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Environmental Life Cycle Assessment Of North American Shale Gases

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Background

In the U.S. and Canada, the rapid growth of shale production has been accompanied by public interest regarding its environmental impact. Particular interest has been focused upon greenhouse gas (GHG) emissions and freshwater consumption associated with hydraulic fracturing and flowback. However, GHG emissions and freshwater consumption may also result from other operations throughout the shale gas life cycle, including gas gathering systems, processing and treatment facilities, transmission pipelines, and the ultimate users of natural gas. Increasingly, the end use of natural gas is the North American power sector, which is shifting from coal-fired generation to gas power.

Life cycle assessment (LCA) is the preeminent method for estimation of environmental impacts of products, from "cradle to grave". LCA facilitates characterization of the *relative* environmental impacts of particular operations (e.g. hydraulic fracturing) *within* the life cycle of a product under investigation. Moreover, if conducted with compatible constraints, LCAs of alternative power sources (such as coal, shale gas or wind) may be used to quantify their relative impacts upon the environment[1].

LCA can also be used to investigate the relative environmental impacts among shale gases extracted from different reservoirs. Inasmuch as these reservoirs vary by depth, age, and geochemistry, there is technological variability in the life cycles of the gases produced from them. This in turn may result in differences in the environmental impacts associated with drilling, completion, gas treatment and processing.

Aim

The aim of this work was to quantify GHG emissions and freshwater consumption associated with North American shale gases over their life cycles, i.e. from drilling and completion to use as a fuel for electricity generation at a combined cycle gas turbine power plant (Figure 1). We incorporated all of the phases of the gas life cycle, as well as supporting operations including the manufacture of cement, steel tubulars employed for well casing (OCTG), diesel employed for drilling and completions, etc.

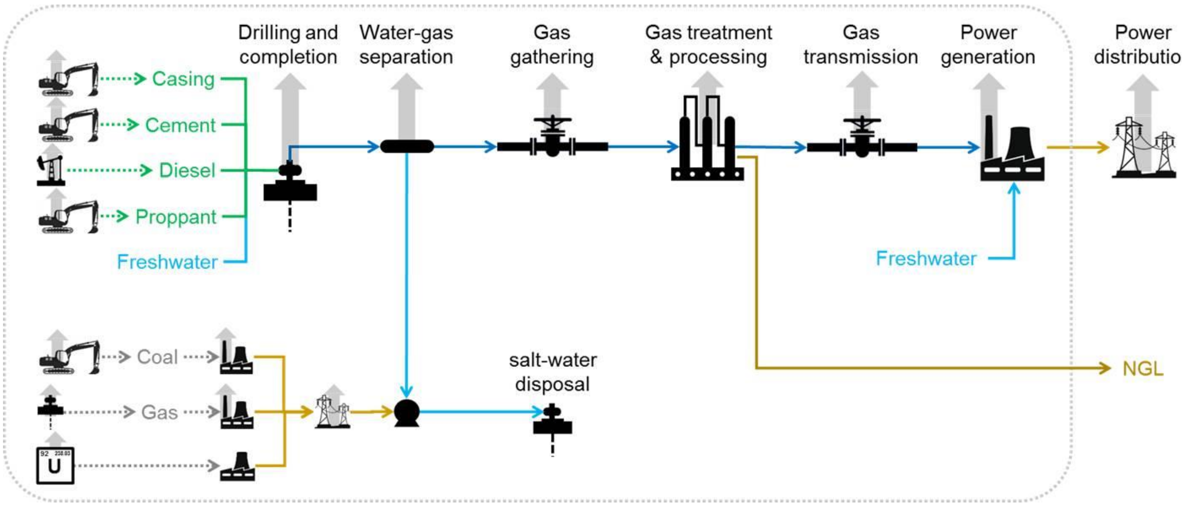

Figure 1 System Boundary for the LCA of shale gas. Natural Gas Liquids (NGL) are separated from the gas at the processing plant and are not included in the system boundary. Impacts associated with drilling and completion, water-gas separation, gathering, and salt water disposal of produced water are allocated to residue gas and NGL in according to their their net energy content (HHV) leaving the processing plant.

We employ a "functional unit" of "Megajoules of electricity generated", or "MJ_e". Expressing GHG emissions and freshwater consumption in terms of this functional unit permits comparison of the carbon and water footprints of power generated from shale gas with other technologies for power generation (e.g. coal power).

Methods

ISO specifies four phases of an LCA: Definition of the goal and scope, Inventory analysis, environmental impact assessment, and interpretation[1]. Methodological details for this LCA are described in our previously published work[2,3].

In this work, GHG emissions are expressed using the global warming potentials (GWPs) reported in the recently released 5th Assessment Report of the IPCC[5] (Table 1). The Kyoto Protocol (Decision2/Cp.3)[6] recommended the assessment of the effects of GHGs over a 100-year time horizon. This is the precedent for LCAs of power generation.

Table 1 Global Warming Potentials (GWPs) used in this LCA for the assessment of GHG emissions5

	CO_2	CH_4	N_2O
GWP (kg CO_2eq/kg)	1	30	265

In Table 2, we highlight some of the key features of the life cycles of Barnett and Marcellus shale gases. Key inventory data have been reported in our previously published work[2,3].

Table 2 Key factors in the LCAs of shale gases considered in this study

	Barnett		Marcellus	
	Rich	Lean	Rich	Lean
EUR (Bcf)	1.4	1.4	1.8	1.8
Drilling Fuel	Diesel	Diesel	Diesel	Diesel
Methane, vol%	80.3%	94.1%	78.8%	98.3%
C2+, vol%	17.3%	1.5%	20.6%	1.5%
Inerts, vol%	2.5%	4.5%	0.6%	0.3%
Hydraulic Fracturing Fuel	Diesel	Diesel	Diesel	Diesel
Disposition of Flowback Gas	Captured/Vented	Captured/Vented	Flared	Flared
Acid Gas Removal	Yes	Yes	No	No
Processing	GSP	None	GSP	None
Power Plant Efficiency (HHV)	50.2%	50.2%	50.2%	50.2%

Results - Barnett Shale Gas

We conducted LCAs of both rich (high NGL) and lean (no NGL) Barnett gases. Results for rich Barnett gas are illustrated in Figure 2 and Figure 3. GHG emissions associated with the hydraulic fracturing procedure itself (due to the use of diesel fuel to operate frac pumps), amount to 0.12% of the total GHG emissions. GHG emissions associated with the venting of flowback gas amount to 0.10% of the total GHG emissions, largely due to the use of "green completions" in the Barnett. By contrast, 98.3% of the GHG emissions are due to the combustion of gas as a fuel; 88.2% of which occurs at the power plant.

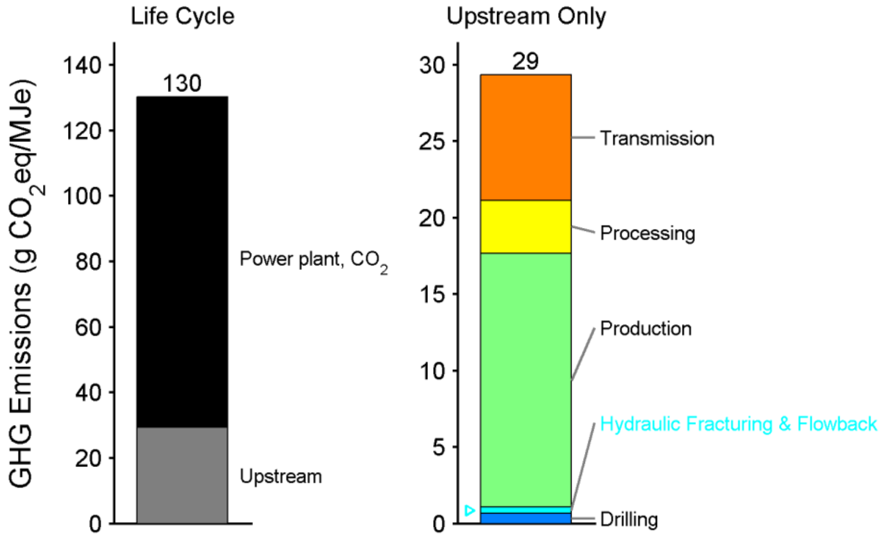

Figure 2 Life cycle GHG emissions associated with rich gas produced from the Barnett shale (IPCC AR5 GWPs, 100-year time horizon)

As our results in Figure 3 illustrate, almost all of the freshwater consumption associated with Barnett shale gas occurs at the power plant as a consequence of closed loop cooling. Only 6.9% of the freshwater consumption results from the pumping of water during hydraulic fracturing.

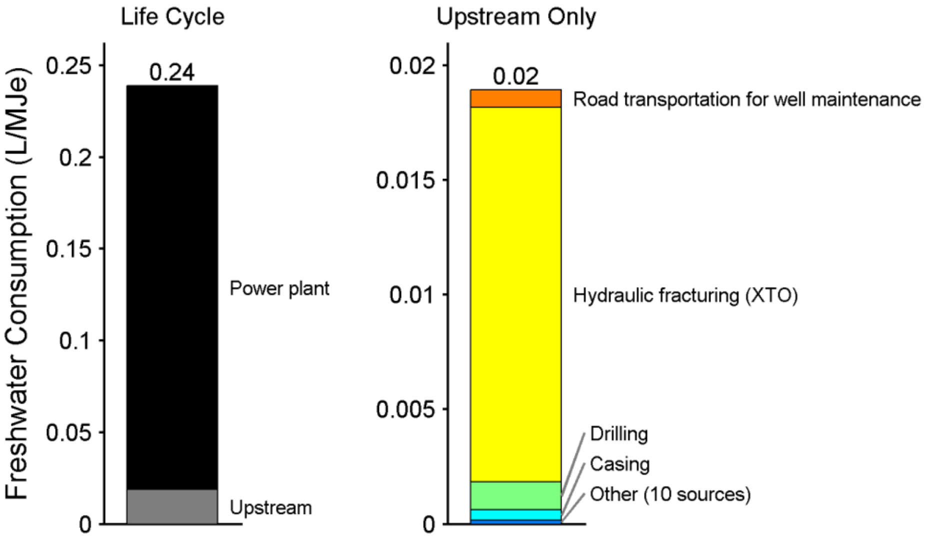

Figure 3 Freshwater consumption associated with rich Barnett shale gas

The results of our LCA of lean Barnett gas are similar to those for rich Barnett gas: 0.14% of the life cycle GHG emissions are due to hydraulic fracturing itself (diesel combustion), and 0.15% due to flowback venting, for a total of 0.29%. Hydraulic fracturing accounts for 8.15% of the life cycle freshwater consumption. The difference in these figures is partly a consequence of allocation: rich gas impacts associated with fracturing are allocated to both residue gas and NGL leaving the processing plant, whereas 100% of the impacts associated with fracturing follow lean gas through its life cycle.

Results - Marcellus Shale Gas

In Figure 4 and Figure 5 we report the results of our LCA of rich Marcellus shale gas. Hydraulic fracturing constitutes 0.66% of the life cycle GHG emissions, almost completely due to diesel fuel combustion and the flaring of flowback gas. As in the Barnett LCAs, life cycle freshwater consumption is almost completely due to closed loop cooling at the power plant, but 6.9% is attributable to hydraulic fracturing. For lean Marcellus gas, hydraulic fracturing constitutes 0.72% of the life cycle GHG emissions, and 7.4% of the life cycle freshwater consumption.

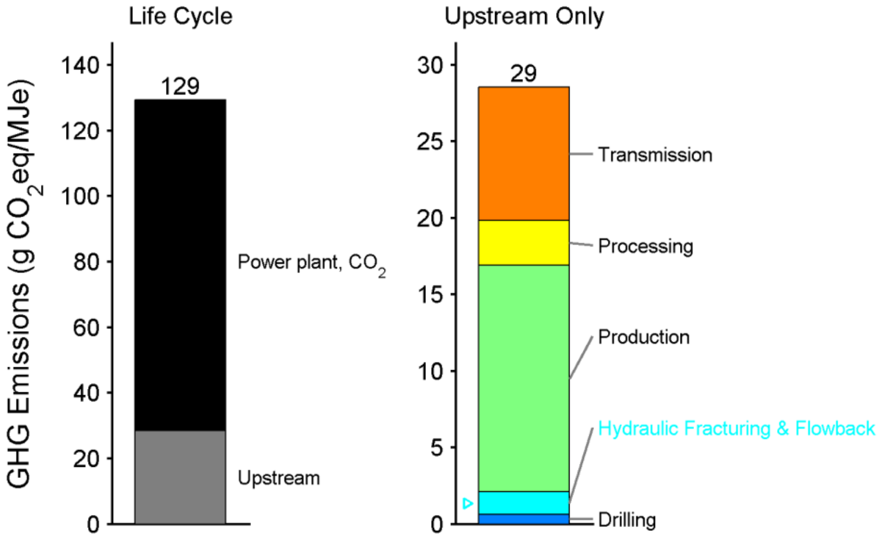

Figure 4 Life cycle GHG emissions associated with rich gas produced from the Marcellus shale (IPCC AR5 GWPs, 100-tear time horizon)

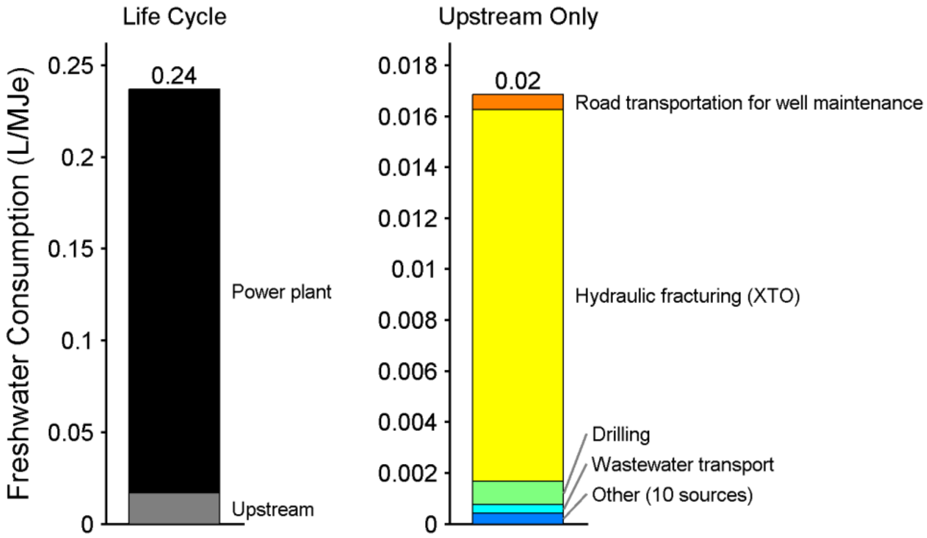

Figure 5 Life cycle freshwater consumption associated with rich gas produced from the Marcellus shale

Results – Comparison with Coal

As previously discussed, our use of a functional unit of "generated electricity" (MJe) allows for a meaningful comparison of shale gases with other energy resources. In Table 3, we report our findings along with the results of an LCA of U.S. coal power conducted by the U.S. Department of Energy, re-expressed using the GWPs from the IPCC AR5 (Table 1). From these results, we conclude that both the GHG emissions and freshwater consumption associated with shale gas are about half those of coal when the fuels are used for power generation. Moreover, we conclude that the differences in the impacts associated with Barnett and Marcellus shale gases are negligible. As we have shown previously[2], the differences in the impacts associated with these shale gases is primarily a consequence of differences in the ultimate recoveries of the well. Hence, we may also conclude that there is no significant difference in the life cycle GHG emissions associated with shale gases and conventional gases within the same range of expected ultimate recoveries and compositions reported in Table 2.

Table 3 Results of LCAs of shale gases and coal. Coal results are adopted from an LCA conducted by the U.S. Department of Energy[4].

	Barnett		**Marcellus**		**Coal**
	Rich	Lean	Rich	Lean	
GHG Emissions (g CO_2eq/MJ_e)	130	134	129	128	288
Fraction of Gross CH_4 Emitted	1.7%	1.6%	1.5%	1.4%	
Freshwater Consumption (L/MJ_e)	0.24	0.24	0.24	0.24	0.47

In recent years, there has been specific interest in the fraction of gas that is emitted from extraction to the point of use. Our LCA reveals that this is typically between 1.4 and 1.7%, of which as much as 0.3% may be due to incomplete combustion in gas engines used to power compressors.

Conclusions

Despite differences in geology, total vertical depth, and geological history, we find that there are no significant differences in the life cycle GHG emissions and freshwater consumption associated with North American shale gases. However, the coal life cycle has twice the GHG emissions and freshwater consumption of shale gas.

Our LCA also revealed that more than 98% of natural gas is burned between extraction and end use. The power plant is the source of more than 87% of life cycle GHG emissions, and more than 90% of the freshwater consumption.

In conclusion, substantial GHG reductions and freshwater consumption may result by replacing coal-fired power plants with shale gas-fired power plants. Moreover, as geologists and drilling engineers leverage their experience to increase the EURs of shale gas wells, and advances in gas turbines increase the efficiencies of combined cycle gas power, further decreases in the life cycle GHG emissions associated with shale gas may be expected.

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