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Energy Choices

By Robert B. Jackson

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Author

Robert B. Jackson is Douglas Provostial Professor and Chair of the Department of Earth System Science at Stanford University.

Contact

Department of Earth System Science
473 Via Ortega, Room 140
Stanford, CA 94305

https://jacksonlab.stanford.edu/

rob.jackson@stanford.edu

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Abstract

Energy fuels our lives, raising our standard of living and improving our health. This year, change is in the air. U.S. coal consumption declined by 15 percent in 2015 to levels not seen since the early 1980s and fell an additional 20 percent through May of 2016.[1] Natural gas should surpass coal in electricity generation for the first time this year as well.[2] Wind and solar will provide most of the newly installed electrical capacity in the United States and globally, just like in the past two years.[3]

There are economic and environmental reasons to support the transition from coal to renewables and natural gas that is already occurring. A recent study from Duke University estimated that the 49,000 jobs lost in the coal industry between 2008 and 2012 were outpaced by 175,000 jobs gained in the wind, solar and natural gas industries.[4] Coal is a carbon- and water-intensive fuel that generates air pollution, killing at least 10,000 Americans and a million or more people around the world each year. Reducing our reliance on coal will save lives, create jobs, cut water use and help the climate and the environment.

The greenhouse gas benefits of renewables compared with coal are clear, but the case for natural gas is more complicated. Burning natural gas generates only half the CO_2 emissions per unit of electricity that coal combustion does.[5] However, methane's potency as a greenhouse gas means that emissions and leakage from the natural gas infrastructure need to be less than approximately 3 percent of production to provide net climate benefits. Right now we are near to, or possibly above, that threshold nationally. We need to do better.

In this paper, I make four energy-related recommendations:

1. Allow coal use to continue to fall, cutting greenhouse gas emissions, saving water and reducing mercury, particulate and sulfur pollution that kill more than 10,000 Americans each year.
2. Reduce methane and hydrocarbon emissions from oil and natural gas infrastructure through best practices, new incentives and regulatory enforcement; natural gas currently provides little net climate benefit compared with coal – but it could.
3. Promote renewables, including wind and solar photovoltaics, that are carbon and water neutral and that generate no air pollution during use.
4. Charge federal agencies to collect more data and develop energy metrics that combine multiple environmental factors – including health, water quantity and quality, air pollution, and greenhouse gas emissions.

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[1] Energy Information Administration, *Monthly Energy Review*, August 2016.
[2] Ibid.
[3] REN21, *Renewables 2016 Global Status Report,* http://www.ren21.net/status-of-renewables/global-status-report/.
[4] D. Haerer and L. Pratson, "Employment Trends in the U.S. Electricity Sector, 2008–2012," *Energy Policy* 82 (2015): 85–98.
[5] Energy Information Administration, "How Much Carbon Dioxide Is Produced Per Kilowatthour When Generating Electricity with Fossil Fuels?," www.eia.gov/tools/faqs/faq.cfm?id=74&t=11.

Energy Choices

1. Allow coal use to continue to fall, cutting greenhouse gas emissions, saving water and reducing mercury, particulate and sulfur pollution that kill more than 10,000 Americans each year.

Coal has been the fuel of choice for electricity generation for decades. It is cheap, domestically abundant and energy-dense compared to the biomass energy it originally replaced.

Despite these benefits, domestic coal use is plummeting. According to the Energy Information Administration, coal consumption dropped by approximately 30 percent over the past decade.[6] Its use fell another 20 percent so far this year compared to 2015, and we are now at levels of consumption not seen since in the United States since the early 1980s.

Several factors are responsible for coal's decline, including cheap natural gas derived from hydraulic fracturing, the costs of environmental compliance, such as the recent mercury rules issued by the Environmental Protection Agency, and the build-out of renewables through Renewable Portfolio and Renewable Electricity Standards and other policy levers. Coal is the most carbon-intensive of fossil fuels, producing the highest greenhouse gas emissions per kilowatt-hour (kWh) of electricity generated.

Climate change is not the only reason to justify reducing coal use further. Air quality has been improving for decades in the United States, but poor air quality still kills hundreds of thousands of Americans and millions of people around the world each year. A recent MIT study concluded that 200,000 Americans died each year from particulate ($PM_{2.5}$) pollution associated with combustion sources; 52,000 of them were attributed to the power sector.[7] The Environmental Protection Agency's estimate for 2016 is lower, approximately 17,000 deaths from the electricity sector, in part reflecting stronger pollution controls put in place over the last decade.[8] This more conservative number is still higher than the annual murder rate in the United States. Coal-fired power plants are also responsible for about half of all U.S. emissions of mercury, a hazardous air pollutant, and sulfur dioxide, another "big-six" criteria pollutant that causes acid rain.[9] Phasing out coal-fired power pollution will save lives and improve the environment.

Another benefit to phasing out coal-fired power and some other sources will be to save water and improve water quality. Cooling water for power plants is responsible for half of all fresh surface withdrawals in the United States.[10] Coal-fired power plants are not the only water-intensive technologies. Nuclear plants consume about the same amount of water as coal plants do per kWh. In contrast, combined-cycle natural

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[6] Energy Information Administration, "Changing U.S. Energy Mix Reflects Growing Use of Natural Gas, Petroleum, and Renewables," July 21, 2016.
[7] F. Caiazzo et al., "Air Pollution and Early Deaths in the United States. Part I: Quantifying the Impact of Major Sectors in 2005," *Atmospheric Environment* 79 (2013): 198–208.
[8] N. Fann, et al., "The Recent and Future Health Burden of Air Pollution Apportioned Across U.S. Sectors," *Environmental Science and Technology* 47 (2013): 3580–3589.
[9] Environmental Protection Agency, "2011 National Emissions Inventory," www.epa.gov/mercury; https://www.epa.gov/so2-pollution.
[10] M. A. Maupin et al., "Estimated Use of Water in the United States in 2010," *U.S. Geological Survey Circular 1405*, (2014), http://dx.doi.org/10.3133/cir1405.

gas plants in closed-loop or once-through systems consume half or less the amount of water; renewable wind and solar PV consume no water at all.[11,12]

Water quality will improve further as coal's market share in the electricity sector continues to decline. The mercury, sulfur dioxide and other air pollutants released by coal (but not by nuclear, natural gas or renewables) end up in our rivers, lakes and streams and, for mercury, in the fish and other animals we eat. Left behind when the coal is burned, 130 million tons of fly ash stack up each year in the United States – a toxic mix of lead, arsenic and other elements and compounds.[13] After decades of coal use, billions of tons of coal ash sit unused at more than 500 plants across the United States. Some of this fly ash spills, leaks and contaminates our water by leaching into groundwater and streams and through spills, most notably at the Kingston site in 2008 that flushed more than a billion gallons of coal ash slurry across homes and into the Emory River in Tennessee.

Phasing out coal-fired power over time will have many environmental benefits, but we need to address some human costs. I have sampled the water of dozens, even hundreds, of homes in rural Appalachia. In some of these areas, the extraction of coal and other natural resources is one of the only ways for people to earn a living. Where the mines are closing, we need to invest more in training for families and communities. Three of the top four coal-producing companies in the United States – Peabody, Arch, and Alpha Natural – declared bankruptcy this year.

We also need to remember that the loss of coal-mining jobs is not the whole story. Duke University scientists recently estimated that the 49,000 jobs lost in the coal industry between 2008 and 2012 were offset by 95,000 new jobs in the natural gas industry and 80,000 in wind and solar.[14] The balance is a net gain of approximately 125,000 jobs. Coal-mining communities are hurting, but our country is benefitting economically and environmentally from the energy transition.

2. Reduce methane and hydrocarbon emissions from oil and natural gas infrastructure through best practices, new incentives and regulatory enforcement; natural gas currently provides little net climate benefit compared with coal – but it could.

Saving water and millions of lives globally each year are good reasons to continue transitioning from coal to natural gas and renewables. The potential greenhouse gas benefits are also clear for renewables such as wind and solar but less clear currently for natural gas compared with coal.

Natural gas combustion generates only half the CO_2 emissions per unit of electricity generated that coal combustion does.[15] The precise number depends on the quality of coal used and the types and ages of the power plants compared. Regardless, the benefit at the smokestack is reliable.

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[11] J. Macknick et al. "Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies: a Review of Existing Literature," *Environmental Research Letters* 7 (2012): 4.
[12] R. B. Jackson et al., "The Environmental Costs and Benefits of Fracking," *Annual Review of Environment and Resources* 39 (2014): 327–362.
[13] C. L. Carlson and D. C. Adriano, "Environmental Impacts of Coal Combustion Residues," *Journal of Environmental Quality 22* (1993):227–247.
[14] Haerer and Pratson, "Employment Trends."
[15] Energy Information Administration, "How Much Carbon Dioxide?"

What is less clear is the extent to which natural gas emissions (planned) and leakage (unplanned) offset all or part of the combustion benefit. Methane is far more potent as a greenhouse gas than carbon dioxide. Compared to CO_2, the global warming potential of methane is 86 times greater for a 20-year window and 34 times greater over a century.[16]

A new natural gas power plant is estimated to be better than a new coal plant if natural gas emissions are less than 3.2 percent of total natural gas production (a figure that includes methane released during coal mining).[17] Emissions include everything upstream from the wellpad through pipeline delivery downstream to the power plant (or to homeowners, when discussing heating and appliances).

How do recent field data compare to the break-even point of approximately 3 percent methane emissions? Recent studies upstream show large differences between fields that produce natural gas only (dry gas) and those also producing heavier condensates and oil (wet gas). Upstream emissions in dry-gas fields tend to be well below 3 percent, typically 1 to 2 percent.[18] (We also need to add another approximately 0.5 to 1 percent for transmission, storage and, where relevant, distribution.) In wet-gas regions, though, upstream emissions are typically twice as high or higher: 4 percent or more of natural gas production and as high as 10 percent.[19] Weighting estimates based on overall production and adding approximate values for transmission and storage suggests a total countrywide emission of at least 2.5 to 3.5 percent.

Right now, then, the evidence suggests natural gas is providing few climate benefits compared to the coal it is displacing. There could be considerable climate benefits, though, if we reduce methane emissions through improved best practices, government incentives and, in places, stronger regulations.

If emissions were only 1 percent of total production, a target of the ONE Future program initiated by industry,[20] then the greenhouse gas savings compared to coal would be approximately one-third. If methane emissions were eliminated completely, an unrealistic goal because of cost, the savings would be approximately 50 percent fewer emissions compared to coal and equivalent to the smokestack benefit for combustion alone. Short of carbon capture and storage technologies, we cannot change the combustion factors for CO_2 substantially for either coal or natural gas.

In considering how to reduce emissions, one of the biggest opportunities is in oil-producing regions. In fields such as the Bakken, Uintah, Eagle Ford, and Permian Basin, where the economic returns value oil and condensates (i.e., butane and heavier), operators apparently are not being as careful in controlling for methane emissions. The evidence is not just in the basin-wide results discussed earlier. My colleagues and I recently completed a helicopter study using infrared cameras to video 8,200 random wellpads across the

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[16] IPCC Fifth Assessment Report, 2014.
[17] R. Alvarez et al., "Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure," *Proceedings of the National Academy of Sciences USA* 109 (2012): 6435–6440.
[18] A. Karion et al., "Aircraft-Based Estimate of Total Methane Emissions from the Barnett Shale Region," *Environmental Science and Technology* 49 (2015): 8124–8131.
[19] J. Peischl et al., "Quantifying Atmospheric Methane Emissions from Oil and Natural Gas Production in the Bakken Shale Region of North Dakota," *Journal of Geophysical Research Atmospheres* (2016), doi: 10.1002/2015JD024631; A. Karion et al., "Methane Emissions Estimate from Airborne Measurements over a Western United States Natural Gas Field," *Geophysical Research Letters* (2015), doi: 10.1002/grl.50811.
[20] ONE Future, "EPA Finalizes ONE Future Program," August 4, 2016, http://www.onefuture.us/epa-finalizes-one-future-program/.

United States. Large emissions were far more common – as much as 10 times so – in oil-producing regions such as the Bakken and Uintah basins than in dry-gas regions.[21]

Even within the same basin, this result held true. In the Barnett of north-central Texas, one out of every five wellpads in oil-producing areas had emissions visible from the helicopter; less than one in a hundred wellpads producing natural gas had visible emissions. Differences within the same basin cannot be explained by different policies and regulations. Perhaps companies in oil-producing areas do not value cheaper natural gas, particularly if they are flaring it. Alternatively, there are more tanks, valves and infrastructure in wet-gas areas that can leak. Ninety percent of the emissions we filmed from helicopters were from tank vents and hatches.

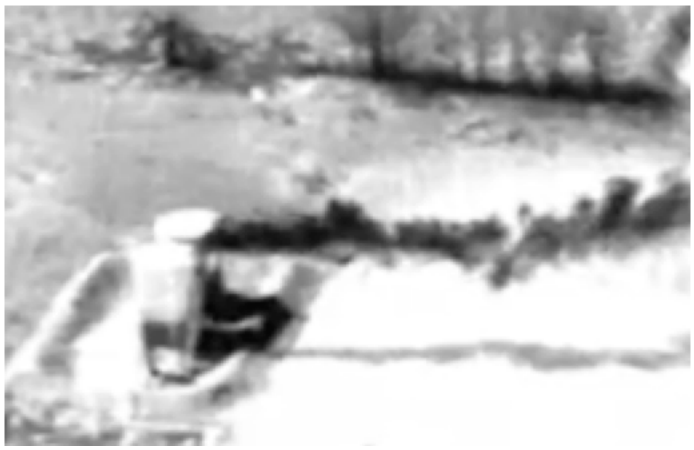

Figure 1. Infrared image showing natural gas emissions from a pair of tanks in the Barnett in Texas. From Lyon et al.[22]

There are key opportunities to reduce emissions and leaks from natural gas infrastructure downstream as well. My group and colleagues produced the first public, citywide maps of pipeline leaks across cities such as Boston[23], Washington, D.C.,[24] and Manhattan.[25] In cities with older infrastructure, we typically found about four leaks per mile using methane-detecting lasers as we drove every city block. In Boston, rooftop measurements over the course of a year showed that natural gas infrastructure accounted for 60 to 100 percent of the methane in the city's air, depending on the season; the average loss rate was 2.7 percent – two and a half times higher than the Massachusetts inventory suggested it should be.[26]

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[21] D. Lyon et al., "Aerial Surveys of Elevated Hydrocarbon Emissions from Oil and Gas Production Sites," *Environmental Science and Technology* 50 (2016): 4877–4886.

[22] Ibid.

[23] N. Phillips et al. "Mapping Urban Pipeline Leaks: Methane Leaks Across Boston," *Environmental Pollution* 173 (2013):1–4.

[24] R. B. Jackson et al., "Natural Gas Pipeline Leaks across Washington, D.C.," *Environmental Science and Technology* 48 (2014): 2051–2058.

[25] M. E. Gallagher et al., "Natural Gas Pipeline Replacement Programs Reduce Methane Leaks and Improve Consumer Safety," *Environmental Science and Technology Letters* 2 (2015): 286–291.

[26] K. McKain et al., "Methane Emissions from Natural Gas Infrastructure and Use in the Urban Region of Boston, Massachusetts," *Proceedings of the National Academy of Sciences USA* 112 (2015): 1941–1946.

The greatest opportunity for reducing methane emissions in downstream pipelines is in older U.S. cities in the Northeast and Midwest. Partnerships among companies, states, and public utility commissions to accelerate pipeline replacements have already succeeded. Our methane mapping showed that cities such as Cincinnati, Ohio, and Durham, North Carolina, that replaced all their century-old cast-iron and unprotected steel pipes had 90 to 95 percent fewer leaks per mile[27] than cities like Manhattan, Washington, D.C., and Boston, where progress was slower. Based in part on our work, Massachusetts passed an accelerated pipeline replacement program in the summer of 2014. The program, which is estimated to cost a household about $1 a month, will reduce leaks and greenhouse gas emissions and make the system safer from the risks of fire and explosion.

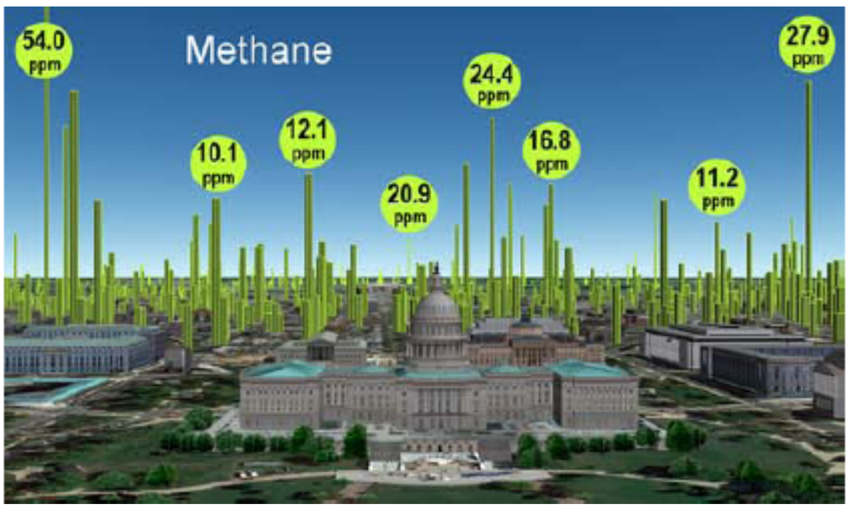

Figure 2. Natural gas leaks around Capitol Hill in Washington, D.C. From Jackson et al.[28]

These examples illustrate how much progress companies have made, and need to keep making, to reduce methane emissions. New aircraft- and satellite-based technologies already being deployed will help identify the super-emitters that generate most of the emissions.[29] If we work hard at this – through improved best practices, government incentives and, in some cases, stronger regulations – we can reduce the climate footprint of natural gas and strengthen natural gas safety.[30] Doing so will maximize its benefits compared to coal and minimize its shortcomings compared to renewables.

3. Promote renewables, including wind and solar photovoltaics, that are carbon and water neutral and that generate no air pollution during use.

Along with the rise of natural gas, a second energy transformation is occurring in the United States and globally – explosive growth in low-cost renewables. The United States is now the global leader in wind

[27] Gallagher, "Natural Gas Pipeline Replacement Programs."
[28] Jackson, "Natural Gas Pipeline Leaks."
[29] C. Frankenberg et al., "Airborne Methane Remote Measurements Reveal Heavy-Tail Flux Distribution in Four Corners Region," *Proceedings of the National Academy of Sciences USA* 113 (2016): 9734–9739.
[30] A. R. Brandt et al., "Methane Leaks from North American Natural Gas Systems," *Science* 343 (2014): 733–735.

power, having generated a record 191 million kWh in 2015.[31] Net U.S. electricity generation from wind doubled from 2010 to 2015 and has jumped 30-fold since 2000. Solar power has grown even faster. Net U.S. solar generation jumped 20-fold from 2010 to 2015 to 26 million kWh.[32] Solar is projected to add more new capacity this year in the United States than any other source.[33]

Renewables are being selected for many reasons, including their falling coasts, clean-power credentials and policy incentives. According to Lawrence Berkeley National Laboratory, the price of utility-scale solar dropped by more than half from 2009 to 2014.[34] Wind and solar PV not only generate zero greenhouse gas emissions during use, they also generate zero air pollution, including particulates, mercury and sulfur dioxide. As mentioned above, air pollution from the power sector kills at least 17,000 people each year.[35] The value could be zero with a renewable-based portfolio.

Some renewables, such as wind, have the added benefit of requiring no water for their operation as well.[36] Cooling water for thermoelectric power is responsible for half of all fresh surface-water withdrawals across the United States, followed closely by agriculture.[37] In contrast to wind and solar PV, which use no water, pulverized coal power plants typically use at least 1,500 liters of water per MWh of electricity generation; natural gas combined-cycle plants use less than half as much, approximately 500 to 800 liters.[38]

We can save a lot of water by deploying renewables, but not all renewables are the same. Despite its low-carbon status, nuclear power (a renewable in some portfolios) requires as much or more cooling water as a typical once-through or closed-loop coal plant. Nuclear is low carbon and low air pollution, but it is a water-intensive technology. Utility-scale concentrated solar is also water intensive, at least currently – as much or more so than coal and nuclear – because of the water needed to cool the reflective lenses and mirrors and to run the steam turbines. Research is needed to reduce the water requirements for all these technologies and to reduce the economic costs of dry cooling that would benefit many types of power plants.

In summary, wind and solar PV emit zero carbon emissions and air pollution and require no cooling water for operations. No other sources of energy can make this claim. For those reasons, and for their rapidly falling costs, we should continue promoting their use through policy vehicles, including renewable portfolio standards, renewable electricity standards and more.

4. Charge federal agencies to collect more data and develop energy metrics that combine multiple environmental factors – including health, water quantity and quality, air pollution, and greenhouse gas emissions.

Linking energy sources to multiple goods and services, including greenhouse gas emissions, health, and water benefits, will inform the energy choices we make. The final recommendation of this paper is to

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[31] Energy Information Administration, *Monthly Energy Review*.
[32] Ibid.
[33] Energy Information Administration, *Today in Energy,* March 1, 2016, http://www.eia.gov/todayinenergy/detail.cfm?id=25172.
[34] Lawrence Berkeley National Laboratory, "Utility-Scale Solar 2014" (2015).
[35] Fann, "The Recent and Future Health Burden of Air Pollution."
[36] Jackson, "Environmental Costs"; Macknick, "Operational Water Consumption."
[37] Maupin, "Estimated Use of Water."
[38] Jackson, " Environmental Costs."

gather more environmental data and to create new quantitative metrics that combine multiple goods and services, using those new metrics to compare energy technologies.

Multiple federal agencies and institutions contribute to this effort, as do researchers in the private sector, universities and nongovernmental organizations. The U.S. Geological Survey[39] and Department of Energy both carry out extensive research on water quantity and quality metrics for the extraction of fuels and the generation of electricity. Many gaps remain, however; the scarce water-use data collected from many nuclear and geothermal plants[40] is one example. The Environmental Protection Agency is responsible for data and metrics associated with air pollution. The National Institutes of Health is an obvious partner for incorporating human health-related aspects of energy generation and use. Collecting more data and making the data publicly available will provide benchmarks for the future and incentives for improvements and greater efficiencies.

The point of using and developing integrated metrics is to provide a framework for comparing different energy sources and accompanying tradeoffs. Coal is abundant and cheap in the United States, but it is water- and greenhouse-gas-intensive to use, and the pollution it generates kills people. Natural gas is better than coal for water and air pollution and, potentially, for greenhouse gas emissions, if we can reduce methane emissions and leakage further. Nuclear is an expensive option that provides a low-carbon, low-air-pollution source of energy but one that is water intensive. Only a subset of renewables provides benefits for climate, air pollution, water and human health. We should acknowledge these differences and incorporate them directly into our energy choices.

[39] Maupin, "Estimated Use of Water."
[40] T. H. Diehl et al., *Methods for Estimating Water Consumption for Thermoelectric Power Plants in the United States,* U.S. Geological Survey Scientific Investigations Report 2013, 5188.