Is Shale Gas Good for Climate Change?

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Abstract: Shale gas is a new energy resource that has shifted the dominant paradigm on U.S. hydrocarbon resources. Some have argued that shale gas will play an important role in reducing greenhouse gas emissions by displacing coal used for electricity, serving as a moderate-carbon "bridge fuel." Others have questioned whether methane emissions from shale gas extraction lead to higher greenhouse gas emissions overall. I argue that the main impact of shale gas on climate change is neither the reduced emissions from fuel substitution nor the greenhouse gas footprint of natural gas itself, but rather the competition between abundant, low-cost gas and low-carbon technologies, including renewables and carbon capture and storage. This might be remedied if the gas industry joins forces with environmental groups, providing a counterbalance to the coal lobby, and ultimately eliminating the conventional use of coal in the United States.

Over the last ten years, technological innovation has transformed U.S. energy resources. Geologists have long known that organic-rich shales contain large quantities of natural gas, but the technology was not available to recover this gas at a reasonable cost. With the development of cheaper, more efficient horizontal drilling methods combined with improvements in hydraulic fracturing ("fracking") techniques that greatly increase the permeability of the shale, vast reserves of natural gas are now available at relatively low cost. In just five years, shale gas has grown from 4 percent to more than 25 percent of the U.S. supply of natural gas. With the new shale gas reserves, the United States has decades of reserves of a critical energy resource for home heating, electricity generation, and a wide variety of industrial processes.

Environmental groups have had a mixed reaction to shale gas. National environmental organizations focused on climate change, as well as organizations concerned with air-quality issues, have cautiously embraced the new technologies in anticipation that greater availability of low-cost natural gas may displace coal in electricity generation, thereby reducing

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carbon dioxide emissions and substantially decreasing emission of other pollutants, particularly mercury and sulfur. Indeed, U.S. coal consumption fell 10 percent between 2007 and 2011, while natural gas production rose by 15 percent. On the other hand, many environmental groups have opposed the expansion of natural gas drilling, especially in places that historically have not seen extensive oil and gas activities. Some groups are concerned that the chemicals used in the fracking process will contaminate groundwater aquifers; others are concerned with natural gas leakage into aquifers and even residential houses; others are concerned with the overall footprint of natural gas extraction, including new roads, new pipelines, truck activity, and storage of toxic waste from produced water (a mixture of formation brines and chemicals from the fracking process).[1]

Is the natural gas boom good for climate change mitigation, independent of other environmental concerns? A common view, including that of a recent commission convened by U.S. Secretary of Energy Steven Chu, is that expanded natural gas activities are inherently good for climate change mitigation because natural gas has lower greenhouse gas emissions than coal, which gas will displace for use in electricity generation.[2] A dissenting view is that methane leakage from shale gas extraction leads to greenhouse gas emissions as bad or worse than those produced from coal,[3] although this view is fiercely debated. Considering the timescale of the carbon cycle and the climate system, both of these perspectives are wrong, but for similar reasons. Leakage of methane is not as important as some have argued because its short lifetime limits its impact on anthropogenic climate change, which has a characteristic timescale of roughly one hundred years. But because of this long timescale of climate change, short-term reductions in greenhouse gas emissions – gained from natural gas displacing coal in the U.S. electricity sector – have a relatively small effect on the progression of anthropogenic climate change relative to other impacts of the shale gas boom. The most important of these is how the availability of low-price natural gas affects investment in the research, development, and deployment of truly low-carbon technologies, including renewable energy and carbon sequestration.

The real benefit of shale gas to a responsible climate change policy is a political one, if the economic power of the new industry can break the stranglehold that the coal industry has had on the national discussion around climate policy. The answer to whether shale gas is good or bad for climate change mitigation depends on what policies are used to regulate it; some policy options that encourage natural gas production in the United States are part of a responsible climate policy, but only if they simultaneously encourage other low-carbon technologies as well as disrupt the political power of the coal industry.

Are greenhouse gas emissions from natural gas better than those from coal? The answer would seem obvious. Natural gas has roughly half the carbon content of the average coal per unit energy, thus producing half as much carbon dioxide when combusted for heat or electricity. Moreover, a combined-cycle natural gas plant that generates base-load electricity has a thermal efficiency of roughly 50 percent, which is higher than the newest ultra-super critical coal plants (40 to 45 percent) and much higher than the average coal plant (33 percent) in the United States. Thus, burning natural gas for electricity, when displacing an average U.S. coal plant, results in a reduction in carbon dioxide emissions of nearly a factor of three.

Cornell University scientists Robert Howarth, Renee Santoro, and Anthony Ingraffea question this calculation, focusing on the emissions of methane associated with natural gas production, distribution, and consumption.[4] In their analysis, shale gas production leaks methane at as much as twice the rate of conventional gas wells. Most of this extra leakage, they assert, comes during the well-completion phase, immediately after the fracking, when brine from the formation and water used in the fracking process come out of the well. They argue that this methane leakage, along with leakage during processing, transport, and distribution, results in shale gas having higher greenhouse gas emissions than coal due to the high warming potential of methane relative to carbon dioxide.

Even if one accepts the leakage rates proposed by Howarth and colleagues (and there is considerable uncertainty about their findings), there remains the question of the value of greenhouse gases other than carbon dioxide, particularly those like methane that have short atmospheric lifetimes. To compare the impact of different greenhouse gases, a physical metric called the Global Warming Potential (GWP) was adopted by the Intergovernmental Panel on Climate Change (IPCC) in its *First Assessment Report*.[5] The GWP of a greenhouse gas is defined as the time-integrated global mean radiative forcing of a pulse emission of 1 kg of the gas relative to 1 kg of carbon dioxide over a specified time period, commonly one hundred years. This metric has persisted for the past twenty years despite many economic and technical criticisms.[6] The IPCC established the one hundred–year timescale as a standard for comparison between greenhouse gases, but it is an arbitrary designation. If one chooses a longer timescale – for example, five hundred years – the GWP for methane would be 8 rather than 25. If one chooses a shorter timescale – for example, twenty years – the GWP for methane would be 70.

In the analysis by Howarth and his colleagues, natural gas and coal for electricity are compared for both one hundred–year and twenty-year timescales, but the standard GWP values are amplified by roughly 50 percent based on a model calculation[7] that includes the inhibitory effect of methane emissions on the formation of sulfate aerosols, which cool the climate. Using this calculation raises the twenty-year and one hundred–year GWP values to 33 and 105, respectively. This is a controversial adjustment; sulfate aerosols come primarily from sulfur dioxide emissions associated with coal combustion and are a major contributor to respiratory illness. One might expect sulfur emissions to decrease in the future, even if greenhouse gases do not, and so it is difficult to know how to measure the future impact of methane on emissions of sulfate aerosols. Moreover, the analysis does not use similar accounting to evaluate coal combustion; if one used an identical approach and included coal combustion's impact on sulfate aerosols (as was done for methane), the sulfur emissions associated with coal can substantially offset the warming effects of coal's carbon emissions.[8] Of course, this would be absurd: the longer-term consequences of coal combustion are disastrous. Thus, one can see how Howarth and colleagues reached their conclusion if they value a ton of methane at 105 times the value of a ton of carbon dioxide.

Putting aside the issue of the relationship between methane and sulfate aerosols, the major problem with the comparison between natural gas and coal by Howarth and colleagues is that the GWP does not provide a good indication of the warming caused by different greenhouse gases. Rather, it considers only the time integral of the radiative forcing. A series of studies propose a better metric for comparing different greenhouse gases, the Global Temperature Potential (GTP), defined similarly to the GWP but using the global average temperature response to a pulse emission in a climate model instead of the radiative forcing.[9] The disadvantage of a GTP is that it is model-dependent, although the importance of climate sensitivity of any individual climate model is relatively minor, as one is looking not at the absolute temperature response but the response of the model for one greenhouse gas relative to carbon dioxide. The specific values for GTPs from different climate models are systematically lower for short-lived gases like methane than what are found with GWPs. For example, the GTP for methane for one hundred years is approximately 7.[10] This figure is more than three times lower than the one hundred–year GWP value used by the European Union and the U.S. Environmental Protection Agency (EPA) to compare different greenhouse gases, and is fifteen times lower than the twenty-year GWP used by Howarth and colleagues. Thus, even if shale gas production results in large methane emissions, burning natural gas is still much better for the climate system than burning coal.

The preceding discussion has left unresolved the question of what timescale to adopt for a comparison between greenhouse gases. Howarth and colleagues defend the use of a twenty-year timescale because, they assert, we should care more about climate change over the next few decades. Some have also suggested that the rate of warming is important, especially in terms of the ability of ecological systems to adapt to climate change.[11] Similar arguments are made in a recent UN Environment Programme/World Meteorological Organization report on the climate mitigation value of reducing black carbon and methane through pollution abatement measures.[12] This debate raises a more general question about what timescale is best for evaluating climate mitigation efforts, such as a policy that promotes natural gas consumption relative to coal.

One thing is clear: twenty years is far too short a timescale over which to evaluate climate change policies. This simple fact poses enormous problems for the formulation of climate change policy, as making projections for even the next decade is difficult enough, to say nothing of projecting out over a century. And yet it is the century timescale (at least) that matters. An insightful study by climate scientist Myles Allen and his colleagues[13] showed that the peak warming in response to greenhouse gas emissions depends on cumulative greenhouse gas emissions over a period of roughly one hundred years; moreover, the climate response to any specific emissions scenario is surprisingly insensitive to the emissions pathway.[14] They concluded that climate policy should focus on limiting cumulative emissions rather than setting emissions-rate targets. This result has been replicated by several studies; all find that it is the cumulative emissions over a century, not the rate of emissions, that is most important for the climate response to greenhouse gas emissions.[15] This finding contradicts the argument that the rate of warming warrants attention to shorter timescales. Such assertions are often made without mention of any specific rates or scenarios. In reality, different emissions scenarios with different mixes of methane and carbon dioxide emissions, for example, result in very similar rates of warming over the century. Focusing on reducing methane emissions over the next two decades merely delays warming by a few years by the end of the century – a small benefit relative to efforts to reduce the cumulative emissions of greenhouse gases, which are dominated by carbon dioxide.

Dissecting this result to understand exactly which process is responsible for the one hundred–year timescale is complicated because there are so many different timescales at play. One important factor is the general shape of global emissions scenarios, whose timescale is set largely by the lifetime of new energy infrastructure and the rate of investment in new infrastructure at the global scale. Because carbon dioxide concentrations will continue to rise through much of the century, the impact of any short-term reduction in emissions is offset by future emissions, resulting in only a small delay in eventual warming. Another important timescale is the residence time of carbon dioxide in the atmosphere. Once carbon dioxide is emitted from the combustion of fossil fuel, it is transferred among atmospheric, terrestrial, oceanic, and sedimentary reservoirs by a wide variety of biogeochemical processes that convert carbon dioxide to organic carbon, dissolved bicarbonate ion, or calcium carbonate, and then back again. The rates of these processes determine how long carbon resides in each reservoir, and how long it will take to bring the elevated concentrations of carbon dioxide in the atmosphere back to pre-industrial levels. There are also longer timescales in the carbon cycle. Over the timescale of several thousand years, once ocean equilibration is complete and only 20 to 40 percent of cumulative emissions remain in the atmosphere, dissolution of carbonate rocks on land and on the ocean floor will further reduce the airborne fraction to 10 to 25 percent, over a range of several thousand years to ten thousand years. This remnant of anthropogenic carbon dioxide emissions will stay in the atmosphere for more than one hundred thousand years, slowly drawn down by silicate weathering that converts the carbon dioxide to calcium carbonate, as well as by slow burial of organic carbon on the ocean floor.[16] The size of this "tail" of anthropogenic carbon dioxide depends on the cumulative emissions of carbon dioxide, with higher cumulative emissions resulting in a higher fraction remaining in the atmosphere.

Understanding these long timescales of the carbon cycle shows us that climate change is likely to persist for centuries and millennia. Earth will continue to warm as long as humans continue to emit carbon dioxide from fossil fuel. The long-term goal of a responsible climate policy must be zero emissions – or at least very low emissions. A partial reduction in emissions – especially within just one country – only delays the extent of climate change as the carbon continues to accumulate in the ocean-atmosphere system.

If the climate system is relatively insensitive to shorter timescales of emissions changes, then any methane emissions associated with shale gas extraction are not as important as portrayed by Howarth and his colleagues. So if the shale gas boom in the United States results in lower greenhouse emissions overall because it displaces some use of coal for electricity generation, isn't that a good thing for climate change mitigation? Not necessarily. There are several ways that the shale gas boom's more harmful effects on climate mitigation may outweigh the climate benefit (that is, reduced coal use). For this analysis, I embrace the conclusion of Allen and his colleagues: that effective climate policy should focus on reducing cumulative emissions, not the rate of emissions at a certain point in time. This is not to say that setting targets for the rate of emissions in the near term is a bad idea. First, there will always be some basic connection between rates of emissions and cumulative emissions. Lowering the rate of greenhouse gas emissions is always good for climate change, as lower emissions rates will affect the cumulative emissions. Second, having short-term emissions targets forces our society to invest in the infrastructure and other changes required to reach a low-carbon economy, actions that would be less likely if there were only long-term targets. The problem is that emissions rates are a very imperfect metric for progress toward the long-term goal of near-zero emissions. Indeed, several possible impacts of the shale gas boom in the United States may lead to slightly lower greenhouse gas emissions in the short term, but may actually increase cumulative emissions by delaying the deployment of near-zero emission technologies in the long term.

The argument for the climate benefits of shale gas depends heavily on a comparison between natural gas and coal. But is a direct comparison with coal appropriate? There is no question that natural gas competes with coal in the electricity sector, but only 31 percent of natural gas in the United States is used for electricity generation, compared with 93 percent of coal consumption. Cheap and abundant natural gas may stimulate additional demand in the residential, commercial, or industrial sectors that would negate any displacement in coal combustion. A side effect might also be reduced investments in energy efficiency, for example, that could result in substantial reductions in emissions over the long term. If one designed an energy policy that encouraged shale gas production, with the anticipation that it would lead to lower greenhouse gas emissions by displacing coal, one might discover that emissions reductions in the electricity sector were offset by increased emissions in other sectors that also use natural gas. A quantitative analysis of this issue is difficult to perform because of many other macroeconomic factors that affect natural gas demand, but it is worthy of more attention.

Another serious concern is the impact of low-priced natural gas on the electricity sector for technologies beyond coal – specifically renewable technologies such as wind and solar – and for investment in R&D in renewable and low-carbon energy systems. If the goal is to minimize cumulative emissions and reach near-zero emissions as soon as possible, renewable energy technologies must play a much larger, perhaps even a dominant role in the world energy system. And to do so, the cost of these technologies must compete with fossil fuel systems. Driving down their price will likely come only through wider deployment and through development of new technologies. Both of these actions have been adversely affected by the shale gas boom in the United States, with natural gas prices currently hovering below $3 per thousand cubic feet. The negative impact of low gas prices on renewable energy is not significant if we measure climate progress by looking only at near-term emissions; renewable electricity makes up too small a fraction of the overall electricity sector. But if our goal is to minimize cumulative global emissions over the next century, the delayed investment in renewable technologies may set us back more than the climate benefits achieved from a marginal reduction in U.S. coal consumption. Low gas prices have similarly inhibited investment in nuclear power and carbon capture and storage, both of which are likely to be needed to achieve a near-zero carbon emissions society.[17] Of course, these technologies have faced challenges independent of the competition with low-priced natural gas for electricity generation.

There are enormous benefits in having cheap, abundant natural gas for the United States in terms of the competitiveness of U.S. industry and economic growth in general. But from the climate perspective, the negative impacts on innovation in low-carbon technologies appear to outweigh the benefits of a marginal reduction in emissions from reduced coal consumption.

Ironically, the natural gas industry and the renewable energy industry share a common goal: higher natural gas prices. If the shale gas boom's major negative impact on climate change mitigation is its negative effect on investment in renewable energy and low-carbon technology more generally, then a higher price for natural gas would remedy that situation. And with natural gas prices reaching lower and lower levels in the past two years, the profitability of shale gas has already become more marginal. Some companies are now targeting "wet" shale deposits, which contain a higher fraction of hydrocarbon liquids along with gas, to make the economics of drilling more favorable. A policy that raises the price of natural gas without encouraging increased use of coal would reap the benefits of natural gas, including reduced conventional air pollution; but it would also stimulate investment in renewable energy. This may be the key to reconciling the benefits of the shale gas boom with a responsible strategy for the mitigation of climate change.

Who would be the real winner over the next ten years if a significant price on carbon – for example, $30 per ton of carbon dioxide – were introduced? Renewable energy companies would benefit from a carbon price, although their market share is still quite small. The costs for wind and solar power have come down, but these costs do not include electricity storage or other strategies for dealing with intermittency, which is essential to address as the renewable capacity grows; this would still limit their scale in many places. Nuclear power will also be aided by a price on carbon, although the Energy Information Administration projects that only 9 GW of new nuclear power will be built by 2035 in the United States.[18] Oil is relatively unaffected by a price on carbon simply because oil is already so expensive per ton of carbon. Energy efficiency would be very attractive with a significant carbon price, particularly in states with large amounts of coal-generated electricity. But the major impact of a price on carbon in the United States would be an arbitrage of natural gas for coal in the electricity sector. Even with an increase in natural gas price because of the price on carbon, the natural gas industry would be the winner with regard to climate legislation because it would not be affected as much as the coal industry.

This argument is not based merely on economics. A major obstacle to comprehensive climate legislation in the United States, whether in the form of a carbon tax or a cap-and-trade regime, has been the staunch opposition of the coal lobby, a combination of coal companies and large utilities that own coal-fired power plants. This industrial alliance is notoriously powerful, particularly in the Senate because states with abundant coal resources or numerous coal power plants make up a disproportionate share of the United States relative to their population. Overcoming this political challenge and placing a significant price on carbon (or an equivalent policy that encourages renewables and discourages coal) would represent a major step toward a low-carbon economy, and would achieve many of the goals discussed above, including more deployment of and investment in renewables and carbon capture and storage.

If this analysis is correct, then perhaps there is a path forward on climate change that puts shale gas in a favorable light. Could the economic power of the natural gas industry be pitted against the political power of the coal industry to lobby for climate legislation that puts a price on carbon? Historically, the coal industry has been better organized than the natural gas industry, but natural gas has one important advantage: shale gas has resulted in substantial job growth in the United States, creating far more jobs than would come from an increase in coal production. Consider the case of Pennsylvania, where coal production exceeds gas production on an energy-equivalent basis, but employment by the gas industry now exceeds employment by the coal industry.

A price on carbon would be in the best interests of the natural gas industry; whatever market losses would come with the incentives for renewable and low-carbon technologies would be more than compensated by the decline in coal consumption and the rise in natural gas demand. With a price on carbon, we could see a slight drop in demand for natural gas in the residential, commercial, and industrial sectors, but the elimination of even half the coal from the electricity sector would increase natural gas demand by roughly 25 percent, thus driving up the price (and the profitability) of natural gas.

Building a coalition between the natural gas industry and the environmental community to support a comprehensive climate policy will not be easy. The oil and gas industries have long had a combative and distrustful relationship with the environmental movement. They understand that climate mitigation will ultimately mean an attack on all fossil fuels, not just coal, and so supporting climate legislation may prove folly over the long run, even if there are substantial economic benefits over the next two decades. But if the oil and gas industries will not use their financial and political power to support climate legislation directly, dual attacks on the coal industry by environmental groups and the natural gas industry will still provide substantial benefits in terms of progress toward a low-carbon world. The key is not just to displace some portion of current coal use in the United States, but rather to weaken severely the coal industry's political power by virtually eliminating conventional coal use in the United States. A first step could be for the oil and gas industries to support the new EPA regulations on sulfur and mercury, which would likely force the closure of many older coal plants that were effectively grandfathered under the Clean Air Act and its later amendments.

In the one hundred–year war to build a low-carbon world, it is not necessarily prudent to open up multiple fronts in early battles. By focusing current political efforts on attacking the coal industry and leaving the oil and gas industries out of the initial fight, a path toward a low-carbon economy in the United States can be constructed in a politically pragmatic manner. This does not mean giving the gas industry a free pass on irresponsible practices on drilling or waste disposal. By leveraging the financial self-interest of the natural gas industry to broaden political support for anti-coal policies, environmental groups can simultaneously use a grassroots campaign to pressure existing coal-fired power plants to shut down. The success of this strategy will determine whether shale gas is indeed good for climate change.[19]

ENDNOTES

1 For a good review of the environmental issues surrounding shale gas, see *The Future of Natural Gas: An Interdisciplinary MIT Study* (Cambridge, Mass.: Massachusetts Institute of Technology, 2011).

2 Secretary of Energy Advisory Board, "Shale Gas Production Subcommittee Second Ninety Day Report," November 18, 2011, http://www.shalegas.energy.gov/resources/111811_final_report.pdf.

3 Robert W. Howarth, Renee Santoro, and Anthony Ingraffea, "Methane and the Greenhouse-Gas Imprint of Natural Gas from Shale Formations," *Climatic Change* 106 (4) (2011).

4 Ibid.

5 Intergovernmental Panel on Climate Change, *First Assessment Report* (Geneva, Switzerland: UN Environment Programme and World Meteorological Organization, 1990).

6 For examples, see Keith P. Shine, "The Global Warming Potential – The Need for an Interdisciplinary Retrial," *Climatic Change* 96 (4) (2009): 467 – 472.

7 Drew T. Shindell, Greg Faluvegi, Dorothy M. Koch, Gavin A. Schmidt, Nadine Unger, and Susanne E. Bauer, "Improved Attribution of Climate Forcing to Emissions," *Science* 326 (5953) (October 30, 2009): 716 – 718.

8 Tom M.L. Wigley, "Coal to Gas: The Influence of Methane Leakage," *Climatic Change* 108 (2011): 601 – 608.

9 Keith P. Shine, Jan S. Fuglestvedt, Nicola Stuber, and Kinfe Hailemariam, "Alternatives to the Global Warming Potential for Comparing Climate Impacts of Emissions of Greenhouse Gases," *Climatic Change* 68 (3) (2005): 281 – 302; Jan S. Fuglestvedt, Keith P. Shine, Jolene Cook, Terje Berntsen, David Lee, Andrea Stenke, Ragnhild Bieltvedt Skeie, Guus Velders, and Ian Waitz, "Transport Impacts on Atmosphere and Climate: Metrics," *Atmospheric Environment* 44 (2010).

10 Andy Reisinger, Malte Meinshausen, Martin Manning, and Greg Bodeker, "Uncertainties of Global Warming Metrics: CO_2 and CH_4," *Geophysical Research Letters* 37 (14707) (2010).

11 Howarth et al., "Methane and the Greenhouse-Gas Imprint of Natural Gas from Shale Formations."

12 *Integrated Assessment of Black Carbon and Tropospheric Ozone* (Geneva, Switzerland: UN Environment Programme and World Meteorological Organization, February 2011).

13 Myles R. Allen, David J. Frame, Chris Huntingford, Chris D. Jones, Jason A. Lowe, Malte Meinshausen, and Nicolai Meinshausen, "Warming Caused by Cumulative Carbon Emissions towards the Trillionth Tonne," *Nature* 458 (7242) (2009): 1163 – 1166.

14 Ibid.

15 H. Damon Matthews, Nathan P. Gillett, Peter A. Stott, and Kirsten Zickfeld, "The Proportionality of Global Warming to Cumulative Carbon Emissions," *Nature* 459 (June 11, 2009): 829 – 832.

16 David Archer and Victor Brovkin, "The Millennial Atmospheric Lifetime of Anthropogenic CO_2," *Climatic Change* 90 (3) (2008): 283 – 297.

17 Daniel P. Schrag, "Making Carbon Capture and Storage Work," in *Acting in Time on Energy Policy*, ed. Kelly Sims Gallagher (Washington, D.C.: Brookings Institution Press, May 2009).

18 Energy Information Administration, *Annual Energy Outlook 2010* (Washington, D.C.: Department of Energy, April 2010).

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