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Life Cycle Greenhouse Gas Inventory of Natural Gas Extraction, Delivery and Electricity Production

DOE/NETL-2011/1522

Final Report

October 24, 2011

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DOE Contract Number DE-FE0004001

Acknowledgments

This report was prepared by **Energy Sector Planning and Analysis (ESPA)** team for the United States Department of Energy (DOE), National Energy Technology Laboratory (NETL). This work was completed under DOE NETL Contract DE-FE0004001, and ESPA Task 150.02.

The authors wish to acknowledge the excellent guidance, contributions, and cooperation of the NETL and DOE staff, particularly:

Strategic Center for Natural Gas and Oil

Maria Vargas, Deputy Director

Albert Yost, E&P Technical Manager

Department of Energy, Office of Oil and Natural Gas

Christopher Freitas, Senior Program Manager

The authors also wish to acknowledge the valuable feedback and contributions of the following reviewers:

Argonne National Laboratory

Dr. Michael Wang, Senior Scientist

El Paso Corporation

Fiji George, Carbon Strategies Director

Environmental Defense Fund

Dr. Ramon Alvarez, Senior Scientist

Massachusetts Institute of Technology, MIT Energy Initiative

Dr. Qudsia Ejaz, Postdoctoral Associate

Dr. Sergey Paltsev, Principal Research Scientist

Resources for the Future

Jan Mares, Senior Policy Advisor

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Acronyms and Abbreviations

AGR	Acid gas removal	kWh	Kilowatt-hour
API	American Petroleum Institute	lb, lbs	Pound, pounds
bbl	Barrel	LCA	Life cycle assessment, analysis
Bcf	Billion cubic feet	LNG	Liquefied natural gas
BOE	Barrel of oil equivalent	m	Meter
Btu	British thermal unit	m ³	Meters cubed
CBM	Coal bed methane	Mbbl	Thousand barrels
CCS	Carbon capture and sequestration	Mcf	Thousand cubic feet
cf	Cubic feet	MJ	Megajoule
CH ₄	Methane	MMbbl	Million barrels
CO ₂	Carbon dioxide	MMBtu	Million British thermal units
CO ₂ e	Carbon dioxide equivalent	MMcf	Million cubic feet
DOE	Department of Energy	MW	Megawatt
eGRID	Emissions & Generation Resource Integrated Database	MWh	Megawatt-hour
EIA	Energy Information Administration	N ₂ O	Nitrous oxide
EPA	Environmental Protection Agency	NETL	National Energy Technology Laboratory
ERCOT	Electric Reliability Council of Texas	NG	Natural gas
EUR	Estimated ultimate recovery	NGCC	Natural gas combined cycle
EXPC	Existing pulverized coal	NMVOC	Non-methane volatile organic compound
g	Gram	NREL	National Renewable Energy Laboratory
gal	Gallon	PRB	Powder River Basin
Gg	Gigagram	psig	Pounds per square inch gauge
GHG	Greenhouse gas	PT	Product transport
GTSC	Gas turbine simple cycle	RMA	Raw material acquisition
GWP	Global warming potential	RMT	Raw material transport
H ₂ S	Hydrogen sulfide	SCPC	Super critical pulverized coal
hp-hr	Horsepower-hour	T&D	Transmission and distribution
IGCC	Integrated gasification combined cycle	Tcf	Trillion cubic feet
IPCC	Intergovernmental Panel on Climate Change	ton	Short ton (2,000 lb)
kg	Kilogram	tonne	Metric ton (1,000 kg)
km	Kilometer	UP	Unit process

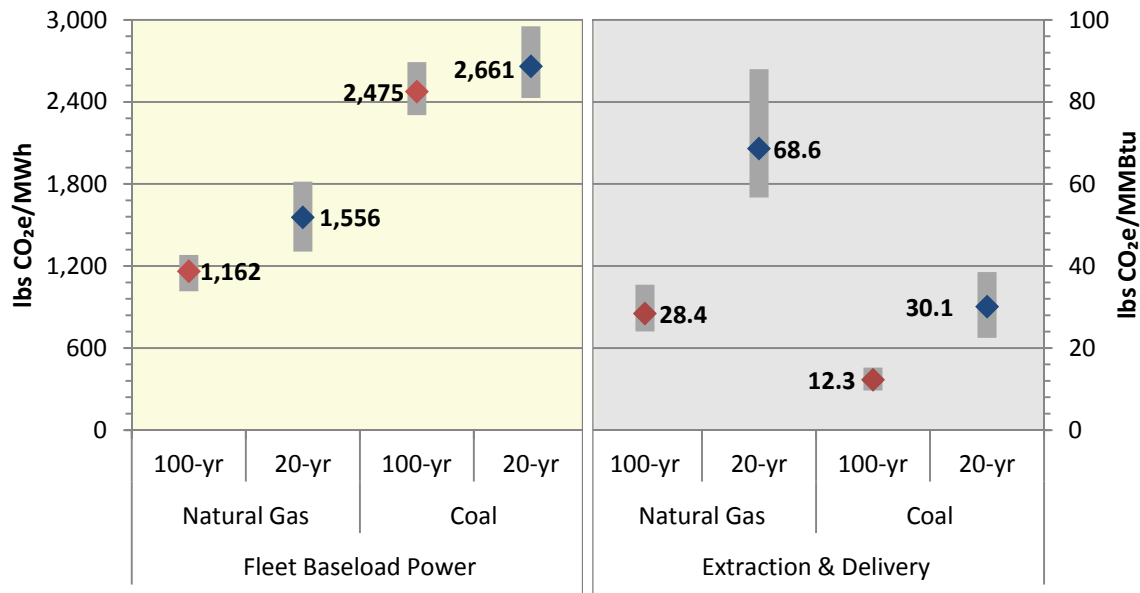
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Executive Summary

Natural gas-fired baseload power production has life cycle greenhouse gas emissions 42 to 53 percent lower than those for coal-fired baseload electricity, after accounting for a wide range of variability and compared across different assumptions of climate impact timing. The lower emissions for natural gas are primarily due to differences in the current fleets’ average efficiency – 53 percent for natural gas versus 35 percent for coal, and a higher carbon content per unit of energy for coal than natural gas. Even using unconventional natural gas, from tight sands, shale and coal beds, and compared with a 20-year global warming potential (GWP), natural gas-fired electricity has 39 percent lower greenhouse gas emissions than coal per delivered megawatt-hour (MWh) using current technology.

In a life cycle analysis (LCA), comparisons must be based on providing an equivalent service or function, which in this study is the delivery of 1 MWh of electricity to an end user. This life cycle greenhouse gas inventory also developed upstream (from extraction to delivery to a power plant) emissions for delivered energy feedstocks, including six different domestic sources of natural gas, of which three are unconventional gas, and two types of coal, and then combines them both into domestic mixes. These are important characterizations for the LCA community, and can be used as inputs into a variety of processes. However, these upstream, or cradle-to-gate, results are not appropriate to compare when making energy policy decisions, since the two uncombusted fuels do not provide an equivalent function. These results highlight the importance of specifying an end-use basis—not necessarily power production—when comparing different fuels.

Figure ES-1: Natural Gas and Coal GHG Emissions Comparison

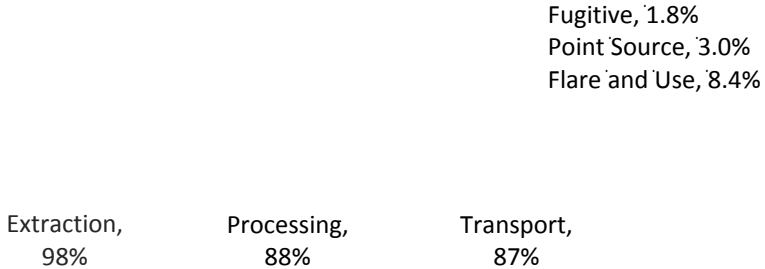


Despite the conclusion that natural gas has lower greenhouse gases than coal on a delivered power basis, the extraction and delivery of the gas has a large climate impact —32 percent of U.S. methane emissions and 3 percent of U.S. greenhouse gases (EPA, 2011b). As **Figure ES-2** shows, there are significant emissions and use of natural gas—13 percent at the city or plant gate—even without considering final distribution to small end-users. The vast majority of the reduction in extracted

natural gas —64 percent cradle-to-gate—are not emitted to the atmosphere, but can be attributed to the use of the natural gas as fuel for extraction and transport processes such as compressor operations. Increasing compressor efficiency would lower both the rate of use and the CO₂ emissions associated with the combustion of the gas for energy. Note that this figure accounts for the total mass of natural gas extracted from the earth, including water, acid gases, and other non-methane content.

But, with methane making up 75 to 95 percent of the natural gas flow, there are many opportunities for reducing the climate impact associated with direct venting to the atmosphere. A further 24 percent of the natural gas losses can be characterized as point source, and have the potential to be flared—essentially a conversion of GWP-potent methane to carbon dioxide.

Figure ES2: Cradle to Gate Reduction in Delivered Natural Gas for 2009



Fugitive, 1.8%
Point Source, 3.0%
Flare and Use, 8.4%

The conclusions drawn from this analysis are robust to a wide array of assumptions. However, as with any inventory, they are dependent on the underlying data, and there are many opportunities to enhance the information currently being collected. This analysis shows that the results are both sensitive to and impacted by the uncertainty of a few key parameters: use and emission of natural gas along the pipeline transmission network; the rate of natural gas emitted during unconventional gas extraction processes such as well completion and workovers; and the lifetime production of wells, which determine the denominator over which lifetime emissions are placed.

Table ES1: Average and Marginal Upstream Greenhouse Gas Emissions (lbs CO₂e/MMBtu)

Source		Average	Marginal	Percent Change
Conventional	Onshore	34.2	20.1	41.2%
	Offshore	14.3	14.1	1.4%
	Associated	18.5	18.4	0.8%
Unconventional	Tight	32.4	32.4	0.0%
	Shale	32.5	32.5	0.0%
	Coal Bed Methane	19.1	19.3	1.4%
Liquefied Natural Gas		42.8	42.5	0.6%

This analysis inventoried both average and marginal production rates for each natural gas type, with results shown in **Table ES-1**. The average represents natural gas produced from all wells, including older and low productivity stripper wells. The marginal production rate represents natural gas from

