution. These include a cost and cumbersome regulatory process, lengthy construction times, high capital costs with frequent large cost overruns, and public skepticism. *See*, for example, Lucas W. Davis, "Prospects for Nuclear Power," *Journal of Economic Perspectives*, Vol. 26, No.1 (Winter 2012): 49-66.

Two approaches to helping nuclear power are capacity markets and a carbon tax or the internalization of the price of carbon into the wholesale electricity price. Proponents of these actions contend that they would level the playing field for nuclear power compared with other energy sources.

[42] "Catastrophic" refers to not only a scenario with a dramatic increase in temperatures but also with a significant decline in social welfare from a deteriorating economy and other damages. *See*, for example, Robert S. Pindyck, "Climate Change Policy: What Do the Models Tell Us?" *Journal of Economic Literature*, Vol. 51, No. 3 (2013): 860-72.

[43] Wesley Cole et al., *Considering the Role of Natural Gas in the Deep Carbonization of the U.S. Electricity Sector*, National Renewable Energy Laboratory Technical Report NREL/TP-6A50-64654, February 2016.

[44] The issue is that, even though natural gas produces much less carbon emissions than coal and oil do, it is not carbon-free and future use of it in electricity generation will violate the Paris Climate Agreement.

B. Disincentives for stranded natural gas assets

According to many opponents of natural gas, new pipelines or other infrastructures mean that natural gas will become more than a bridge fuel; that is, it will endure beyond the time that is socially optimal.[45]

These opponents alleged that one problem with switching from coal to natural gas is that owners of new gas-fired power plants and other gas facilities will be reluctant to shut down those facilities in 10 or 15 years' time, when we need to move to more substantial GHG reductions than what natural gas can provide. It will prolong, in other words, the use of natural gas beyond the time required to keep climate change to a non-catastrophic level.

One recommendation is that we must consider whether today's investments in natural-gas will lock the country into carbon levels that will be too high in, say, 2030 and beyond.[46] The "too big to fail" rationale may extend the lives of natural-gas assets beyond the level of no return for climate change. Investing billions of dollars in long-lived assets will leave the country committed to that infrastructure for decades.

C. A barrier to the development of zero-carbon resources

In the absence of carbon prices or cap-and-trade, renewable energy would have an unduly economic disadvantage over non-zero carbon fuels such as natural gas. The inadequacy of government R&D for clean energy technologies can also act as a barrier to renewable energy.[47]

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[45] According to the Sierra Club,

> If America is to meet its climate commitments and prevent further climate disruption, we must reject a massive new gas infrastructure expansion. The only solution for preventing further climate disruption is to redirect the proposed fossil fuel investment into accelerating our transition to 100% clean, renewable energy like wind and solar, and keep as much of the dirty fuels in the ground as possible.

[Sierra Club, "The Gas Rush: Locking America into Another Fossil Fuel for Decades," January 26, 2017, 1.]

[46] As noted in one study,

> Climate-specific policies must also create expectations of increasing stringency over time (e.g., rising carbon prices or stricter emissions standards) so that gas infrastructure investment does not effectively lock out lower-emissions technologies and futures.

[Michael Lazarus et al., "Natural Gas: Guardrails for a Potential Climate Bridge," *The New Climate Economy*, May 2015, 13.]

[47] One action supported by many economists is to accelerate R&D instead of subsidies to specific technologies or energy sources as a preferred approach to making clean energy resources economical and socially acceptable in the long run. Another action will be to hold participants in the

But in a world with different forms of subsidies for renewable energy, one would be hard pressed to show that, as of today, the U.S. has too little renewable energy relative to natural gas.[48]

Since natural gas competes with renewable energy, anything that suppresses the usage of natural gas, such as a ban on its use in electricity generation, would certainly help renewable energy and advance its market presence. It is highly doubtful that such an action could be justified economically, especially since market participants have viewed natural gas favorably because of its low cost and other attractive features. Besides, given today's technology, the electric system would find it difficult to operate reliably without the flexibility of gas-fired generation to support the growing penetration of renewable energy.

One can, with good reason, surmise that the barrier natural gas poses to renewable energy is largely the outgrowth of normal market forces.[49] That is, natural gas poses no social problem other than that renewable energy will have to wait its turn to have a larger role in electricity generation until it becomes more economical and reliable.

Advocates often petition policymakers to redress what they consider unfair or excessive obstacles to their favored technology or source of energy. They might lobby the government for subsidies or other forms of financial incentives, or the lifting of certain restrictions. In promoting the public interest, policymakers should distinguish between "artificial obstacles" and "natural obstacles." Examples of a *natural obstacle* are an electric system operator's legitimate response to the uncertainty of power from solar and wind at critical times (e.g., system peak).

An *artificial obstacle* could originate from regulatory or other governmental rules that unduly discourage utilities from accommodating renewable energy, from entry barriers to

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energy market accountable for the adverse effect of GHG emissions. By requiring companies to internalize emissions and their damage to public health and the environment, clean-energy should become more competitive with fossil fuels, triggering additional R&D spending on clean energy.

[48] Some proponents of combined heat and power (CHP) have contended that federal policies and state utility regulation and energy policy show favoritism toward renewable energy that has hindered the growth of CHP. *See*, for example, Ken Costello, "Gas-Fired Combined Heat and Power Looking Forward: What Can State Utility Commissions Do?" NRRI Paper 14-06, June 2014.

[49] Alleviating normal market barriers is unlikely to produce a nonzero-sum outcome. For example, by under-pricing partial requirements service to rooftop solar customers to bolster renewable energy, while benefiting the solar sector , would result in full-requirements customers paying for the subsidy. Whether this outcome would improve aggregate welfare depends on the validity of "artificially" bolstering the solar sector. Policymakers should determine whether barriers in a generic sense are actually socially harmful or whether they simply represent normal market features for which intervention by the government would worsen the state of affairs. For a discussion of how government policies can cause counterproductive results or mitigate a problem at a higher-than-necessary cost, *see* Clifford Winston, *Government Failure versus Market Failure: Microeconomics Policy Research and Government Performance* (Washington, D.C.: AEI-Brookings Joint Center for Regulatory Studies, 2006); and Charles Wolf, Jr., "Theory of Nonmarket Failure: Framework for Implementation Analysis," *Journal of Law and Economics*, April 1979: 107-39.

renewable-energy providers, or from faulty price signals to consumers that make renewable energy less economically attractive. Policymakers should try to mitigate artificial obstacles, which, by definition, derive from market imperfections or flawed government practices and policies, as long as the benefits exceed the costs of mitigation.

D. An impediment to deep carbonization

The question of whether natural gas is compatible with U.S. climate-change targets is separate from the issue of the potential production of U.S. natural gas. Although we have an abundance of coal resources, coal's future looks rather dim because of its environmental effects. Even today, some observers have this perception of natural gas.[50]

One view is that if temperatures rise beyond a certain threshold (e.g., 3 degrees Centigrade above preindustrial levels), the risk increases for catastrophic climate change. Prudence would then dictate that society takes some action today, notwithstanding the high uncertainty. According to some observers, prudence also means that we should not stick with fossil fuels such as natural gas too long, before severe climate-change stabilization becomes irreversible. The evidence shows that this assertion may have some credibility but is far from certain.

It therefore seems correct to say that prudence would exclude a no-action plan today as well as drastic actions that would jeopardize economic growth.[51] People pay a premium for insurance against catastrophic events, but generally they limit how much they are willing to pay. The evidence is too conjectural to measure, with a reasonable level of accuracy, the cost that society should spend to mitigate GHG emissions.

What follows is the relationship between the length of the "bridge" for natural gas and specific climate greenhouse gas targets,[52] as construed by objective analysts:[53]

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[50] Environmentalists and others have argued that the U.S. should be on a path of deep decarbonization, at the latest, by mid-century.

[51] One thing policymakers should do is to weigh the outcome of an overly lenient policy against the outcome of an overly stringent policy. The first policy could provide inadequate protection against a "black swan" where disastrous climate change occurs. The latter policy could result in excessive waste of resources to combat a problem that will remotely happen. (A "black swan" is a highly improbable event with three distinct characteristics: It is unpredictable; it has a substantial effect; and, after the fact, analysts make the event seem less random and more predictable than it was.) Policymakers should adhere to Mark Twain's advice: "It ain't what you don't know that gets you into trouble. It's what you know for sure that just ain't so."

[52] The pre-industrial concentration of CO_2 in the atmosphere in the 1750 to 1850 timeframe was about 280 parts per million (ppm). The current level of CO_2 is around 400 ppm.

1. **450 ppm** (target temperature limit of around 2°C): allows the use of natural gas for a short time, peaking before 2030; many experts concede that the 450-ppm target will almost surely be breached;[54] if they are correct, the focus should shift toward adapting to a hotter world;[55]

2. **350 ppm** (target temperature limit below 2°C): requires removing CO_2 out of the atmosphere and stop using all fossils fuels immediately; and

3. **550 ppm** (large negative climate impacts): assumes that natural gas can play the role of a bridge, peaking in usage around 2050.

The 450-ppm scenario is compatible with a set of policies where the international goal is to limit the rise in the long-term average global temperature to 2°C. To reach this goal, the Intergovernmental Panel on Climate Change (IPCC) has estimated that the industrialized countries' combined GHG emissions must fall by 80 to 95 per cent relative to the 1990 level by 2050.[56]

A cap of temperature increase of 2°C is devoid of scientific rigor, but it focuses countries to commit to a target. It has been established as a goal of international climate policy.[57] A better measure may be concentrations of greenhouse gases (the cause of climate warming).[58]

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[53] One must first quantify the relationship between GHG emissions and atmospheric GHG concentrations, followed by how changes in GHG concentrations affect changes in temperature.

[54] As commented by one noted climate-economics scholar, "[I]t will be extremely difficult to achieve the 2°C target of international agreements even if ambitious policies are introduced in the near term." He also suggests that countries lack the will to take aggressive action (i.e., depart from a business-as-usual strategy) because of politics. [William D. Nordhaus, "Projections and Uncertainties about Climate Change in an Era of Minimal Climate Polices," Cowles Foundation Discussion Paper No. 2057, December 2016, 1.]

[55] Society could allocate more funds toward adapting better and reducing its vulnerability to greenhouse gases. In other words, society can become more resilient and adaptable in a world with global warming. In what ways can society lessen the damage from higher temperatures? Resilience can lower the long-term cost of climate change and allow for more gradual implementation of costly GHG-mitigation measures. One ramification is that society can endure a higher level of greenhouse gases and climate change before catastrophe befalls. The defense for adaptation as an essential part of any climate-change strategy is that it complements GHG-mitigation efforts, which cannot guarantee non-catastrophic climate-change levels.

[56] According to many analysts, a target of 450 ppm would require (a) immediate halting of new fossil-fuel infrastructure and (b) a significant reduction in fossil-fuel consumption over the next few decades.

[57] Whether targets are based on science, are politically driven or because of inertia, they have remained intact without revisiting in view of continuously new information. *See*, for example, "Climate

E. Overall arguments against natural gas

Many climate advocates contend that renewable energy has become so compelling that we should phase-out natural gas as quickly as possible. One of their arguments is that governmental policy can help to replace coal with renewable energy, at reasonable cost, and slash U.S. GHG emissions without the problems of "fracking", and CO_2 and methane emissions.

They warn that by sinking hundreds of billions of dollars into new natural-gas infrastructure instead of expanding renewable power, the U.S. could lock itself into a carbon-based future. This would delay the time before zero-carbon energy would eventually dominate the market.

Perhaps most damning is the assertion that because natural gas systems leak methane – a potent greenhouse gas – a shift from coal to natural gas could actually increase global warming. Climate benefits from natural gas use therefore depend on system leakage rates. Although natural gas is generally regarded as the cleanest fossil fuel, it is debatable for certain uses if actual methane emissions are on the high side of estimates. One rule of thumb developed by the Environmental Defense Fund is that, at a 3.2 percent leakage rate in the natural gas system, coal and natural gas (used as boiler fuel) have an equivalent effect on global warming.[59]

Whether these arguments are valid is questionable, as this paper points out elsewhere. It seems that the economic cost of going straight from coal to renewable energy would be significant. While we should not ignore methane emissions in the natural gas system, the "consensus" evidence shows that even with these emissions, natural gas has a lesser effect on global warming than coal.[60]

Diplomacy: Goal Difference," *The Economist*, December 5, 2015. The article points out that some analysts implicitly consider the 2°C target as a substitute, although an imperfect one, for balancing costs and benefits in controlling climate change.

58 The two are pretty closely linked; that is 450 ppm versus 2 C° are pretty similar in practice.

59 Other studies have shown a threshold in the range of 3.5 to 4.0 percent, depending on several factors. *See* Gavin Bade, "On Earth Day, Natural Gas is the Power Sector's Biggest Environmental Problem," *Utility Dive*, April 22, 2016.

One study concluded that at somewhere between 3-4 percent leakage, there is some brief period in the next 20 years in which natural gas would have a greater climate impact than coal. Averaged over the 100-year period, however, the leakage rate would have to be around 9 percent in a new gas vs. existing coal scenario. [Zeke Hausfather, "Bounding the Climate Viability of Natural Gas as a Bridge Fuel to Displace Coal," *Energy Policy*, Vol. 86 (November 2015): 286-94.]

60 *See*, for example, Michael Levi, "Climate Consequences of Natural Gas as a Bridge Fuel," *Climatic Change*, Vol. 118, Issue 3 (June 2013): 609-23. A relevant empirical question is: How do methane emissions aggravate climate change when natural gas is a bridge fuel versus a scenario where the transition goes straight from coal to renewable energy?

III. Prime Questions on the Future of Natural Gas

Policymakers should ask themselves several questions about the short- and long-term role of natural gas. Specifically, they need to assess where natural gas fits in a world with deep or moderate decarbonization targets. In a business-as-usual scenario, for both market conditions and public policy on climate change, natural gas plays an important role. Its value would continue for both electricity generation and other uses, such as space and water heating.

The following are relevant questions to ask:

1. What accounts for the growing concern by some groups over natural gas as a bridge fuel?[61]

2. What evidence presented either to support or oppose natural gas is reasonably credible versus advocacy?[62]

3. What should be the future role of natural gas in the electric sector? Bridge fuel, exit fuel, enduring fuel?

4. What are the positive and negative attributes of natural gas as a fuel source for electric generation? These attributes are from an economic, environmental, energy portfolio, and societal perspective?

5. What does it mean to over rely, or under rely, on natural gas?

    a. What are potential sources of suboptimal natural gas usage?[63]

    b. What are the consequences? Which are the most serious ones and pose the greatest societal threat?

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[61] Natural gas has two major advantages over coal: It produces lower carbon emissions per unit of chemical energy, and it can be converted into electricity at a higher efficiency (less energy is lost as waste heat). These two combined mean that the CO_2 emissions from new natural gas power plants can be as little as one third of the emissions of existing coal plants. Natural gas also has a serious potential downside: If it is leaks out of the production, delivery or storage components before burning, the 100-year average climate effect of that leaked methane is about 12 times worse for the climate than the effect of CO_2 from the same amount of gas if it were burned.

[62] Advocates of natural gas would tend to include those who will continue to benefit economically from a major role for natural gas in the future. Opponents would tend to benefit economically with a lesser role for natural gas (e.g., supporters of other fuel sources) or view natural gas at odds with adequate controls on GHG emissions (e.g., climate activists).

[63] One likely cause is the overbuilding of gas-peaking plants because of seasonally-uniform electricity rates that fail to account for the higher costs of producing electricity during system-peak periods. Electricity is therefore over-consumed during peak periods.

c. If gas-fired electric generation is socially suboptimal, how can policymakers best compensate for this problem?

d. To what extent can markets address this problem?

e. What is the rationale for government intervention?

6. Is natural gas part of the problem to a low-carbon future, or is it part of the solution?

7. What is the status of the dialogue on electrification,[64] which is the switching from fossil fuels to electricity for water and space heating, and transportation?[65] Some experts now believe we are approaching a tipping point: We cannot achieve climate stability if we continue to burn fossil fuel on-site in millions of homes across the country.[66]

   a. What are the arguments for electrification?[67]

   b. What developments have heightened the interest for electrification? [68]

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[64] Some policymakers and analysts have begun to investigate options for decarbonizing heat, such as electric heat pumps and district heating based on non-gas alternatives. Demand-side technologies which improve efficiency, both in relation to overall energy use and reducing peak demand, are also likely to make significant progress, potentially reducing the need for both power and heat supply. There are several options for displacing natural gas as part of a decarbonization agenda.

[65] Gas has diversified uses. The question of which uses should we concentrate first to reduce, and over what time frame, requires both quantitative analysis and the policymaker's judgment.

[66] Appendix A provides some basic information on electrification.

[67] To say it more succinctly, meeting climate goals requires reducing significantly the use of natural gas in home appliances. Some analysts favor immediate electrification; otherwise, they argue, we risk falling short of reaching climate goals that would avoid catastrophe.

As one article points out:

> [I]t is possible to achieve deep greenhouse gas reductions by 2050 with little change in life-style (although the potential for life-style change deserves further study). The logical sequence of deployment for the main components of this transformation is EE [energy efficiency] first, followed by decarbonization of generation, followed by electrification. This transformation will require electrification of most direct uses of oil and gas.

[Steve Weissman, "Natural Gas as a Bridge Fuel: Measuring the Bridge," paper prepared by the Center for Sustainable Energy, March 2016, 3.]

c. Which groups are advancing them?

d. What empirical evidence have they presented?[69]

e. What market and public-policy conditions would make electrification a reality and socially desirable?

IV. Some Comments on the Arguments

Any public-policy discussion should steer away from "rhetorical heat" and toward "analytical light."[70] Rhetorical heat is reflected in the positions of climate-change deniers and anti-fossil fuel extremists. A more balanced position would advocate for incurring "prudent costs"[71] today to prevent a climate-change catastrophe while avoiding the disruption of the economy and onerous government intervention.[72] It would also include a discussion of the costs

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[68] Technological trends, driven in part by public policies, are creating a perception of electrification as an environmentally superior choice over on-site fossil fuel use for space and water heating, vehicles, and other equipment.

[69] A Canadian study reported that electrification – fuel switching to zero-carbon electricity – could account for over one quarter of the abatement required to achieve deep decarbonization in Canada by 2050. [Navius Research Inc., "Mitigating Climate Change Through Electrification – Final Report," prepared for Clean Energy Canada, September 20, 2016.] The report also mentioned that "electrification policies accelerate two key trends of Canada's electricity sector…First, demand for electricity rises more quickly as demand sectors switch from fossil fuels to electricity to comply with the electrification policies. Second, the electricity sector decarbonizes more quickly and more completely.") [at iv]

[70] This is a phrase coined by the MIT economist Richard Schmalensee in his article "From 'Green Growth' to Sound Policies: An Overview," *Energy Economics*, Vol. 34 (2012): S2-S6.

[71] Of course, "prudent" has different interpretations depending on what perspective one comes from.

[72] Another way of saying this is that the possibility of climate catastrophes can justify prudent actions today to sharply reduce the chances that they will occur sometime in the future. Spending money now is like buying fire protection (not insurance, as many have described, since insurance requires diversifiable risk) to avoid the possibility of a worst-case outcome in the future. The possibility exists for irreversible large-scale changes that have substantial consequences. That is, we can wait too long to take action that could avoid a worst-case scenario or catastrophe.

This idea is compatible with what economists call the "precautionary principle," which argues for taking some action today to better prepare for a future that could turn out catastrophic. Tighter controls reflect a hedging policy rationalized by uncertainty. There are four distinct sources of societal risks associated with "climate" investments: (a) global economic growth (which affects the level of GHG emissions), (b) the effect of GHG emissions on climate, (c) the effect of climate on the environment, productivity and economic welfare, and (d) the effectiveness of current investments in mitigating future and benefits of various levels of actions and of alternative policies. If we decide to phase-out natural gas for electricity generation by 2050, what would be the consequences for electricity prices and reliability? What environmental benefits, if any, would result?

A. Balancing the economic and environmental effects

A U.S. natural-gas strategy should look beyond the effect on the environment. Those who advocate less natural-gas use generally skew their finding by giving little weight to the economic effects.[73] Their obsession centers on the urgency of controlling climate change, no matter the cost.[74] Climate change concerns should surely be a factor in forming energy policy, but not the sole or even overriding factor. Any rational policy should account for the totality of economic, environmental, and other effects from the future consumption of natural gas.

As an economic benefit, shale gas has undoubtedly boosted the U.S. economy during an otherwise weak stretch, even if its economic benefits are often exaggerated and unevenly felt.[75] We can expect natural gas to have a similar positive effect in the future.

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harm. For example, as of today the loss function relating temperature increases to economic decline lacks a precise theoretical or empirical underpinning. One analyst concluded that the greatest area of uncertainty lies with the economic and health effects of climate change. [Robert S. Pindyck, "The Climate Policy Dilemma," *Review of Environmental Economics and Policy*, Vol.7, No.2 (2013): 219-37.] For critiques of the precautionary approach, *see* Richard A. Posner, *Catastrophe: Risk and Response* (New York: Oxford University Press, 2004); and Robert W. Hahn and Cass R. Sunstein, "The Precautionary Principle as a Basis for Decision Making," *The Economists' Voice*, Vol. 2, No. 2 (2005), article 8.

According to option theory, policymakers should prepare to eliminate a disastrous outcome without having to incur a large cost when it fails to occur. Policymakers should question whether to spend, for example, hundreds of billions of dollars to avoid a catastrophe from climate change when much less severe effects are conceivable. *See*, for example, Council of Economic Advisors, "The Cost of Delaying Action to Stem Climate Change," July 2014.

[73] Some groups lament the fact that cheap natural gas has spurred economic growth and energy consumption, in the process contributing to a higher level of greenhouse gases. While the latter may be true, it is hard to imagine how one can have a negative perception of higher economic growth. This view exemplifies the perverse views that frequently infiltrate the public dialogue on climate change.

[74] One example is interest groups who regard anything less than a maximum effort to address climate change as a social injustice. An obsession with climate change can threaten other policy objectives, like reasonable and stable rates, affordable energy bills, economic growth and reliable utility service.

[75] One study concluded that, although as a percentage of the total Gross Domestic Product (GDP) it is not significant, shale gas has had a positive effect on the general economy:

Fracking, along with horizontal drilling, has made it possible for the U.S. and other countries to recover large amounts of shale gas economically, which has the potential to fuel power electric generating plants, industries, businesses, and homes for decades. The potential benefits of recovering these recently discovered vast resources in terms of job creation, reduced energy dependency on foreign sources, and revenues for local, state, and federal governments are enormous and undeniable. Having ample amounts of shale gas is a major positive development that promises to bolster our economy in the years ahead.

Opponents of natural gas seem to endorse what decision-theory experts call a c*onjunctive strategy*. This strategy requires that for any single option to warrant non-rejection it must satisfy a minimum threshold for a specific criterion. A decision-maker might outright reject natural gas just because it breaches the objective of a stringent greenhouse-gas target. For example, the decision-maker might dismiss a plan to expand a natural gas pipeline because it would violate such a target. Building the pipeline, however, might have significant economic benefits, something rational policymakers cannot ignore; but they would still reject it because the pipeline fails to satisfy what they consider an essential criterion, namely compatibility with a stringent greenhouse-gas target.[76]

An artificial barrier can originate when policymakers give undue weight to a certain stakeholder, policy objective or position. Policymakers should instead attempt to balance the interests of all stakeholders, rather than adhering to a specific stakeholder's position as a threshold for decision-making. An environmental group, for example, might oppose natural gas only because it is a fossil fuel and its presence delays the market penetration of renewable energy. Someone else might oppose natural gas because it hurts the coal industry and its employees, or, as in Kosovo and other European countries, conversion to natural gas may impose a heavy burden on the local economy.[77] The policymaker has the duty to review all perspectives

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> Relative to its path in the low-shale case, the inflation-adjusted gross domestic product (or real GDP) is higher in all models that track the economy's aggregate output. The cumulative aggregation of these GDP gains over all years is significant standing at $1.1 trillion (2010 dollars). (All prices, gross domestic product levels and economic damages from pollution or climate change in this section are adjusted for inflation and expressed in 2010 dollars.) When amortized over the horizon of the study (through 2035 or 2050 depending upon the model), these GDP premiums average $70 billion each year. This amount is about 0.46 percent of $15 trillion, the approximate 2012 GDP level for the United States.
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> [Energy Modeling Forum, Stanford University, "Changing the Game?: Emissions and Market Implications of New Natural Gas Supplies," EMF Report 26 (Volume I), September 2013, 7.]

[76] What one observes too frequently in different contexts is policymakers subordinating the public interest to peripheral interests.

[77] As noted elsewhere, this concern exists in some European countries where politics favor coal over natural gas. According to the International Energy Agency, Kosovo generates over 97 percent of its electricity from coal. Absent some sort of external support, the move to gas or other fuels could have a devastating effect on the country's economy.

and weigh them in reaching a decision. Yet, if the policymakeracts solely based on whether a single group will find its decision offensive, it invites a bad outcome antithetical to society's interest.

B. Analysis of the different perspectives

1. Criteria

The criteria for evaluating the future role of natural gas in electricity generation should parallel those included in a conventional cost-benefit analysis:

1. Price and reliability of electricity;
2. Adaptation to uncertainty;[78]
3. Target level of greenhouse gases (CO_2 plus CH_4);
4. Other environmental effects; and
5. General-economy effect.

Some observers have argued that natural gas is a cost-effective bridge to reducing GHG emissions.[79] Natural gas is also valuable for supplementing renewable energy to maintain electric-system reliability and operations.

(http://www.iea.org/statistics/statisticssearch/report/?year=2013&country=KOSOVO&product=ElectricityandHeat).

[78] Diverse power systems or financial portfolios tend to better respond to unexpected adverse events. A network with a greater variety of generation facilities would more likely have a greater ability to adapt to internal or external changes.

[79] A MIT study on natural gas concluded that:

> In a carbon-constrained world, the power sector represents the best opportunity for a significant increase in natural gas demand, in direct competition with other primary energy sources. Displacement of coal-fired power by gas-fired power over the next 25 to 30 years is the most cost-effective way of reducing CO_2 emissions in the power sector.

[MIT Energy Initiative, "The Future of Natural Gas: An Interdisciplinary MIT Study," June 6, 2011, 9.]

See also, Lawrence Makovich and Aaron Marks, "Reducing the Electricity Sector CO_2 Emissions: Why the U.S. Set the Pace," *The Wall Street Journal*, Special Advertising Feature, CERAWeek, March 8, 2017.

With a more diversified mix of fuels (i.e., a physical hedge), an electric system can better adapt to unexpected changes in fuel prices and other conditions. By leaving natural gas out of the mix, electric systems become more risky.[80]

2. Natural gas and GHG emissions

Studies have reached different conclusions on the future role of natural gas in the U.S. energy sector. The American Petroleum Institute found that the lowest-cost solution to different EPA-defined compliance scenarios has the highest level of natural-gas generation. Another major conclusion is that total electricity-generation costs reach their minimum level when market forces drive the future resource mix to achieve compliance, rather than relying on government mandates favoring renewable energy.[81]

According to IHS Markit, the most cost-effective action for CO_2 reduction (in terms of dollars-per-ton of CO_2 saved) is replacing coal with natural gas.[82] That approach is so cost-effective that it has already occurred on a large scale, with U.S. electric utilities having shifted dramatically from coal to natural gas over the past several years. This action is largely the result of the combination of market forces (i.e., low natural gas prices) and EPA rules directed at emissions of toxic metals from the combustion of coal.[83]

Another study showed that, while switching from coal to natural gas for electricity generation can help to reduce the costs of achieving GHG-reduction targets, it may have only a minimal effect on global GHG concentrations:

> We examine the evidence and analyze modeling projections to understand how these two dynamics affect greenhouse gas emissions. Most evidence indicates that natural gas as a substitute for coal in electricity production, gasoline in transport, and electricity in

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[80] The primary justification for diversification lies with risk reduction, a strategy used by many financial investors to achieve both tolerable risk and reasonable returns. For electric generation, identifying and quantifying these risks are crucial questions that industry planners and policymakers face.

[81] American Petroleum Institute, "Natural Gas Solutions: Power Generation," 2016.

[82] The cost-effectiveness approach acknowledges that policymakers typically have some ultimate target for limiting the amount of projected climate change or atmospheric GHG accumulations. The question is then what policy would achieve alternative goals at minimum economic cost, accounting for practical constraints, such as incomplete international coordination. An alternative more theoretically-preferred approach is to weigh the benefits and costs of slowing climate change. This approach introduces highly contentious issues, like measuring damages, identifying responses to extreme climate risks, and inter-generational discounting.

[83] According to the EIA, 30 percent of the country's coal generating capacity that closed in 2015 was in April, the month that the EPA's Mercury and Air Toxics Standards went into effect. [www.eia.gov/todayinenergy/detail.php?id=26972.]

buildings decreases greenhouse gases, although as an electricity substitute this depends on the electricity mix displaced. Modeling suggests that absent substantial policy changes, *increased natural gas production slightly increases overall energy use, more substantially encourages fuel-switching, and that the combined effect slightly alters economy wide GHG emissions; whether the net effect is a slight decrease or increase depends on modeling assumptions including upstream methane emissions*. [Emphasis added][84]

One study questioned whether the increased abundance of natural gas will actually reduce carbon emissions in the future.[85] Between 2011 and 2013, a group at Stanford University brought together 14 expert teams of energy modelers to each independently predict the effect of shale gas production on U.S. carbon-dioxide emissions over the next 20 years.[86] Half of the teams found that more shale gas ultimately means lower emissions, but the other half found the opposite. None of the teams concluded that shale gas would do much to U.S. emissions over the next 20 years unless the government institutes new energy or environmental policies.[87]

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[84] One of the study's findings is that a net emissions reduction is likely if the amount of coal displaced is greater than combined renewables and nuclear energy replaced. *See* Richard G. Newell and Daniel Raimi, "Implications of Shale Gas Development for Climate Change," *Environmental Science and Technology*, Vol. 48, No. 15 (April 2014), 8360.

[85] The study concluded that:

> [W]e find that having low-carbon policies in place is essential if natural gas is to serve as a bridge to a low-carbon future. Without such policies, more abundant natural gas does not reduce CO_2 emissions. Although greater natural gas resources reduce the price of natural gas and displace the use of coal and oil, they also boost overall energy consumption and reduce the use of nuclear and renewable energy sources for electric power generation.

[Stephen P.A. Brown et al., "Abundant Shale Gas: Some Implications for Energy Policy," *Backgrounder*, Resources for the Future, April 2010, 2.]

[86] The team study excluded the effect of different scenarios on methane emissions. They also omitted the benefits of natural gas over coal in reducing air pollutants like sulfur-dioxide, mercury and nitrogen oxide. [*Supra* note 75.]

[87] Increasing shale gas supplies would cut CO_2 emissions when removing coal for electricity generation and, much more modestly, replacing some gasoline and diesel in cars and trucks. But there are factors, quantifiable from energy-economy models, which would counteract them: For example, the models found that both globally and for the United States, the increase in emissions from the scale effect (i.e., added gas supplies reducing energy prices, thereby increasing economic activity, promoting more energy-intensive activities, and reducing incentives for energy efficiency; these effects in turn can result in increased energy use and CO_2 emissions) fully offsets the emission benefits from the substitution effect (natural gas for coal), net of methane leakage. Accounting for all factors, the studies conclude that more abundant and less expensive natural gas supplies are, on their own, unlikely to produce a significant climate benefit. [S*upra* note 75.]

A study by the National Renewable Energy Laboratory (NREL) showed that currently available renewable technologies can affordably and reliably provide 80 percent of U.S. electricity needs by 2050.[88] Other studies have come to similar conclusions. The policy implication is that over the next 20 to 30 years, the U.S. can pretty much phase-out natural gas for electricity generation to be displaced by renewable energy with minimal effect on costs and reliability.[89]

As noted in one article, outcomes from models have limited value:

> [They] should be viewed not as predictions where confidence can be attributed to the absolute numbers but rather as illustrations of the directions and relative magnitudes of various influences on the role of gas, and as a basis for forming intuition about likely future developments in a greenhouse-gas-constrained market environment.[90]

This limitation on modeling dilutes the predictions of both the pro-gas and anti-gas groups. Policies or recommendations based on predictions contain inherent uncertainties about the future. Models are generally non-robust in that changing the inputs ever so slightly can have a significant effect on the results. Modelers typically display unwarranted confidence in their predictions. For many things, predicting a year ahead is difficult, let alone trying to predict what will happen in the next century. Policymakers should therefore interpret the arguments of both sides of the debate with trepidation, even when they apply sophisticated models.

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[88] Maureen M. Hand et al., "Renewable Electricity Futures Study," report by the National Renewable Energy Laboratory, Vols. 1-4, 2012.

[89] "100% Renewable Energy Vision," *The Solutions Project* at http://thesolutionsproject.org/.

[90] *Supra* note 25 at 5311.

Another study commented that:

> Models sometimes convey the impression that we know much more than we really do. They create a veneer of scientific legitimacy that can be used to bolster the argument for a particular policy… In effect, the model is just a black box: we put in some assumptions…, and we get out some results.

[Robert S. Pindyck, "The Use and Misuse of Models for Climate Policy," MIT Center for Energy and Environmental Policy Research Working Paper 2015-003, April 2015, 6.]

C. Methane leaks

Studies[91] on methane leaks have, on balance, shown that leak rates in the natural-gas supply system, while in some instances higher than EPA estimates,[92] are well below levels that would neutralize the benefits of switching from coal to natural gas on climate change.[93]

One analyst has questioned whether methane emissions have any effect on the catastrophic outcome of climate change:

> The climate system has a lot of inertia. This means that it's the long-term impact of methane – known to be much smaller than its short-term impact – that really influences peak temperatures. That weakens the ultimate impact of methane. Because peak temperatures lag the decline of conventional fossil fuel combustion by several decades, the effect of methane leakage largely dies out (loosely speaking) before it can influence peak temperatures much.[94]

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[91] One widely cited study argues that the EPA underestimates methane leakage and the leakage rate is probably in the 2-4 percent range. [Adam R. Brandt et al., "Methane Leaks from North American Natural Gas Systems," *Science*, Vol. 343, no.6172 (February 14, 2014): 733-35.]

[92] *See*, for example, A.J. Turner et al., "A Large Increase in U.S. Methane Emissions over the Past Decade Inferred from Satellite Data and Surface Observation," *Geophysical Research Letters*, Vol. 43, Issue 5 (March 2016): 2218-24.

[93] Some studies have suggested that 3.2 percent leakage rates or higher would make natural gas as damaging as coal for global warming. Many other studies have since questioned the data used in the Cornell study (*supra* note 30), with most concluding to various degrees that in reducing greenhouse gas emissions, natural gas is preferable to coal. Most observers view the Cornell results as outliers that hold little credibility for policy actions.

One study, for example, conclude that:

> [N]atural gas infrastructure with modest leakage could remain in place for 1.5-2.4 times the time interval that coal generation would have persisted prior to replacement with near-zero carbon technologies before the climate benefits of replacing coal with natural gas are negated. Natural gas can serve a viable bridge away from coal-based generation if avoiding longer-term climate impacts is prioritized, fugitive methane emissions are minimized, and the large-scale transition to near-zero carbon alternatives is unlikely to happen in the near-term.

[*Supra* note 59.]

[94] Michael Levi, "A New Paper on Natural Gas as a Bridge Fuel," Blog on the website of the Council on Foreign Relations, January 4, 2013 at http://blogs.cfr.org/sivaram/2013/01/04/a-mixed-verdict-on-natural-gas-as-a-bridge-fuel/.

To say it differently, while more methane leakage contributes to short-term warming, it has little impact on peak temperatures, which are the ultimate metric of climate change and the best indicator of whether the world might surpass dangerous climate thresholds.

Another analysis also downplays the concern that natural gas could have a larger effect on climate change than coal:

> If we replaced current coal generation with new natural gas power plants today, and leakage rates end up being the EPA's current best estimate, we could use that natural gas for 2.4 years for every year of coal that it replaces before breaking even on warming over the next 100 years. If you compare a coal plant used for 10 years and replaced by renewables to a gas plant used for 24 years and replaced by renewables, you get the same amount of warming. This means that you could end up delaying renewables by quite a bit before the climate benefit of using gas as a bridge fuel is eliminated.[95]

D. Natural gas has many attractive features for electricity generation

Natural gas for electricity generation has several positive attributes. In prematurely phasing-out natural gas, society would forgo certain benefits:

1. Natural gas can be used in a range of efficient, flexible, and scalable generating technologies,[96] making it a good fit for renewable-energy sources such as wind and solar power.[97]

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[95] Berkeley Earth, "Natural Gas Can Help Reduce Global Warming Even If It Modestly Delays Renewables," Blog, July 30, 2015 at http://berkeleyearth.org/natural-gas-can-help-reduce-global-warming-even-if-it-modestly-delays-renewables/.

[96] Overall, gas-fired generation is the primary option to meet the variable portion of the electricity load because it is more flexible than coal when it comes to changes in output, and typically it supplies peak power. The relatively low natural-gas prices have resulted in more base-load, gas-fired generation.

[97] More renewable, variable energy on the grid will lead to the need for additional gas-fired generation to maintain stability. The potential benefits of natural gas therefore include both a reduction in short-term CO_2 emissions and its role as a complement to the intermittency of wind and solar power. Greater penetration of intermittent renewables is stressing the capabilities of conventional forms of flexibility, and is triggering much interest in R&D to develop new forms of storage. *See*, for example, Peter D. Lund et al., "Review of Energy System Flexibility Measures to Enable High Levels of Variable Renewable Electricity," *Renewable and Sustainable Energy Reviews*, Vol. 45 (May 2015): 785–807.

In Europe, low-cost coal has significant advantages despite its CO_2 content and air quality problems. Domestically produced coal has a high policy priority as it provides job creation/retention in some regions. Coal is also seen as more secure than imported (especially Russian) gas, and (with low carbon prices) has been more competitive than natural gas, at least until 2016, in backing up renewable energy. The idea that natural gas is the best complement for renewable-energy development is therefore

2. Gas generation can cycle more quickly than base-load coal or nuclear generation.

3. The combination of evolving environmental regulations limiting reliance on coal generation and low natural-gas prices has led to a significant increase in the amount of economical gas-fired generation in the U.S.

4. Absent subsidies, renewable energy generally is not economical; when renewable energy comprises a major part of the generation mix, it also requires quick- response grid support that gas-fired generation can provide.

5. Natural gas plants can be sited and built with reasonable certainty.

6. They are relatively cheap to construct.

7. They do not require subsidies.

8. As long as natural gas prices are low, power plant producers enjoy low marginal fuel costs; gas-fired plants are sometimes cheaper to operate than coal power plants; for base load plants, this outcome means more constant hourly generation.

E. Concerns with natural gas as a fuel for electricity generation

Natural gas has drawbacks that diminish its value in electricity generation:

1. Some electric generators are wary of committing to investments that require the purchase of natural gas over a multi-year period unless offered price stability[98]; their concern is that future prices could lie substantially above current levels.

2. Even though natural gas prices have become more stable over the past few years, a common perception is that they are inherently volatile.[99]

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not universal. [Jonathan Stern, "The Future of Gas in Decarbonising European Energy Markets: The Need for a New Approach," The Oxford Institute for Energy Studies Paper NG 116, January 2017.]

[98] Competitive pressures have made long-term commercial arrangements more expensive for buyers of natural gas. A major reason for the restructuring of the U.S. natural-gas industry was the high social costs from rigid multi-year contractual arrangements as the industry morphed into a more liberalized structure. *See* Ken Costello, "Going 'Long' with Gas: Considerations for State Regulators," NRRI Paper 10-13, September 2010.

[99] There may be some concern that, like what happened in the 1990s, new generating capacity will be predominately natural gas, heightening the risk of high and volatile natural gas prices adversely affecting generators and consumers.

3. As mentioned a number of times in this paper, relying on natural gas too long may jeopardize the country's ability to achieve GHG targets that would assure against climate catastrophe.[100]

4. Some electric utilities are hesitant to rely almost exclusively on natural gas to fuel new generation or replacement generation, since they desire more diversity of generation technologies as a physical hedge.[101]

5. As natural gas replaces base-loaded coal, gas-fired generation in the winter months can place extreme stress on pipelines and storage facilities; this can jeopardize service reliability to homes and businesses that depend on natural gas during those months for meeting critical space-heating demands.[102]

It is worth noting that over the past decade, the share of natural gas in some European countries' energy mix has declined sharply in the face of a rise in renewable energy; coal demand has remained robust, however.[103] A major factor is low coal prices combined with an excessively low carbon price disfavoring the economics of gas-fired power generation. In

[100] One article warned that, "While taking advantage of …treating gas a 'bridge' to a low-carbon future, it is crucial not to allow the greater ease of the near-term task to erode efforts to prepare a landing at the other end of the bridge." [Henry D. Jacoby et al., "The Influence of Shale Gas on U.S. Energy and Environmental Policy," *Economics of Energy and Environmental Policy*, Vol.1, No.1 (2012), 50.]

[101] More diverse systems tend to exhibit a higher degree of robustness in response to external shocks whether or not they were previously assigned a probability distribution (i.e., subject to risk or ignorance). The economic perspective on diversity and robustness is succinctly captured by the adage "don't put all of your eggs in one basket." The notion of diversity and robustness comes up in many social contexts. For example, evidence shows that the sustenance of growth and economic well-being of cities hinge importantly on industrial diversity; take the example of Detroit compared to Chicago, which has successfully diversified its industrial base over time. As another example, the practice of peasants in the Middle Ages to farm on non-contiguous fields derived from the desire to minimize crop damage and avoid a catastrophe (not uncommon, starvation) caused by hail and flooding. A last example revolves around building a production system so that it can change easily from one input to another or from one product to another. Such a flexible system creates "real options" in the sense that the company can switch gears by responding efficiently and quickly to new market developments.

[102] Demand growth of gas use in electric generation, especially during critical periods, can cause operational problems for both regional power systems and gas pipelines. Many gas-fired plants operate year round, posing potential delivery problems during the winter months when traditional gas customers consume most of their natural gas. *See*, for example, Ken Costello, "Efforts to Harmonize Gas Pipeline Operations with the Demands of the Electricity Sector," *The Electricity Journal*, Vol.19, Issue 10 (December 2006): 7-26.

[103] *See*, for example, http://energypost.eu/german-conundrum-renewables-break-records-coal-refuses-go-away/; and http://blogs.ft.com/nick-butler/2015/05/24/the-burning-issue-of-german-coal/.

Europe, the coal industry also has substantial political clout and is an important source of employment in some countries.[104]

F. Natural gas as a hedge

The justification for bypassing the natural gas bridge and going straight to a complete renewable-energy world makes some dubious assumptions. Some analysts assume, for example, that renewable-energy costs will continue their dramatic decline, electric vehicles will become the norm, and a massive network of hydrogen storage facilities and fueling stations will emerge at affordable cost.[105] While those expectorations may materialize, they are far from certain.[106]

Natural gas can act as a hedge in the event that these projections turn out to be overly optimistic.[107] One scenario supporting this role for natural gas is if the different countries cannot agree on a climate policy. Under this scenario, natural gas would have a lesser impact on the climate than coal. In other words, using natural gas as a hedge, although making it more difficult to achieve the stringent target of 2^{o}C or less, can help to avoid a catastrophic change in temperature. As such, natural gas in the future can continue to act as a cost-effective substitute for old coal plants.

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[104] Europe also has natural-gas supply issues from depending on Russian gas, heightened by the continuing Russia-Ukraine crisis.

[105] *See supra* notes 88 and 89.

[106] EIA projections suggest that the unsubsidized levelized cost of electricity for wind and solar will continue to be above that for natural gas (conventional combined cycle), on average across the United States in 2018 and 2022. [U.S. Energy Information Administration, *Annual Energy Outlook 2016*, August 2016.]

[107] One study concluded that "it may be useful to think of a natural gas bridge as a potential hedging tool against the possibility that it will be more difficult to move away from coal than policymakers desire, rather than merely (or primarily) as a way to achieve particular desired temperature outcomes." [Supra note 60.]

V. Options Available to Policymakers

A rational public policy would search for the proper balance between the costs and the benefits of climate control. Specifically, maximizing societal welfare would equate the costs and the benefits, on the margin.

A. Different policy approaches to natural gas

1. Quick phase-out of natural gas

One option is to phase-out natural gas use as fast as practical. This means aborting the use of natural gas as well as other fossil fuels. As a practical matter, system operators will still have to rely on natural gas to maintain reliability and a smoothly-running electric grid as renewable energy becomes more dominant. A total ban on natural gas therefore seems beyond reach, at least during the transition before new technologies come along (e.g., advanced battery storage).

The critical question is: What are the economic and environmental effects of such a draconian action? Eliminating natural gas from the mix will prolong the use of highly-polluting coal but likely accelerate the use of renewable energy and maybe even nuclear power. The overall effect on carbon emissions becomes an empirical question. [108] In the short term, however, it would likely defer the retirement of coal plants, leading to higher carbon emissions.[109] The short-term economic effect would be more certain: Higher electricity costs and prices, and less reliable service.[110]

The "quick phase-out" policy is, in effect, an all-in bet on renewable energy that may be our best opportunity to achieve 450 ppm or a temperature limit around 2°C, but it is a risky bet from an economic and electric-system reliability perspective. A target of 550 ppm assumes a longer bridge for natural gas (with natural gas consumption peaking around 2050), but it poses a greater risk for climate-change catastrophe.

One lesson learned in Europe is that forcing the electric system to rely mostly on renewable energy requires keeping older fossil-fuel plants available as a standby in addition to covering peak demands. These plants may require subsidies to be financially viable. The result

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[108] Continuing to use natural gas for electricity generation would cut carbon emissions and other pollutants by shoving aside coal for electric power generation. But, as noted earlier, forces would tend to push in the other direction.

[109] As discussed elsewhere in this paper, a study by the Energy Modeling Forum involving 14 expert teams of energy modelers concluded that an abundance of shale gas would have little effect on U.S. carbon dioxide emissions over a 20-year time horizon. [*Supra* note 75.]

[110] The latter effect could come from the inability of renewable energy to use natural gas as a back-up.

is that system operators have to run carbon-intensive plants more to maintain system reliability. In Germany, these plants burn brown coal while in Great Britain the plants burn back-up diesel. These plants are high polluting and would otherwise be uneconomical.[111]

2. Bridging natural gas to the future

Many observers have emphasized the importance of reducing CO_2 emissions in the next decade to mitigate the odds of disruptive climate change. One policy question is: What role should natural gas play in achieving these reductions?

Under the "bridge" option, electric generators will continue to rely on natural gas until large-scale renewable energy becomes economical.[112] As a hedge, natural gas would serve as a backstop if policymakers decide to take little action on climate change or if clean-energy technologies fail to meet their expectations. Natural gas could then continue to displace coal and produce environmental benefits.

The presumption is that, in the long run, renewable energy, and perhaps even nuclear power would be both economical and environmentally essential for controlling climate change. Until the cost of these technologies further declines and the challenges of intermittency with solar and wind power are overcome, natural gas will continue to play an important function.[113]

3. Natural gas as a long-term solution

Reliance on natural gas as a long-term source of fuel in electricity generation may require CCS[114] or other technological breakthroughs that would make natural gas more environmentally benign. Natural gas can then be a "new permanent pathway" to the long-term future. It seems that, given the present state of technologies, if the country pursues a deep decarbonization policy, natural gas will have to be phased-out and fall outside the long-term mix in electricity generation.[115] On the other hand, if the country adopts a more relaxed policy on carbon dioxide,

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[111] *Supra* note 103; and Kiran Stacey, "UK Turns to Diesel to Meet Power Supply Crunch," *Financial Times*, November 3, 2015.

[112] One possible trajectory would be to virtually eliminate all natural gas use by 2050 while phasing-out natural gas during the interim.

[113] The Obama Administration aggressively embraced replacement of coal with natural gas as a key component for meeting its 2030 climate targets. [*See* The White House, "Climate Action Plan: Strategy to Reduce Methane Emissions," March 2014.]

[114] CCS can help prolong and increase natural gas use in a low-carbon future.

[115] Other countries (such as the United Kingdom) also projects the same scenario. *See*, for example, Christophe McGlade et al., "The Future Role of Natural Gas in the UK," UK Energy Research Centre, February 2016.

natural gas can have a long life as a major source of energy for electricity generation. As noted in one study:

> Without a carbon target enforced, natural gas generation…grows over the long-term, showing no indication of a natural gas bridge that eventually phases out over time. Applying a carbon target that forces the electricity system to reduce 2050 CO_2 emissions by 41.5% below 2005 levels results in little change in natural gas generation relative to the same scenarios with no carbon target imposed.
>
> This situation is not the same, however, when 2050 electricity system emissions are reduced by 83% below 2005 levels. In these low carbon target scenarios, 2050 natural gas generation is reduced relative to the scenarios with no carbon target, indicating that under a stringent CO_2 emission requirement, natural gas shows signs of acting as a bridge to a low-carbon future.[116]

4. Markets versus government

The mix of markets and government influences the future fate of natural gas. Government should intervene when market failure exists and its actions pass a cost-benefit test.[117] The last condition recognizes that governmental actions have their own inherent inefficiencies and other problems.

The notion that a thriving shale-gas industry will make climate policy unnecessary seems far-fetched. One prevailing thought is that the market by itself is unable to adequately deal with climate change. Nevertheless, contrary to what anti-fossil fuel advocates claim, natural gas can play a vital short-term role in reducing carbon emissions. Plentiful, low-priced natural gas can lower the cost of weaning the country off of coal, which accounts for about three-quarters of the carbon produced in U.S. electricity generation.

Examples of market failure justifying governmental intervention are inadequate R&D for clean-energy technologies, and the absence of carbon pricing and pricing for other negative externalities[118] caused by natural gas production and delivery. Producers of carbon do not

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[116] *Supra* note 43 at 28.

[117] In the present context, a market failure refers to characteristics of the market that prevent the socially optimal level of natural-gas consumption. They might stem from third-party environmental and public benefits not reflected in the price consumers pay for natural gas. A draconian action that bans the use of natural gas for electricity generation would have to be premised on large external costs from natural gas production, delivery or consumption. Even then, such action would be economically inferior to imposing a tax on carbon and other external costs from natural gas.

[118] A "negative externality" means that the natural gas or electricity sector ignores the social costs of an activity – for example, polluting the air. By controlling the activity through efficient governmental action, the societal benefit would be greater than the cost.

account for the public-health and environmental damages, thus leading to overproduction of carbon emissions. Innovation has public good characteristics that inevitably lead to its underinvestment by the private sector. .[119]

The form of government intervention affects the social desirability of its actions. Government can subsidize potentially desirable technologies, pick winners and losers, and tax undesirable technologies and actions.[120] One example is subsidies for clean-energy technologies. Another is mandatory controls on fossil-fuel use. A third is policies that restrict supply; for example, tight regulations on "fracking" and barriers to infrastructure expansion. A fourth is a carbon tax or cap-and-trade, which economists would argue is the preferred way to curtail GHG emissions and to promote clean-energy technologies.[121] Their argument is that a well-designed carbon tax could make moot the debate over whether public policy should restrict the production/consumption of natural gas and the building of new natural-gas infrastructure, as well as the treatment of stranded assets. It would also make academic the question of whether natural gas should be a bridge fuel, let alone what should be the length of the bridge. A carbon tax would provide proper price signals.

A *laissez faire* posture (e.g., the absence of a carbon tax) of relying principally on markets to reduce carbon emissions from fossil fuels will require two developments. One is that the marginal cost of fossil fuel will exceed the cost of clean-energy technologies. A second is improvements in energy-efficiency and carbon-free technologies. It seems that over the next decade and beyond, these developments will be inadequate to drastically reduce our dependence on fossil fuels. Continuing with current public policy on climate change along with expected market conditions (i.e., business-as-usual) will inevitably fall short of reducing GHG emissions enough to have a consequential effect on climate change.[122]

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[119] R&D represents investment in knowledge. This knowledge can turn into a new technology. New knowledge is therefore an enabler of new technologies and other innovations. Knowledge embodies a public good: If someone produces knowledge, others can benefit from it without paying for it (i.e., others are "free riders"). The person producing it will therefore be unable to collect the full value of the knowledge created. *See*, for example, Ken Costello, "A Primer on R&D in the Energy Utility Sector," NRRI Report 16-05, May 2016.

[120] If the U.S. government institutes a tax to curb carbon emissions, for example, we should expect to see more replacement of coal by natural gas in the near term. In addition, we should see more replacement of coal and natural gas by renewable energy, and likely additional energy conservation. In the long term, there will be less consumption of natural gas.

[121] Without substantial GHG policies, it is likely that the U.S. and the rest of the world will rely heavily on fossil fuels indefinitely. Over the next several years, renewable energy will unlikely play a primary role in base-load electric generation or as a replacement for petroleum-fueled transportation vehicles. [Thomas Covert et al., "Will We Ever Stop Using Fossil Fuels?" *Journal of Economic Perspectives*, Vol. 30, No. 1 (Winter 2016): 117-38.]

[122] Ibid.

B. Questions for evaluating the options

In reviewing possible future scenarios for natural gas, policymakers should start by asking the following questions:

1. As the primary policy question, what are benefits and costs of relying on natural gas as a bridge fuel to a zero-carbon future? That is, what role should natural gas play in the near-term U.S. energy mix?[123]

2. What is the effect of different natural gas scenarios on climate change? If natural gas consumption continues to grow rather than decline, what effect would that have on the peak temperature?[124]

3. If the U.S. takes actions to mitigate the chance of disruptive climate change, what are its options?[125] Options include carbon capture and storage,[126] and the drastic decline of future fossil-fuel consumption.[127]

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[123] Technological change in the electricity sector seems likely to have an increasingly negative effect on the natural gas industry. Cost reductions for renewable energy and advances in electricity (battery) storage have raised questions over both the future competitiveness of gas-fired power generation against wind and solar power, as well as the need for it to back up intermittent renewables.

[124] Of course, any quantitative analysis would have to project what energy sources would replace natural gas in a world where its consumption declines.

[125] There is disagreement over what factors would have the most effect on climate change. Three broad factors are government policy, technological developments, and general economic conditions. Some observers have questioned whether new government actions would have any material effect on CO_2 emissions, compared to emissions from business-as-usual; for example, some analysts contend that innovations have had more effect on reducing carbon (notably, hydraulic fracturing) than GHG-emission targets and timetables, and international agreements aimed at curtailing national emissions. [*See* Ted Nordhaus and Jessica Lovering, "Does Climate Policy Matter? Evaluating the Efficacy of Emissions Caps and Targets around the World," report by the Breakthrough Institute, November 28, 2016.]

[126] The economics of carbon capture and storage technology will have to improve dramatically before it allows fossil fuels to play a prominent role in a low-carbon future.

[127] Since we will have an abundance of fossil fuels for several decades, phasing them out will require deep reductions in demand.

VI. Final Remarks

The questions about natural gas are complex and require consideration of the overall effect of an action on society, instead of just what happens to climate change. For instance, as a public-policy matter, should we encourage more natural-gas use,[128] or should we consider phasing-out natural gas? Do we have to act now or can we wait? Policymakers should view natural gas in terms of its economics, environmental effects, and other factors (e.g., domestic source of energy) that affect societal welfare. Natural gas provides identifiable economic benefits but the environmental effects (from production to delivery, and end-use consumption) have come under attack and are subject to legitimate questioning.[129]

As predicted by one energy expert, Peter Fox-Penner, we will likely see declining use of natural gas during the second wave of decarbonization (2030 to 2060) when renewable energy will be more cost-competitive, storage will be more prevalent, and transportation will become electrified. Each of these will hasten the retirement of gas-fired generating plants.[130]

The future of natural gas depends critically on the government's established GHG target, technology developments, and the cost of clean energy. Even though there is uncertainty in the next few years over the creation of a federally-mandated target, some states will and some have already established their own targets. States like California may support phasing-out natural gas from the energy mix sooner than other states, as they strive to reach their GHG targets.

Presently, the most rational policy would support continued reliance on natural gas for electric generation for the next 10 to 15 years, and possibly even longer.[131] As long as production remains high and price is relatively low, natural gas should continue to displace coal for the next few decades. Whether natural gas has a bright or declining future beyond, say, 2030

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[128] One study suggests that we should encourage more natural-gas use. [IHS CERA, "Fueling the Future with Natural Gas: Bringing It Home," prepared for the American Gas Foundation, January 2014.]

[129] The shale gas revolution and increased flexibility of the electricity sector have facilitated the task of meeting short- and medium-term climate targets, while providing price stability for industry, businesses and households.

[130] *Supra* note 59.

[131] In addressing climate risks, the U.S. needs to expand its set of options to achieve lower economic and environmental costs, as well as a more secure electric power system. Besides energy efficiency and renewable energy, this means finding ways to reduce the emissions from fossil fuels, like switching from coal to natural gas, as well as carbon capture and storage. At the same time, the cost of these options needs to come down. This implies a close connection between energy security, climate change and innovation.

is uncertain.[132] It will depend on factors such as the cost of clean energy and GHG-emissions targets.

The U.S. should expand its set of energy options for dealing with the threat of climate change, not narrowing them by taking natural gas off the table. Not only are we uncertain about the economic and other effects of climate change, we also cannot assume that new technologies that seem promising today will turn out to be economically and socially desirable in the future.

R&D in the electric industry points to a path of low-carbon generation and more electrification of water and space heating, both of which could dramatically reduce the future demand for natural gas.[133] One view is that in order for natural gas to have a long-term future, the industry has to embark on a decarbonization strategy.

For electrification, where customers switch from natural gas and other fossil fuels to electricity for direct use, for example transportation, water and space heating, the costs seem high as of today and the environmental benefits dubious as long as fossil fuels continue to generate electricity. Electrification probably does not pose a major threat for the natural gas industry in the near future. Electrification is a hard sell as long as natural gas is cheap and electricity generation still requires fossil fuels. It will likely receive only a lukewarm reaction from policymakers. The correct response, from an economics perspective, is to assure that policies do not unduly favor one energy source over the other.

Although electrification may have little effect on natural gas over the next several years, it is a topic of increasing interest, as the U.S. electric power system moves toward zero-carbon technologies. At the point when decarbonization takes hold, the natural gas sector will have to rationalize why a world with zero-carbon electricity generation should not favor households and businesses switching from natural gas and other fossil fuels.

[132] The long-term role of natural gas depends on GHG or climate-change targets established by the government. The more stringent the targets, the shorter is the bridge for natural gas. The question becomes: To what extent can natural gas be compatible with U.S. climate-change targets?

[133] In February 2016, the Electric Power Research Institute (EPRI) announced what it calls an Integrated Energy Network (IEN) as a pathway to a more efficient, reliable and productive energy system. The announcement identified requisite key actions, technology development, policy, regulation and standards. One component is "efficient electrification...as a cornerstone for environmental improvement in addition to its potential to lower customers' costs, increase productivity, improve product quality and provide a cleaner, safer work environment. Since February, EPRI has made several presentations touting the IEN concept. [http://www2.epri.com/Press-Releases/Pages/EPRI-Introduces-the-Integrated-Energy-Network-at-NARUC-Meetings.aspx.]

In the interim, it will be ill-advised for the natural gas industry to underestimate the importance of R&D for making natural gas more carbon friendly.[134] A 2016 NRRI paper points out the concern of inadequate R&D funding in the natural gas industry:

> [T]he natural gas sector has encountered drastic cuts in R&D investments largely because of the combination of industry restructuring, loss of funding for collaborative industry R&D and the decline in government funding for R&D. These factors taken together have caused a sharp drop in R&D investments over the past two decades. The lost opportunities from the potentially high returns from R&D investments, ultimately, deprive benefits to utility customers and shareholders, the environment and society at large. One indicator of this concern is the small size of R&D expenditures (as a percentage of industry revenues) and the potentially high gains from well-defined, cost-effective R&D projects.[135]

For the natural gas industry to prosper in the long term, it is imperative that it proactively and continuously addresses environmental concerns, which to date has not always happened. The electric industry will promote electrification to bolster sales, just as at the beginning of this decade the natural gas industry attempted (unsuccessfully, by the way[136]) to have customers switch from electricity to natural gas for space and water heating, and other end-uses.[137]

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[134] R&D is essential for the long-term development of new technologies. A precursor to technological change is investments in R&D. The main purpose of R&D is to advance the current state of technology. Some new technologies, while ultimately deployed by utilities, would likely require government support during the formative stages of development (e.g., basic research). There is a widespread concern over the possibility of deficient basic research in the future because of the federal government's budgetary problems and the increasingly myopic mindset of both government and business decision-makers.

[135] *Supra* note 119, iv. Another study remarked that, relative to the role of natural gas in the energy sector, DOE, the lead government funder of energy R&D, has historically spent little on projects related to natural gas exploration, production, transportation and use. During 1978-2010, for example, total DOE research funding for natural gas was just over $1 billion, or about $31 million per year. From FY 2008 to FY 2012, DOE R&D funding for gas technologies fell sharply from $70 million to $10 million. Overall, DOE has given a low priority to natural gas R&D. [MIT Energy Initiative, *The Future of Natural Gas: An Interdisciplinary MIT Study*, June 6, 2011.]. A study by the American Gas Foundation came to the same conclusion. [American Gas Foundation, *Research and Development in Natural Gas Transmission and Distribution*, March 2007.]

[136] Few state commissions have a policy favoring electric-to-gas substitution. Possible reasons for this reluctance include: (a) commissions are disinclined to favor one fuel over another – they trust the market to produce efficient outcomes, which means that they tend to believe that any market problems are less-than-severe to warrant intervention; (b) the strong opposition of electric utilities; (c) the difficulties of measuring the benefits and costs of electric-to-gas substitution; (d) the benefits to consumers being less obvious than the benefits from promoting energy efficiency (Some commissions may place a high priority on utility energy-efficiency programs because they reduce the demand for fossil fuels; electric-to-gas substitution typically merely substitutes one fossil fuel, natural gas, for a group of what are largely fossil

To wit, while the abundance of competitively-priced natural gas points to a bright future, it is critical for the industry to spend more on R&D and take other actions that will make natural gas more environmentally and overall socially acceptable. Major technological breakthroughs are a requisite for including natural gas in the long-term energy mix, in addition to extending the "bridge" period for natural gas.

The natural gas sector cannot therefore just sit back on its heels, but needs to aggressively support R&D that will produce innovations that will assure its long-term prosperity or just even its existence.[138] Technology can work either for or against the future of natural gas. It is obvious that the natural gas industry would want it to work in its favor. Examples are technologies that will reduce methane leakage throughout the natural-gas system, the environmental damage from "fracking" on local communities, and carbon emissions from electric generating facilities. Natural gas could then have a longer life as a major fuel source serving electric generators, households and businesses.

As carbon-dioxide concentrations continue to accumulate, incremental changes are insufficient to aggressively mitigate climate change, at least in the minds of many. Their argument is that we need big, game-changing technologies that can be widely adopted and exported to the rest of the world. Many observers believe that clean energy will remain cost-inferior to conventional sources of energy unless major technological breakthroughs emerge. Even though we have witnessed promising new technologies that seem to have bright futures, their wide penetration in the marketplace will depend on further refinements to lower their costs and improve their performance. The U.S. and other countries will require further development of emerging technologies to advance the goals of climate-change policies, with some yet to come

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fuels in the production of electricity.); and (e) the difficulties in addressing the additional planning complexities and issues surrounding electric-to-gas substitution. Some of these reasons may have implications in the future for electric utilities trying to "sell" electrification to their regulators.

137 The natural gas sector cited four benefits from small electricity consumers switching to natural gas for direct applications such as space and water heating: (a) less primary energy consumption, mostly from eliminating the high energy losses in producing and transmitting electricity, (b) over time, the building of fewer new generating facilities, (c) reduced energy costs incurred by end-use consumers, and (d) reduced CO_2 emissions. *See* Ken Costello, "Electric-to-Gas Substitution: What Should Regulators Do?" NRRI Paper 09-07, May 2009.

138 The key variables affecting the long-term future of natural gas are: (a) energy and environmental policy, (b) technology and (c) economics (price of natural gas relative to the prices of other sources of energy, affected by policy measures such as carbon pricing). Unless the natural gas industry can capture and store its CO_2 emissions, then, according to some analysts, natural gas can only be a transitional (i.e., bridge) fuel, and even the length of that is unclear.

on the scene and others currently immature and still unable to be economically competitive without subsidies.[139] For these reasons, R&D has potentially large benefits.

Finally, policymakers must know the risks of their actions.[140] One risk is an overreliance on renewable energy when technological and economic problems still prevail and may continue for several years out. Policymakers should avoid placing renewable energy in a dominant role when it is not ready for prime time. Natural gas can buy time before zero-carbon technologies become more economical. If we prematurely eliminate natural gas from the energy mix, either coal would likely damage public health and contribute to climate change for a longer period, or high-cost renewable energy would lead to higher electricity bills and a less secure and reliable electric power system. Neither outcome would be good for society.

[139] New technologies in the electric industry include solar, wind and other renewable energy resources, storage, the smart grid and electric vehicles. Not all of these technologies are economical presently and will require further technical improvements or changing economic conditions, which may be several years down the road, before they are. Some enjoy large tax subsidies with uncertain futures. The benefit-cost performance of these technologies will also vary by locale. In certain places, some of these technologies will fail to pass muster, both politically and economically.

[140] Policymakers often apply Type I and II errors to evaluate the risks associated with a particular decision given that their projections of the future and other assumptions turned out to be wrong. A Type I error can result from policymakers limiting natural-gas usage when projections about clean-energy technologies turn out to be over-optimistic. A Type II error can result in society sticking with status-quo policies when actual future conditions would dictate a radical reduction in carbon and, accordingly, natural-gas usage in the shortest time possible. A trade-off exists between a Type I and a Type II error: Reducing one type of error compromises the other. For a general discussion of Type I and Type II errors, *see* William Mendenhall & James E. Reinmuth, *Statistics for Management and Economics* 323-33 (3d ed. 1978).

Appendix A: A Summary of Electrification

- **The definition of electrification (E)**: Customers switching from natural gas and other fossil fuels to electricity for direct use (e.g., transportation, water and space heating).[141]

- Proponents argue that E is the only way that we will achieve ambitious CO_2 emissions reduction goals.[142]

- Proponents also contend that E is one often overlooked as a potentially cost-effective way to achieve deep decarbonization.

- E will help the electric industry to revive its sales and become more financially viable.[143]

- Policymakers should reexamine whether reduced or stagnant electricity consumption is an optimal path to a low-carbon future; the conventional thinking is that the best path to a lower-carbon electricity sector is to reduce consumption.

- "Environmentally beneficial electrification" is the electrification of energy end-uses presently powered by fossil fuels (natural gas, propane, gasoline, diesel or fuel oil) that results in reduced GHG emissions.

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[141] E can also encompass diesel agricultural pumps, small internal combustion engines like lawnmowers and commercial blowers.

[142] According to one study,

> Full electrification of the heating and transport sectors, when coupled with 100 percent decarbonization of the electric sector by 2050, would reduce energy-sector related GHG emissions by 75 percent relative to the AEO BAU [Annual Energy Outlook Business-as-Usual] case and 72 percent relative to 2015 levels. This is close to the 80 percent decarbonization goal often cited as necessary to stabilize current global warming to 2 to 3˚C by 2050 and beyond. Modest reductions in other sectors not modeled here (around 30 percent) would allow for the U.S. to meet its 2050 GHG emissions targets in this scenario.
>
> [Jurgen Weiss et al., "Electrification: Emerging Opportunities for Utility Growth," Brattle Group White Paper, January 2017, 8.]

[143] One study reported that, "Our modeling of upper-bound growth (i.e., technical potential) in this scenario suggests that electricity sales could double from 2015 levels by 2050 if the heating and transportation sectors were to switch from their current fuel mix to 100-percent electricity." (Ibid., 1) The study also said this large increase in electricity demand could coexist with a decline in GHG emissions.

- E would affect two developments in the electricity sector: (1) the demand for electricity rises more over time as demand sectors switch from fossil fuels to electricity and (2) the electricity sector decarbonizes more quickly and completely.

- The focus should shift from "energy efficiency" to a new metric, "emissions efficiency."[144]

- Advocates of E contend that, because environmentally beneficial E is necessary to achieve GHG emissions-reduction goals, policymakers should find ways to encourage it.

- E is an important step to wean our economy from fossil fuels.

- Two components of E

  - Shifting energy consumption from fossil fuels to electricity

  - Ensuring that electricity generation comes from zero emission sources[145]

- Positive outcomes from E include reduced GHG emissions, better electric grid management and improved financial position of electric utilities, while electricity consumption would increase.

- Negative outcomes from E include financial harm to the natural gas and other fossil-fuel industries, high capital cost for switching customers, and for the foreseeable future higher economic costs in meeting the demands of energy customers.

- Zero-carbon residential building codes (which is being considered in some jurisdictions) require E assuming no fossil fuels in the generation of electricity (unless there is CCS).

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[144] Specifically, is it time to consider whether reduced electricity consumption (i.e., kWh) is the optimal path to a low-carbon future when, in fact, substitution of electricity for fossil fuels would increase electricity consumption? The argument is that policy goals are shifting from energy efficiency to achieving GHG reductions. Policymakers therefore need to refocus efforts to measuring GHG emissions, rather than simply the amount of kilowatt-hours consumed. Consequently, the concept of "emissions efficiency" should have as much importance as "energy efficiency" looking ahead. *See*, for example, Keith Dennis et al., "Environmentally Beneficial Electrification: The Dawn of 'Emissions Efficiency'," *The Electricity Journal*, Vol. 29, Issue 6 (July 2016): 52-8; and Keith Dennis, "Environmentally Beneficial Electrification: Electricity as the End-Use Option," *The Electricity Journal*, Vol. 28, Issue 9 (November 2015): 100-12.

[145] The idea that on-site fossil fuel combustion is environmentally preferred to on-site use of electricity, an argument advanced by the natural gas industry, will become less true in the future as electricity generation will increasingly come from zero- or low-carbon sources.

- A major rationale for E is that we are on carbon-emissions path far above what some would deem prudent to mitigate the risk of significant and potentially devastating climate change.

- Restrictions in CO_2 emissions will result from decreased burning of fossil fuels, especially as the electric grid becomes decarbonized.

- There is strong agreement among climate scientists that near full decarbonization of the energy sectors in advanced economies will be needed by mid-century (2050) to prevent long-term temperature increases beyond 2^oC.

- To a certain extent, both heating[146] and charging an electrical vehicle are dispatchable loads.[147] One can pre-heat or pre-cool buildings because all buildings are storage.

- **Economic issues:**

  - Is electrification cost-effective relative to other decarbonization approaches?

  - Significant capital costs would be required and, for residential space and water heating, energy costs would likely rise.

  - Arguably, converting from oil and propane to natural gas, rather than from natural gas to electricity, would be more cost-effective and economical.

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[146] *See* Ryan Hledik et al., "The Hidden Battery: Opportunities in Electric Water Heating," report by the Brattle Group, January 2016.

[147] Recent technological advancements have enabled a utility to control "grid interactive water heaters" over short time intervals and with near instantaneous response, allowing them to provide frequency regulation and other grid balancing services that have higher value on an electric grid with renewable energy. Water heaters can function as batteries, with charging during low-cost periods to produce savings to customers. [Ibid.]

Appendix B: Highlights of Michael Levi's Analysis[148]

1. Natural gas only makes sense as a bridge if we're willing to risk a "hefty dose" of global warming.

2. By contrast, if we want to avoid a 2°C rise in temperatures, much of the natural gas will likely have to stay in the ground.

3. Natural gas can play the important role of a hedge; that is, if the policymakers are reluctant to do anything about climate change, then natural gas is at least less damaging to the climate than coal is.[149]

4. Methane leakage from natural gas operations is unlikely to neutralize the climate benefits of substituting natural gas for coal in the transition to carbon-free technologies.

5. At a GHG target of 550 ppm (compared with a target of 450 ppm), natural gas can extend the transition period (i.e., the "bridge") for natural gas.

6. A target of 450 ppm would require (a) halting of new fossil-fuel infrastructure over the next several years and (b) a significant reduction in fossil-fuel consumption over the next few decades.

7. Shale gas is no panacea for climate control, but with the right "fracking" policies to protect communities and to harness it as part of a broader climate strategy, it can play a critical role in combating global warming.

8. For natural gas to a beneficial bridge fuel, it has to be a short bridge with natural gas consumption peaking by 2020 or 2030.

9. Without shale gas, (a) U.S. GHG emissions would be higher, (b) our climate policies would be weaker and (c) the odds of slashing future CO_2 emissions and meeting U.S. climate goals would greatly decline.

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[148] Michael Levi, "Climate Consequences of Natural Gas as a Bridge Fuel," *Climatic Change*, Vol. 118, Issue 3 (June 2013): 609-23; and Michael Levi, "A New Paper on Natural Gas as a Bridge Fuel," blog on the website of the Council on Foreign Relations, January 4, 2013 at http://blogs.cfr.org/sivaram/2013/01/04/a-mixed-verdict-on-natural-gas-as-a-bridge-fuel/.

[149] Even with a goal to keep CO_2 concentrations below 450 ppm, transitioning from coal to natural gas may be valuable as a hedge in the event of a delay in the ultimate transition to zero-carbon energy.

10. One policy recommendation is to more actively subsidize innovation in zero-carbon sources, including renewable energy, so that they can increasingly displace both natural gas and coal (in the absence of CCS), driving U.S. power plant emissions close to zero.

11. Between 2008 and 2012, the United States increased its electricity production from natural gas by enough to power more than 30 million typical homes; if that electricity had come from coal instead, U.S. carbon-dioxide emissions would have been much higher, canceling out more than a quarter of their decline.

12. Merely making natural gas more abundant may do little, if anything, to curb carbon dioxide emissions in the decades ahead.

    - On this point, analysts are in remarkable agreement.[150]
    - Between 2011 and 2013, for example, a group at Stanford University[151] brought together 14 expert teams of energy modelers to each independently simulate the impact of booming shale gas production on U.S. carbon dioxide emissions over the next 20 years.
    - Half found that more shale gas ultimately meant lower CO_2 emission, but the other half found higher emissions.
    - None of the teams concluded that shale gas would do much to U.S. emissions over that time unless new energy policies were put in place.

13. Increasing shale gas supplies do two simple things to cut CO_2 emissions:

    - It shoves aside coal for electric power generation.
    - It also (much more modestly) replaces some gasoline and diesel in cars and trucks.

14. But four forces push in the other direction:

    - Cheaper gas boosts economic growth, and a bigger economy means more emissions.
    - Low-priced gas gives a competitive edge to industries that are heavy energy users and big emitters.
    - It also hurts lower-carbon competitors, like renewable energy and nuclear power, just as it harms higher-carbon coal and oil.

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[150] The main body of this paper referenced studies reaching this conclusion.

[151] The group was the Energy Modeling Forum, whose major findings the main body of this paper enumerated. (*Supra* note 75)

- Cheaper natural gas also means that consumers will use more of it.

- Analysts consistently observe that the forces pushing in both directions mostly cancel each other out.

15. Recent studies have tended to overestimate the importance of methane emissions on climate change.

16. Some observers have overemphasized the potential value of natural gas as a bridge fuel for achieving stringent climate goals.

17. A relatively short-term horizon (e.g., 20 years) is inappropriate for discerning the impact of methane leaks on peak temperatures; it is the long-term impact of methane emissions – known to be much smaller than its short-term impact – that really influences peak temperatures.