Comparing Life Cycle Greenhouse Gas Emissions from Natural Gas and Coal

March 14, 2011

Mark Fulton
Managing Director
Global Head of Climate Change Investment Research

Nils Mellquist
Vice President
Senior Research Analyst

Written in collaboration with:

WORLDWATCH INSTITUTE

Saya Kitasei
Sustainable Energy Fellow
Worldwatch Institute

Overview

— Backdrop: In late 2010, DBCCA and Worldwatch separately published analysis concluding that natural gas and renewable energy can play complementary roles in lowering greenhouse gas (GHG) emissions from the United States' electricity sector by displacing coal-fired generation.[1] Both groups also analyzed the environmental risks associated with the development of natural gas, especially from shale, and concluded that while well-designed and strongly enforced regulations and industry best practices can minimize these risks, such regulations and practices were not yet in place at all operations in all states.[2]

— Recent developments: Recent questions about the environmental risks posed by the production of natural gas have focused on two issues that must both be factually and responsibly addressed: 1) the adequacy of current technology and regulation to ensure the safe disposal of waste water produced during the extraction of natural gas, particularly from wells that have been completed using horizontal fracturing in areas lacking Class II deep water injection disposal wells, and 2) the comparison of GHGs emitted during the life-cycles of natural gas and coal. Since we published our research last year, greater public attention has focused on concerns over disposal of wastewater associated with natural gas production, which we discuss at the end of this note.[3] This note and our current research, however, focus on the life-cycle GHG comparison of natural gas and coal.

— Emissions: The U.S. Environmental Protection Agency (EPA) has recently released documents with upwardly revised greenhouse gas emissions factors from natural gas production, prompting several researchers and journalists to question the greenhouse gas advantages of natural gas over coal on a life-cycle basis. Consequently, we have embarked on a deep dive analysis of the EPA revisions and are doing our own life-cycle GHG comparison between coal and gas which we will publish over the course of the next few months. For its part, the EPA maintains that "available data demonstrate that switching from another fossil fuel to natural gas reduces emissions of carbon pollution and other harmful pollutants that threaten Americans' health".[4]

— New emission factors: Nevertheless, EPA's updated emissions estimates from natural gas systems have raised questions surrounding life-cycle GHG emissions throughout the natural gas life-cycle. Much of the difference in the EPA's new GHG estimates comes from methane emissions in the field production stage of gas extraction. Methane (CH_4), the main component of natural gas, has a much shorter atmospheric life than CO_2 (~12 years compared to 50-200 years for CO_2), but is ~25 times more potent in trapping heat on a 100-year basis.[5] The estimates of total methane emitted by U.S. natural gas systems have

[1] *Saya Kitasei, Powering the Low Carbon Economy: The Once and Future Roles of Renewable Energy and Natural Gas (Worldwatch Institute: December 2010); Mark Fulton and Nils Mellquist, Natural Gas and Renewables: A Secure Low Carbon Future Energy Plan for the United States (Deutsche Bank Climate Change Advisors: November 2010)*
[2] *Mark Zoback, Saya Kitasei and Bradford Copithorne, Addressing the Environmental Risks from Shale Gas Development (Worldwatch: July 2010)*
[3] *http://www.nytimes.com/2011/02/27/us/27gas.html?_r=1&scp=4&sq=natural%20gas&st=cse*
[4] *EPA response posted by Energy in Depth, "Propublica's Fuzzy Math," available at http://www.energyindepth.org/2011/01/propublica%E2%80%99s-fuzzy-math/, viewed 13 February 2011*
[5] *IPCC: Changes in Atmospheric Constituents and in Radiative Forcing. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf, p. 141*

roughly doubled in the EPA's new study – a change that preliminary calculations suggest increases life-cycle GHG emissions from natural gas combined- cycle plants by around 10% using a 100-year time span, the convention most commonly used by EPA and the Intergovernmental Panel on Climate Change (IPCC). These groups are also discussing alternative metrics such as a 20-year global warming potential (GWP), where the IPCC estimates methane's climate forcing effect to be about 72 times that of CO2.

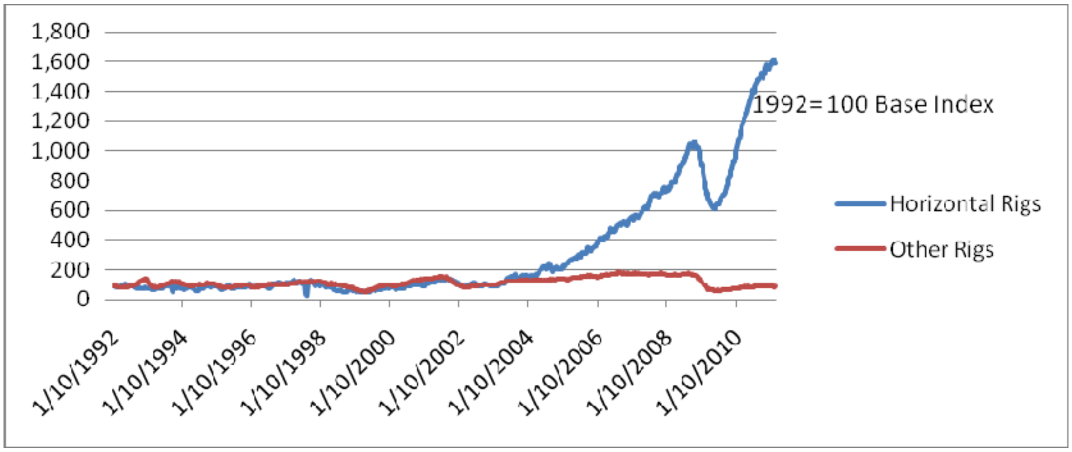
— Given the potential implications of life-cycle GHG emissions comparisons for a U.S. energy transition from coal to natural gas and the fact that many of the metrics and assumptions used today are from older studies, more research and analysis is needed on the life-cycle GHG intensity of both fuels so that clean energy policies are properly calibrated to incentivize investment decisions given the rapidly evolving role of shale gas.

— Next Steps: Over the next several months, Worldwatch Institute and DB Climate Change Advisors (DBCCA) plan to address these questions, conducting our own transparent assessment of available data and life-cycle analyses with the help of best-in-class experts, the results of which we will make publically available. Given the state of current data and information available on this subject and the rapidly evolving industrial and regulatory landscape, analysts, investors, policy-makers, and other stakeholders should recognize that the **complex systems issues and uncertainties in comparing emissions of natural gas to coal need to be tied to current market realities and behavior.** In the next 12-18 months, natural gas life-cycle emission analysis and the environmental footprint issues will be subject to greater scrutiny by a variety of stakeholders—which is appropriate—and better data should lead to more informed decisions and interpretations of the relative environmental merits of gas and coal generation from human health, water quality and climate change lenses.

Introduction

Natural gas is widely described as a "cleaner" fuel than coal because it emits less smog and acid rain-forming pollutants, air toxins, and greenhouse gases when it is burned. We are not aware of any controversy surrounding the lower greenhouse gas emissions of natural gas over coal at the point of combustion. However, in recent months, some have begun to question natural gas's greenhouse gas advantages versus coal on a life-cycle analysis (LCA) basis. In particular, much attention has been devoted to gas extracted from shale, the most rapidly growing source of marginal supply in North America. Shale gas has already dramatically increased the share of wells using horizontal drilling. (See Exhibit 1.) This is relevant from a climate change perspective because 1) unconventional wells using horizontal drilling and hydraulic fracturing produce less gas than traditional gas wells but have greater odds of success, hence many more will be drilled but at fewer sites and 2) the specific GHG profile of each horizontal well may be significantly different from conventional vertical wells. Although natural gas produced from shale resources represents about 15% of total U.S. gas production today, by 2035 the Energy Information Agency (EIA) projects that shale will account for 45% of total production.[6]

Exhibit 1: Horizontal Drilling Activity Has Increased Rapidly Since 2008



Source: Bloomberg, Baker Hughes Rig Count Data, DBCCA

[6] *EIA Annual Energy Outlook 2011, Early Release*

Because the production of shale gas will increase the share of wells in the United States that are horizontally drilled and hydraulically fractured, some have questioned whether emissions factors adequately account for the use of these technologies. Questions have been raised about the accuracy of emissions factors, especially of fugitive methane, used by the EPA to calculate the amount of GHGs released during the extraction, processing, and transportation of natural gas and coal, with critics divided as to whether the EPA's emission factors are too high or too low. We believe that an up-to-date, thorough, robust life-cycle greenhouse gas analysis of electricity from natural gas and coal is urgently needed as a benchmark for informed decision making. Such analysis is critical to quantifying the potential natural gas emissions reductions that can be achieved in the U.S. power sector by switching from coal to gas more rigorously than has previously been possible.

Background on DBCCA and Worldwatch's Natural Gas View

From a climate change perspective, the current global energy mix is not sustainable and must be oriented toward lower carbon emitting sources of energy. In the final months of 2010, the Worldwatch Institute and DBCCA each released reports and detailed analysis concluding that based on current industry fundamentals natural gas and renewable energy can play complementary roles in lowering greenhouse gas (GHG) emissions from the United States' electricity sector by displacing coal-fired generation.[7] Our conclusions hinge on four key factors.

1. Competitive Economics: Since 2009, natural gas has become a more competitive fuel to coal, which has been the dominant source of electricity generation in the U.S. for more than 100 years. The choice of which type of power plant to dispatch is based on gross margin, defined as power price less fuel cost. The decision of whether to make electricity from a coal or a gas plant in large measure rests on the difference in the cost of generation, or fully loaded gas to coal spread. This spread consists of fixed and variable costs, including the cost to deliver and store gas and coal to the power plant by pipeline or rail, and is adjusted by the relative efficiency of the plant. There are two factors at play in the relationship between coal and gas prices and their impact on electricity production: 1) Relative spot and contracted fuel prices for immediate dispatch decisions and 2) long term relative fuel price expectations that impact asset, fuel procurement and hedging strategies and decisions. Over the past two years, **the biggest story in energy in North America has been the technological and productivity revolution of shale gas extraction,** which has brought heretofore stranded gas to market quickly and cheaply while introducing much greater pricing stability to gas prices. Simply put: shale gas has the potential to be a game changer in the U.S. power sector if it can be produced in an environmentally sustainable manner.
2. Superior Flexibility: The future power grid will be characterized by larger penetrations of intermittent renewable power, which will necessitate a fundamental change in the architecture and operation of the electricity system. The ramping flexibility of natural gas generation technologies can facilitate higher penetrations of variable renewable energy sources such as wind and solar power with lower emission profiles than will can inflexible baseload coal power plants. Based on in-depth analysis, DBCCA expects that coal's share of power generation will decrease from about 45 percent of U.S. electricity supply today to 22% by 2030.[8]
3. Abundant Supply: Vast domestic supplies of natural gas in unconventional reservoirs, especially shale, mean that the United States has sufficient secure supplies of natural gas to displace coal in a substantial share of the U.S. power market. There appears to be a 20-year supply below a marginal breakeven price of $6/mmBtu assuming an average of 25 Tcf of annual demand, and an additional 20-year supply at a price of $8-9/mmBtu assuming an average of 28 Tcf per year of demand, which DBCCA anticipates based on increased demand from the power generation sector.[9]
4. Lower Emissions (Current Assumptions): Natural gas generation has a superior environmental footprint compared to coal generation, and will be advantaged by tougher EPA regulation of not only criteria pollutants such as nitrogen dioxide, sulfur dioxide, and particulate matter, but greenhouse gases, especially carbon dioxide. EPA has calculated that the cost/benefit analysis of **public and private efforts to meet the 1990 Clean Air Act Amendment requirements** is skewed decidedly in favor of benefits with annual costs reaching $65 billion by 2020 offset markedly by **an estimated $2 trillion of annual economic value** stemming from improvements in human health and air quality.[10] Based on our assessment of information available in 2010, we concluded that the environmental risks associated with

[7] *Saya Kitasei, Powering the Low Carbon Economy: The Once and Future Roles of Renewable Energy and Natural Gas (Worldwatch Institute: December 2010); Mark Fulton and Nils Mellquist, Natural Gas and Renewables: A Secure Low Carbon Future Energy Plan for the United States (Deutsche Bank Climate Change Advisors: November 2010).*
[8] *U.S. Energy Information Administration, Monthly Flash Estimates of Electric Power Data: Data for November 2010, available at http://eia.gov/cneaf/electricity/epm/flash/flash.pdf, viewed 11 February 2010; Mark Fulton and Nils Mellquist, Natural Gas and Renewables: A Secure Low Carbon Future Energy Plan for the United States (Deutsche Bank Climate Change Advisors: November 2010).*
[9] *The Future of Natural Gas: An Interdisciplinary MIT Study, June 2010; Deutsche Bank Climate Change Advisors analysis 2010*
[10] *http://www.epa.gov/air/sect812/feb11/summaryreport.pdf*

the extraction of unconventional natural gas are manageable through a combination of best practices and improved regulation. The November 2010 DBCCA report forecasts significant GHG reductions in the power sector through 2030 due to an assumed ~60% CO2 emission advantage per megawatt-hour (MWh) generated from natural gas combined cycle plants compared to coal steam turbines. DBCCA estimates that the U.S. is capable of reducing its power sector CO2 emissions by up to 44 percent from 2005 levels by 2030, and that some 35 percent of the reduction in CO2 emissions could be achieved by a shift from coal-fired generation to natural gas-fired power plants.[11] We also concluded that while the available data for the greenhouse gas emissions associated with the full life-cycles of electricity produced from coal and natural gas were old and out-of-date, no credible evidence had yet been published suggesting that natural gas was not at least 44 percent better than coal on a life-cycle basis.

Several life-cycle assessments available by the end of 2010 estimated the greenhouse gas emissions per unit of electricity generated from coal and gas plants. (See Exhibit 2.) A 2007 life-cycle assessment by Dr. Paulina Jaramillo of Carnegie-Mellon University concluded that electricity generated by natural gas–fired power plants emitted about 361 to 774 kg CO2e/MWh on a life-cycle basis, compared to coal, which the study concluded emitted about 892 to 1142 kg CO2e/MWh.[12]

A set of life-cycle analyses published by the U.S. National Energy Technology Laboratory (NETL) in October 2010 provides an additional point of comparison, placing GHG emissions from combined- cycle power plants using natural gas from a mixture of domestic sources, including shale gas and coalbed methane, at 466.64 kg CO2e per MWh—51 percent less than a modern supercritical pulverized coal plant and 58 percent less than a representative existing coal power plant in the U.S.[13] These were the life-cycle emissions figures cited by the Worldwatch Institute in its December 2010 report.

Exhibit 2: Summary of Findings from Selected Pre-2011 Life-Cycle Comparisons

	Jaramillo 2007	**NETL 2010**
North American NG (kg CO_2e/MWh)	361 to 774	467
Coal (kg CO_2e/MWh)	892 to 1142	1109
Implied Natural Gas Emissions Savings Versus Coal	-44%[14]	-58%
Notes	Jaramillo 2007 uses a top-down life-cycle analysis approach to compare emissions from natural gas and coal plants. Their range of natural gas plant efficiencies may capture a range of generating technologies, including but not limited to natural gas combined cycle units. Jaramillo 2007's upstream emissions calculations do not account for unconventional natural gas.	NETL 2010 uses a bottom-up life-cycle analysis approach to compare emissions from natural gas and coal plants. They use representative natural gas combined-cycle and existing pulverized coal steam turbine plants rather than looking at the entire U.S. fleet. NETL 2010's upstream emissions calculations include estimates for conventional onshore, associated onshore, offshore, coalbed methane, and Barnett Shale natural gas.

Source: Jaramillo, NETL,Worldwatch, DBCCA, ICF

[11] Mark Fulton and Nils Mellquist, Natural Gas and Renewables: A Secure Low Carbon Future Energy Plan for the United States (Deutsche Bank Climate Change Advisors: November 2010), p. 22,
[12] Paulina Jaramillo, et al. "Comparative Life-Cycle Air Emissions of Coal, Domestic Natural Gas, LNG, and SNG for Electricity Generation," Environmental Science and Technology 41, 6290-6296 (2007).
[13] Robert James, Life-cycle Analysis: Power Studies Compilation Report (National Energy Technology Laboratory, October 2010), http://www.netl.doe.gov/energy-analyses/refshelf/PubDetails.aspx?Action=View&PubId=358.
[14] This figure is based on the differential between the midpoints of the ranges Jaramillo gives for life-cycle emissions from natural gas and coal.

Summary of Recent Developments in 2011: GHG and Wastewater Issues

In recent months, several sources have called natural gas's GHG emissions reductions potential over coal into question. One, published by online investigative journalism outlet Propublica, calculates that using estimates of upstream GHG emission factors for natural gas from a November 2010 Technical Support Document published by the U.S. EPA, "the median gas-powered plant in the United States is just 40 percent cleaner than coal."[15] Another 2-page document by Dr. Robert Howarth at Cornell University uses the same EPA source to state, "Compared to coal, the footprint of shale gas is 1.2-to 2.1-fold greater on [a] 20-year time frame and is comparable when compared over 100-years."[16]

For its part, the EPA has so far not endorsed either of these life-cycle analyses, releasing the following response to the Propublica article on 31 January 2011:

> *EPA has not conducted an analysis of coal versus natural gas, and there is no new report. The information referred to in the article was developed based on information from a Technical Support Document, however, which was developed as support for the Greenhouse Gas Reporting Program. The reporter used that data and did his own calculations to arrive at the figures used in the article. EPA has not reviewed the analysis described in the article in detail, but we have not seen any indication that the benefits of natural gas have been called into question. Available data demonstrate that switching from another fossil fuel to natural gas reduces emissions of carbon pollution and other harmful pollutants that threaten Americans' health.*[17]

Meanwhile, in January 2011, the United Kingdom-based Tyndall Centre for Climate Change Research released a report estimating the amount of additional GHG emissions that might be associated in the production of unconventional gas versus conventional gas. Using what they acknowledge to be "non-peer reviewed data from a limited number of site measurements," the authors conclude that "CO2 emissions from shale gas are likely to be only marginally higher than those from conventional gas sources." Nonetheless, the authors continue, "there is little evidence from data on the U.S. that shale gas is currently, or expected to, substitute, at any significant level for coal use."[18] The Tyndall Centre's analysis does not tackle fugitive or vented GHG emissions, two main focuses of recent controversy over the true life-cycle GHG footprint of natural gas production.

Finally, the New York Times launched an investigative series of articles on natural gas extraction on February 26, 2011, arguing that ineffective legislation has resulted in toxic waste water from gas drilling being dumped into rivers, focusing on Pennsylvania.[19] In response, former Secretary of the Pennsylvania Department of Environmental Protection (DEP) John Hanger, whose department was criticized in the New York Times article, wrote that there were significant gaps in the reporting; notably, more forceful environmental safeguards that the DEP put in place in 2010 were effective in changing and improving industrial behavior and were barely or not at all mentioned in the New York Times article.[20]

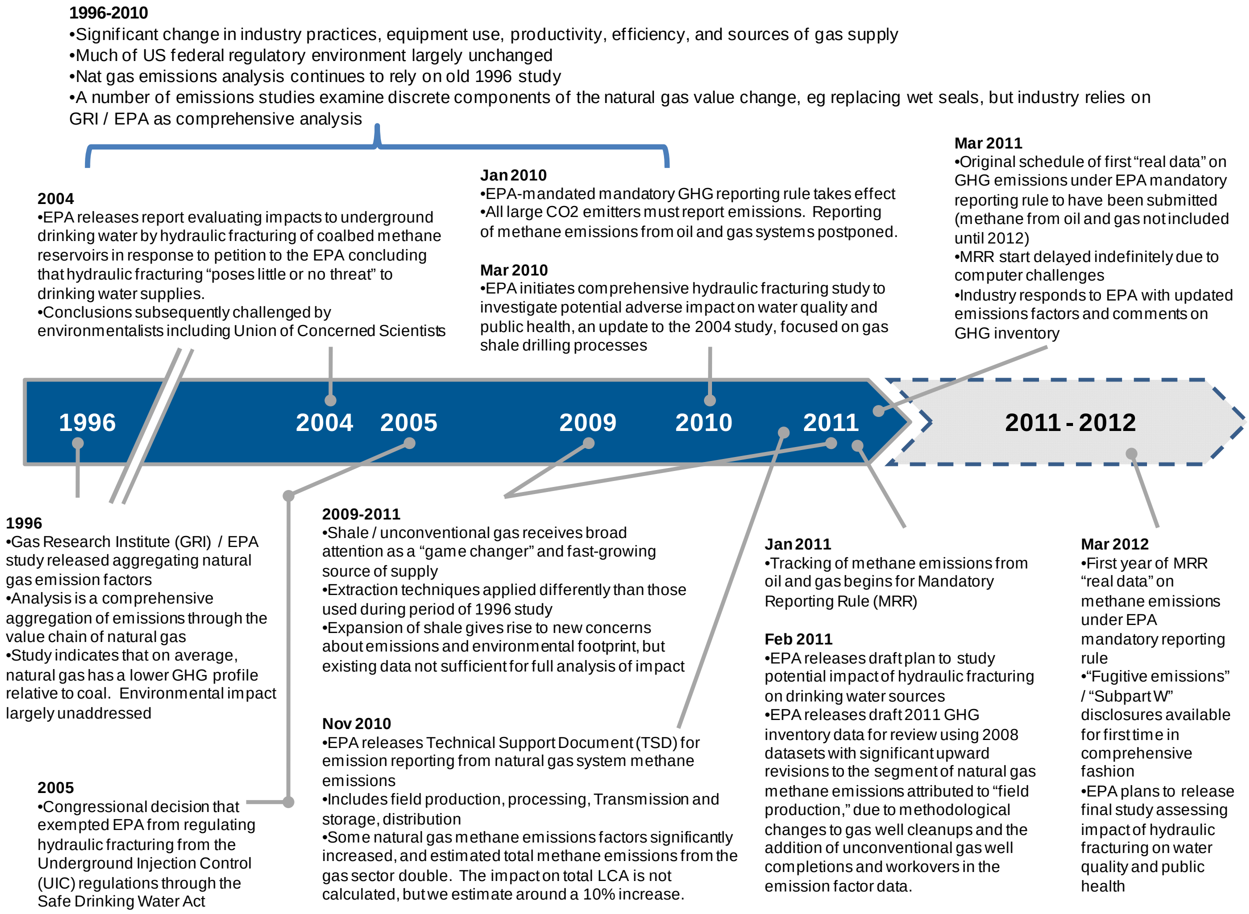
Underground injection has been the preferred long- term industry solution for disposing of waste water derived from natural gas production and has been proven to be safe and reliable. Meanwhile, waste water recycling has rapidly emerged as the best practice solution in shale plays such as the Marcellus that do not have suitable Class II injection wells given the high cost, inconvenience and risk associated with trucking waste to disposal facilities and out- of of-state injection wells. It now appears likely that the industry will be required to disclose the ingredients used in hydraulic fracturing, while shale gas development continues to improve at a rapid pace with faster cycle times, process enhancements and new technology deployment. In addition, we expect that regulation of water issues is likely to be strengthened on a state state-by by-state basis. For now, however, it appears that more restrictive regulation at the Federal level, such as the Federal FRAC Act[21] that was first introduced in 2009, is not likely to be put in place. **More restrictive regulation would probably be an impediment for marginal shale drillers but would be beneficial for the industry overall in terms of defining and adhering to best practices.**[22]

---

[15] *Abrahm Lustgarten, "Climate Benefits of Natural Gas May Be Overstated," Propublica, 25 January 2011, http://www.propublica.org/article/natural-gas-and-coal-pollution-gap-in-doubt.*
[16] *Robert Howarth, "Assessment of the Greenhouse Gas Footprint of Natural Gas from Shale Formations Obtained by High-Volume, Slick-Water Hydraulic Fracturing," updated 26 January 2011, available at http://www.eeb.cornell.edu/howarth/GHG%20update%20for%20web%20--%20Jan%202011%20%282%29.pdf.*
[17] *EPA response posted by Energy in Depth, "Propublica's Fuzzy Math," available at http://www.energyindepth.org/2011/01/propublica%E2%80%99s-fuzzy-math/, viewed 13 February 2011.*
[18] *Tyndall Centre, University of Manchester, Shale gas: a provisional assessment of climate change and environmental impacts, January 2011, pp. 6 and 37.*
[19] *http://www.nytimes.com/2011/02/27/us/27gas.html*
[20] *http://johnhanger.blogspot.com/2011/02/statement-regarding-sunday-nyt-february.html*
[21] *The Fracturing Responsibility and Awareness Chemicals Act (H.R. 2766), known as the "FRAC" Act, was introduced in 2009 by Representatives Diana DeGette (D-CO), Maurice Hinchey (D-NY) and Jared Polis (D-CO)*
[22] *Mark Fulton and Nils Mellquist, Natural Gas and Renewables: A Secure Low Carbon Future Energy Plan for the United States (Deutsche Bank Climate Change Advisors: November 2010), p. 56,*

In Exhibit 3 below we map the history of the key EPA regulatory milestones directed at natural gas life-cycle emissions and environmental issues associated with water and human health. As is clear, there was much stagnation between 1996 and 2009, with 1996 emission factors largely relied upon up until the EPA reassessed its emission factors in 2010.

Exhibit 3: EPA Natural Gas Environmental Impact Assessment Timeline: "An evolutionary process"



Source: DBCCA analysis 2011, EPA, ICF International

What's Next? New Research and Analysis is Needed to Bring Further Clarity to the Environmental Issues Associated With Unconventional Natural Gas

Because the relative GHG savings achievable from coal-to-gas switching are pivotal to conclusions by Worldwatch, DBCCA, the EPA, the Obama administration and many others that natural gas can facilitate a low-carbon transition in the U.S. power sector, it's very important to get the life-cycle GHG comparison and environmental issues right. To do that, understanding the assumptions made in these most recent life-cycle assessments, as well as the origin and quality of the emissions data that underlie them, is critical. This is particularly important given the massive anticipated shift in US natural gas production to shale and the technological advances that are allowing greater volumes to be extracted from wells at a lower unit cost.

We are not aware of any controversy surrounding the comparisons of point-of-use GHG emissions between electricity generated by single single-cycle coal power plants and natural gas combined combined-cycle plants, the technology most likely to displace coal for baseload power generation.[23] Due to the significantly higher efficiencies of natural gas combined combined-cycle plants and the significantly lower carbon content of natural gas, natural gas combined combined-cycle plants themselves produce around 60 percent fewer GHG emissions than do coal power plants.[24] It is unclear to us whether the life-cycle comparisons of coal and gas that have been cited in recent articles and reports adequately account for the difference in relative generating efficiency.

Rather, the source of concern for the latest round of life-cycle analyses is the GHG emissions released during the transportation, distribution, and especially extraction of natural gas. Many previous life-cycle analyses have relied upon upstream GHG emissions estimates published in the EPA's annual Greenhouse Gas Inventory, which assesses CO2, methane (CH4), nitrous oxide (N2O), and other GHGs from the production cycles of natural gas and coal. The EPA's estimates of GHG emissions from natural gas systems rely in large part on emissions factors originally developed in 1996 with the Gas Research Institute and updated several times since.

Life-cycle Analysis (LCA) of Coal and Natural Gas-Fired Electricity in the US

At this early stage of what we see as an inevitable coal-to-gas energy transition, it is incumbent upon all stakeholders to credibly answer the following crucial questions:

Life-cycle analysis of Natural Gas

1. What are the life-cycle GHG emissions in kilograms of carbon dioxide equivalent per British thermal unit of fuel produced (kg CO_2e/Btu) for the production of:
    a. Unconventional gas (shale gas and coalbed methane)
    b. Conventional dry gas resources
    c. Conventional gas associated with oil production
2. What are the best estimates of (and approaches to measuring) GHG emissions from midstream natural gas transmission and distribution?
3. What are the most recent and reliable GHG emission figures in CO_2e per megawatt-hour (MWh) from the use of natural gas in electricity generation?

Life-cycle analysis of Coal

1. What are the GHG emissions in kilograms of carbon dioxide equivalent per British thermal unit of fuel produced (kg CO_2e/Btu) related to 1) surface and 2) subsurface coal mining operations?
2. What are the GHG emissions in CO_2e/Btu for coal transport in the U.S.?
3. What are the GHG emissions in CO_2e/MWh for conversion of coal into electricity for the existing fleet of US power plants?
4. What are the technical learning curve improvements that might make coal generation more efficient in the future?

Life-cycle comparison of Natural Gas to Coal

1. How do the GHG emissions from the full life-cycle of natural gas and coal-fired electricity compare in terms of CO_2e/MWh?

---

[23] Natural gas can be used in a range of other power plant technologies, including low-efficiency, highly flexible gas turbines, which are generally used to provide peaking power and ancillary services, not baseload power, and therefore do not make sense to include in a comparison with baseload coal.

[24] Calculated based on average heat rates of U.S. natural gas combined cycle (7,543 Btu per kilowatt-hour) and coal steam turbine (10,148 Btu per kilowatt-hour) units in 2009 and national average emission factors for combustion of natural gas (53.06 kg CO2 per million Btu) and coal (95.52 kg CO2 per million Btu). Average heat rates from U.S. Energy Information Administration (EIA), Electric Power Annual with data for 2009, "Average Heat Rates by Prime Mover and Energy Source," available at http://www.eia.doe.gov/cneaf/electricity/epa/epat5p4.html. Emissions factors from U.S. Energy Information Administration (EIA), Voluntary Reporting of Greenhouse Gases Program, "Fuel Emission Coefficients," available http://www.eia.doe.gov/oiaf/1605/coefficients.html, both viewed 13 February 2011.

While there is widespread agreement that the emissions factors used in the EPA's Greenhouse Gas Inventories are badly in need of updating, there is debate on how an update would change the existing emissions factors, let alone the life-cycle comparison between electricity produced from coal and natural gas. Some critics say that EPA emission factors do not take into account the rising share of U.S. natural gas production that comes from shales, which generally require horizontal drilling and hydraulic fracturing to be produced—processes that involve additional GHG emissions compared to conventional wells that can be developed without horizontal drilling or hydraulic fracturing.

Others say that the EPA and other sources have underestimated the amount of methane leaked and vented during natural gas production, transmission, and distribution. Methane, the main ingredient of natural gas, is a potent greenhouse gas. On the contrary, however, some sources argue that EPA emissions factors need to be revised downward to reflect the progress the natural gas industry has made in the past 15 years through programs like the EPA's Natural Gas STAR on reducing the venting and leakage of methane.

Over the next 18 months, important new disclosures, analysis and up-to-date information sharing on the environmental issues associated with natural gas extraction from shale resources will become available. The EPA has announced that its study of the safety of hydraulic fracturing, due to be completed by the end of 2012, will focus on water issues throughout the entire life-cycle of unconventional natural gas production.[25] The EPA's Greenhouse Gas Reporting Rule should also generate new empirical data about the greenhouse gases emitted during some portions of the coal and natural gas life-cycles. In the interim, the next Greenhouse Gas Inventory, to be published in April 2011, will shed additional light on the EPA's latest thinking on the emissions associated with natural gas and coal production. A review draft released in February 2011 indicates that the EPA has significantly upwardly revised the agency's estimate of methane (CH4) emitted by natural gas production, transmission, and distribution during 2008 from 4,591 Gigagrams to 10,087 Gigagrams—an increase of some 120 percent over prior estimates–due to changes in how it is calculating emissions from natural gas production.[26] Given the scale of the upward revision this will be a focus of our analysis going forward. Using the EPA's or the IPCC's 100-year GWP and the EPA's upward revisions for methane emissions factors in natural gas production, preliminary calculations yield around a 10% increase in total life-cycle GHG emissions from combined-cycle natural gas-fired electricity.[27]

For the present, it is clear that there is an urgent need for more robust empirical data quantifying the life-cycle greenhouse gas emissions from electricity produced from coal and natural gas, both conventional and unconventional particularly in light of how fast unconventional gas production is growing as a share of total production. It is also clear that a thorough evaluation of those data that are available is necessary to clarify the actual state of knowledge about the relative emissions from natural gas and coal, and that the assumptions and methodologies of new life-cycle assessments should be scrutinized carefully before their authors' conclusions are accepted. However, no matter how the coal-gas comparison turns out, new information about the levels of methane emitted by natural gas systems underscores the importance of utilizing best practices and technologies to minimize fugitive methane emissions. Many of these practices and technologies are available today and can mitigate methane emissions cost-effectively.

Conclusion

With the Obama administration signaling its willingness to include natural gas in a federal Clean Energy Standard, it has become all the more important to get the relative greenhouse gas emissions between coal and natural gas right. We believe that sufficient data do not yet exist to contradict the hitherto accepted greenhouse gas advantages of natural gas over coal, and the ability of natural gas to facilitate emissions reductions in the U.S. power sector. Nevertheless, the issue of life-cycle greenhouse gas emissions must be taken seriously. We plan to conduct our own thorough and transparent assessment of available data and life-cycle analyses, the results of which we will make public. Until such an assessment is available, however, analysts and other stakeholders should be careful about coming to premature conclusions.

---

[25] Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources, EPA, February 2011, page 93.
[26] U.S. Environmental Protection Agency (EPA), DRAFT—Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009, Chapter 3: Energy, available at http://www.epa.gov/climatechange/emissions/downloads11/US-GHG-Inventory-2011-Chapter-3-Energy.pdf, viewed 23 February 2011.
[27] Preliminary calculations based on the 100-year GWP for methane most commonly used by the EPA, 21, and heat rate assumptions for representative NGCC (7,500 Btu/kWh) and coal steam turbine (10,500 Btu/kWh) units.

Disclaimer

DB Climate Change Advisors is the brand name for the institutional climate change investment division of Deutsche Asset Management, the asset management arm of Deutsche Bank AG. In the US, Deutsche Asset Management relates to the asset management activities of Deutsche Bank Trust Company Americas, Deutsche Investment Management Americas Inc. and DWS Trust Company; in Canada, Deutsche Asset Management Canada Limited (Deutsche Asset Management Canada Limited is a wholly owned subsidiary of Deutsche Investment Management Americas Inc); in Germany and Luxembourg: DWS Investment GmbH, DWS Investment S.A., DWS Finanz-Service GmbH, Deutsche Asset Management Investmentgesellschaft mbH, and Deutsche Asset Management International GmbH; in Australia, Deutsche Asset Management (Australia) Limited (ABN 63 116 232 154); in Hong Kong, Deutsche Asset Management (Hong Kong) Limited; in Japan, Deutsche Asset Management Limited (Japan); in Singapore, Deutsche Asset Management (Asia) Limited (Company Reg. No. 198701485N) and in the United Kingdom, RREEF Limited, RREEF Global Advisers Limited, and Deutsche Asset Management (UK) Limited; in addition to other regional entities in the Deutsche Bank Group.

This material is intended for informational purposes only and it is not intended that it be relied on to make any investment decision. It does not constitute investment advice or a recommendation or an offer or solicitation and is not the basis for any contract to purchase or sell any security or other instrument, or for Deutsche Bank AG and its affiliates to enter into or arrange any type of transaction as a consequence of any information contained herein. Neither Deutsche Bank AG nor any of its affiliates, gives any warranty as to the accuracy, reliability or completeness of information which is contained in this document. Except insofar as liability under any statute cannot be excluded, no member of the Deutsche Bank Group, the Issuer or any officer, employee or associate of them accepts any liability (whether arising in contract, in tort or negligence or otherwise) for any error or omission in this document or for any resulting loss or damage whether direct, indirect, consequential or otherwise suffered by the recipient of this document or any other person.

The views expressed in this document constitute Deutsche Bank AG or its affiliates' judgment at the time of issue and are subject to change. This document is only for professional investors. This document was prepared without regard to the specific objectives, financial situation or needs of any particular person who may receive it. The value of shares/units and their derived income may fall as well as rise. Past performance or any prediction or forecast is not indicative of future results. No further distribution is allowed without prior written consent of the Issuer.

The forecasts provided are based upon our opinion of the market as at this date and are subject to change, dependent on future changes in the market. Any prediction, projection or forecast on the economy, stock market, bond market or the economic trends of the markets is not necessarily indicative of the future or likely performance.

For Investors in the United Kingdom
Issued in the United Kingdom by Deutsche Asset Management (UK) Limited of One Appold Street, London, EC2A 2UU. Authorised and regulated by the Financial Services Authority. This document is a "non-retail communication" within the meaning of the FSA's Rules and is directed only at persons satisfying the FSA's client categorisation criteria for an eligible counterparty or a professional client. This document is not intended for and should not be relied upon by a retail client.

When making an investment decision, potential investors should rely solely on the final documentation relating to the investment or service and not the information contained herein. The investments or services mentioned herein may not be appropriate for all investors and before entering into any transaction you should take steps to ensure that you fully understand the transaction and have made an independent assessment of the appropriateness of the transaction in the light of your own objectives and circumstances, including the possible risks and benefits of entering into such transaction. You should also consider seeking advice from your own advisers in making this assessment. If you decide to enter into a transaction with us you do so in reliance on your own judgment.

For Investors in Australia
In Australia, Issued by Deutsche Asset Management (Australia) Limited (ABN 63 116 232 154), holder of an Australian Financial Services License. This information is only available to persons who are professional, sophisticated, or wholesale investors under the Corporations Act. An investment with Deutsche Asset Management is not a deposit with or any other type of liability of Deutsche Bank AG ARBN 064 165 162, Deutsche Asset Management (Australia) Limited or any other member of the Deutsche Bank AG Group. The capital value of and performance of an investment with Deutsche Asset Management is not guaranteed by Deutsche Bank AG, Deutsche Asset Management (Australia) Limited or any other member of the Deutsche Bank Group. Deutsche Asset Management (Australia) Limited is not an Authorised Deposit taking institution under the Banking Act 1959 nor regulated by the Australian Prudential Authority. Investments are subject to investment risk, including possible delays in repayment and loss of income and principal invested.

For Investors in Hong Kong
Interests in the funds may not be offered or sold in Hong Kong or other jurisdictions, by means of an advertisement, invitation or any other document, other than to Professional Investors or in circumstances that do not constitute an offering to the public. This document is therefore for the use of Professional Investors only and as such, is not approved under the Securities and Futures Ordinance (SFO) or the Companies Ordinance and shall not be distributed to non-Professional Investors in Hong Kong or to anyone in any other jurisdiction in which such distribution is not authorised. For the purposes of this statement, a Professional investor is defined under the SFO.

For Investors in MENA region
This information has been provided to you by Deutsche Bank AG Dubai (DIFC) branch, an Authorised Firm regulated by the Dubai Financial Services Authority. It is solely directed at Market Counterparties or Professional Clients of Deutsche Bank AG Dubai (DIFC) branch, which meets the regulatory criteria as established by the Dubai Financial Services Authority and may not be delivered to or acted upon by any other person.

I-020207-2.0