Shale Gas vs. Coal

A comparison of the environmental impacts of shale gas, conventional gas and coal deployment on air, water, and land in the United States.

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Abstract: The aim of this paper is to examine the environmental impacts of shale gas, conventional gas and coal on air, water, and land in the United States. These factors decisively affect the quality of life (public health and safety) as well as local and global environmental protection. Comparing various lifecycle assessments, this paper will suggest that a shift from coal to shale gas would benefit public health, the safety of workers, local environmental protection, water consumption, and the land surface. Most likely, shale gas also comes with a smaller GHG footprint than coal. However, shale gas extraction can affect water safety. This paper also discusses related aspects that exemplify how shale gas can be more beneficial in the short and long term. First, there are technical solutions readily available to fix the most crucial problems of shale gas extraction, such as methane leakages and other geo-hazards. Second, shale gas is best equipped to smoothen the transition to an age of renewable energy. Finally, this paper will recommend tighter regulations.

Keywords: Shale gas, coal, lifecycle analysis, environmental protection, regulation.

JEL Classification: *O13, Q4, Q53, Q54, L95.*

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1 Introduction

On September 10, 1969, the U.S. Atomic Energy Commission detonated an atomic bomb underground in Western Colorado. The bomb was twice the yield of the warhead dropped on Nagasaki in 1945. What President Richard Nixon coined as “nuclear stimulation technology” successfully liberated natural gas that had been trapped in shale formations 7,000 feet deep. Unfortunately, the natural gas was radioactive and Rulison, CO is still sitting on its trove.

In the decades after, the application of two technological innovations, horizontal drilling and hydraulic fracturing made the exploitation of unconventional gas (coal bed, shale, and tight gas) a less dangerous endeavor. By the beginning of this century, natural gas prices adjusted to ever depleting conventional gas supply and increasing industrial demand, eventually peaking at USD 13.58/thousand cf in 2008. Combined, technological hallmarks and excess demand triggered the economic viability of shale gas operations in the United States.

Today, in the “Golden Age of Gas” (IEA 2011), natural gas is abundant in the United States. The technically recoverable reserves are estimated to add up to 2,543 Tcf, with a 3:2 ratio between unconventional and conventional reserves. At constant 2010 levels, wells in Pennsylvania, Texas, Louisiana, Arkansas, and Michigan – to name the five biggest ‘El Dorados’ – can facilitate more than 100 years of continuous gas consumption (EIA 2011a, 2011d). In 2009, shale gas, being the most dynamic driver of the rush into unconventional gas markets, accounted for 3.28 Tcf p.a., or 16%, of U.S. annual natural gas supply. The EIA projects the capacity to almost quadruple to 12.25 Tcf p.a., or 47% by 2035 (EIA 2011a). The Second Ninety-Days Report of the Natural Gas Subcommittee of the Secretary of Energy Advisory Board calls shale gas “the country’s most important domestic energy resource” (DOE 2011b).

As a final energy, natural gas is used for residential (21%) and commercial (14%) heating as well as industrial (27%) and electric power generation (30%) (EIA 2011a). To put the numbers into perspective, coal accounts for 1.9 times as much electricity generation, or 1,772 billion kWh for 2011. High energy density, low ramping time (roughly 15 MW per minute) and a well-developed pipeline infrastructure equip natural gas with low transportation costs. Therefore, natural gas holds a comparative advantage towards anthracite, bitumen and lignite in residential, commercial, and industrial utilization where it outweighs these coals by factors of 500, 46, and 5 respectively. In 2008, the U.S. consumed 100.14 quadrillion Btu of energy: 23.85 quadrillion Btu, or 23.8% came from natural gas and 22.38 quadrillion Btu, or 22.3% were coal-based (EIA 2011a).

An array of unprecedented events at the national and global stage elevated shale gas to a new alternative in the nation’s energy portfolio onto the public stage. In April 2010, 29 coal workers died in a mine accident in West Virginia. A few days later, oil from the

"Deepwater Horizon" platform started spilling into the Gulf of Mexico. In March 2011, several nuclear reactors in Fukushima, Japan, melted down after tsunamis and an earthquake had caused blackouts of the pivotal power supply for the cooling system. The public and environmental safety of nuclear energy, oil and coal were all together scrutinized by "high impact - low frequency" events, leaving natural gas and renewable energies to become the preferred solutions for energy crises of the nation. However, the latter sources, such as solar photovoltaic and onshore wind, are highly intermittent and relatively expensive.

The situation allows for the domestic shale gas reservoirs to become an appealing alternative to "make the world a cleaner, safer place" (The Economist 2011a). Shale gas is known as the cleanest fossil fuel, since it burns roughly half carbon dioxide and three fourths less nitrogen oxide than coal and almost no sulfur dioxide, carbon monoxide, black carbon, particulates, and mercury (Nature 2009). The industry added 200,000 jobs during the recession and filled state budgets with tax revenues (DOE 2011a, Husain et al. 2011, Smil 2008). While the gas price is only slightly higher than the coal price, the levelized electricity costs are lower for new gas fired plants than for new coal fired plants. They are expected to drop further through 2020 (IEA 2011). One could argue that natural gas achieves all the three "energy triangles" objectives: affordability, security of supply, and environmental protection.

Along with the recognition of these benefits, there is also a growing number of concerns. Methane leaks and lower levels of nitrous and sulfur can turn natural gas into a powerful driver of global warming (Howarth et al. 2011). Overstated reserve and productivity estimates did not stand up to academic scrutiny (Kinnaman 2011, Rogers 2011). Confidential emails became public and revealed worries in the industry about overbooking practices in addition to fears of a dot-com like bubble (Urbina 2011a). Some even spoke of an "Enron moment" (Urbina 2011b). Furthermore, explorations face a new *NUMBY* (not under my back yard) trend (Kerr 2010). Motivations to rally against "Big Gas" include fears of groundwater, land and air contamination, seismic eruptions and heavy industrial traffic. Even though the burning tab water in the *Gasland* movie may be a rare event, it still remains the most popular illustration conjured by the opposition.

An increase in shale gas supply can replace coal in the energy portfolio. Especially for base load electricity generation, shale gas fired natural gas combined cycle power plants (NGCC) could substitute the oldest coal-fired power plants. As Susan Tierney suggested in a recent presentation at Harvard University, NGCC could crowd out coal plants that do not employ modern emission control systems. Accounting for up to 65 GW, or 20% of 2009 nameplate capacity, these plants are expected to retire due to stricter EPA Clean Air Rules and could then be replaced by NGCC plants (Bernstein 2010, EIA 2011b).

The aim of this paper is to examine the environmental impacts of shale gas, conventional gas and coal on air, water, and land. These factors decisively affect the quality of life (public health and safety) as well as local and global environmental protection. The remainder of this paper is structured as follows: Section 2 presents the environmental assessment of shale gas vs. conventional gas vs. coal impacts on air (2.1), water (2.2), and land (2.3). Each subsection weighs natural gas vs. coal and then measures the performance of shale gas against the two traditional fuels. Section 3 concludes on the assessment and lists technical and regulatory proposals to fix some of the most imminent problems. Section 3 also discusses shale gas as a transition fuel for renewable energies.

2 Environmental Assessment

2.1 Air

2.1.1 Greenhouse Gases – Can Shale Gas Solve the Bigger Problem?

In 2009, total U.S. emissions of greenhouse gases (GHG) were 6,575.5 MMTCO$_2$e, roughly one fifth of the world total. Carbon dioxide (CO2) holds 82.8%. Weighted according to their global warming potential (GWP) on a 100-years time interval, methane (CH4) and nitrogen oxide (NOx) contribute 11.1% and 3.3%, respectively. 82.5% of total GHG emissions are energy-related. In this energy basket, coal (34.6%) and natural gas (22.4%) rank second and third after petroleum (42.7%). The cross-sector comparison of energy-related GHG emissions is topped by electric power (39.8%). Transportation and the residential, commercial and industry uses are responsible for 34.1% and 26.1%, respectively (EIA 2011c).

How are we to mitigate these GHG emissions that drive anthropogenic global warming? The first best solutions, replacing high-carbon fossil fuels by low-carbon renewable energies or systems with higher energy efficiency, face technical (intermittency, scalability) and economic (cost effectiveness) barriers in the short term. A feasible second best solution can be to replace high-carbon fossil fuels by not-so-high carbon fossil fuels.

Natural gas can substitute coal as mentioned in Section 1. Certainly, this shift will not put the transportation sector on a more sustainable path in the near future because petroleum still serves as the primary fuel for mobility purposes. There is however an indirect way in which the transportation sector could become more sustainable, and affect the balance of gas versus coal usage: the electrification of transportation. Assuming that technology advancements and public policy interventions make economical the use of electric vehicles, probably in urban and densely populated area centers (KEMA 2010), there will be an increase in electricity demand. Depending on the regimes adopted to cater for this additional demand and the extent to which this development becomes a significant source of additional electricity demand, the use of coal for electricity generation can be increased, especially in load pockets in the system (Kintner-Meyer et al. 2007). The final fuel effect will depend on both technology infrastructure (e.g., transmission lines), and the control strategies adopted for charging the batteries in the vehicles (Valentine et al. 2011).[1]

"More gas" and "less coal" could, though, give electric power and other delivered energy sectors a greener edge. But can gas actually be extracted, distributed and combusted at a smaller GHG footprint than coal even if the entire lifecycle is taken into account? Table 1 presents some key metrics that enable us to contrast the environmental performances (and ultimately the potential as GHG mitigation strategies) of both technologies.

Table 1: GHG Metrics

		CO2	CH4	NOx	O3	SO2
Tropospheric Concentration[1] (CO2: ppm, other: ppb)	**pre-1750**	280	700	270	25	
	as of 2000	388.5	1870	323	34	
Lifetime[2] (years)		100	12	114	hours	hours
Global Warming Potential[3] (CO2 standardized)	**20 Years Horizon**	1	72.0	289		
	100 Years Horizon	1	25.0	298		
	500 Years Horizon	1	7.6	153		
Net Radiative Forcing[4] (W/m^2)	**Abundance Based**	1.690	0.480	-0.110	0.370	-0.380
	Emission Based	1.600	0.990	-0.290	0.250	-0.250

Source: [1] Solomon et al. (2007), Blasing (2011), [2] Solomon et al. (2007), Blasing (2011), [3] Solomon et al. (2007), [4] Shindell et al. (2009), Solomon et al. (2007).

CO2 is the major GHG in the troposphere and it takes roughly 100 years to dissolve. Methane has a much shorter lifetime but its GWP greatly outweighs CO2. The concentration of NOx is relatively low but this chemical compound is even more powerful and also stays longer in the troposphere. Ozone und SO2 both dissolve quickly. Cumulatively, CO2, methane, and ozone accelerate the warming of the earth system, as indicated by the net radiative forcing parameters. NOx and SO2 are "cooling agents" (Shindell et al. 2009) with counterbalancing effects because they reflect a portion of sunlight back into space.

To solve our puzzle, it is useful to have a closer look at direct and indirect or fugitive emissions of coal, conventional gas, and shale gas. Direct emissions occur during combustion of natural gas and coal. Indirect emissions or fugitive emissions occur due to leaks earlier in the value chain, i.e. during stages of mining (coal), well completion, routing venting, liquid unloading, gas processing, transportation, storage, and distribution (gas).

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[1] A second alternative for increasing the sustainability of the transportation sector is the use of Liquefied Natural Gas (LNG) for commercial transportation and heavy-duty trucks, as T. Boone Pickens has bet on. Such a change is more on the oil vs. gas debate, but an interesting development in transportation.

Table 2: Emission Factors

Coal

	CO2	CH4	NOx	SO2	BC	CO	Hg	PM
Primary Energy[1](kg/GJ)	25.0		0.196	0.240	0.040	0.089	6.9E-06	1.179
Electricity[2] (kg/GJ_e)	78.1		0.614	0.750	0.130	0.279	2.1E-05	3.684
Fugitive[3]*	7.22	7.06						

Natural Gas

	CO2	CH4	NOx	SO2	BC	CO	Hg	PM
Primary Energy[4](kg/GJ)	15.0		0.040	3.0E-04	2.2E-07	0.017	0.000	0.003
Electricity[5] (kg/GJ_e)	25.0		0.066	5.0E-04	3.7E-07	0.029	0.000	0.005
Fugitive[6]*	1.5	$13.33p$						

Source: [1] NETL (2009), Hayhoe et al. (2002), [2] Hayhoe et al. (2002), [3] CO2: Spath et al. (1999), CH4: Wigley 2011, [4] NETL (2009), Hayhoe et al. (2002), [5] Hayhoe et al. (2002), [6] CO2: Howarth et al. (2011), Santoro et al. (2011), CH4: Wigley 2011.
* CO2: kgC/GJ CH4: TgCH4/GtC.

At a mass (kg) per energy (GJ) level, the average[2] emissions of CO2, NOx, SO2, black carbon (BC), carbon monoxide (CO), Mercury (Hg), and Particulates (PM) over the lifetime of a GJ of coal exceed the respective level of a GJ of conventional gas. The same holds true when power plant efficiency levels (32% LHV for coal-fired plant, 60% LHV for a NGCC) are taken into account, thus receiving emission factors with mass (kg) per electricity (GJ_e) units.

This picture changes dramatically if three aspects are considered that shaped the coal-to-gas issue in the recent past. First, referring to both Table 1 and 2, low levels of NOx and SO2 from gas combustion may be "a boon to public health (…) for global warming, though, gas is a mixed blessing" (The Economist 2011b) because it reduces the magnitude of the two "cooling agents."

Second, recent studies (Howarth et al. 2011, Wang et al. 2011, Wigley 2011) shed light on fugitive methane emissions[3] by tracking methane leakages and losses from the cradle (wellbore construction) to the grave (transmission and distribution to the end-users). They revealed much greater fugitive methane emissions than had previously been reported. Wigley (2011) models 7.06 TgCH4 per GtC of CO2 emissions for the coal lifecycle[4] and

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[2] The average values represent the coal portfolio in the U.S. where 65% comes from deep mining and 35% from surface mining. The average also takes into account that emission factors rank from 16.5 kgC/GJ for bituminous coal to 29.5 kgC/GJ for lignite. The overall average of the entire portfolio is 25.0 kgC/GJ. There is less variation in the natural gas portfolio since gas naturally contains 90% to 98% methane. The representative average is 15.0 kgC/GJ (Hayhoe et al. 2002).

[3] CO2 also leaks but since its 20-years GWP is 72 times lower than the 20-years GWP of methane, the net effect on global warming is much less sensitive to a change in indirect CO2 emissions than in a change in indirect CH4 emissions. These are the emission factors the analysis bases upon: Coal mining: 2.5 kgC/GJ; Coal transportation: 4.7 kgC/GJ; total indirect coal emission factor: 7.2 kgC/GJ (Spath et al. 1999); Conventional gas: 1.5 kgC/GJ (Santoro et al. 2011); Shale gas: 1.54 - 1.95 kgC/GJ (Wood et al. 2011).

[4] Spath et al. (1999) calculated 7.27 TgCH4/GtC. Wigley (2011) says surface mines emit 1.91 gCH4/ton of coal while deep mining contribute 4.23 gCH4/GtC. The weighted average of 3.42 gCH4/ton takes into account the 65% to 35% ratio between coal from deep and surface mines in the U.S. In sum, Wigley (2011) calculates the fugitive methane emissions as 6.85 TgCH4/GtC. He then proceed by taking the average of Spath et al.'s (1999) and his own estimates, 7.06 TgCH4/GtC.

13.33*p TgCH4/GtC for the conventional gas lifecycle, where p represents the leakage rate. Howarth et al. (2011) estimate leakage rates between 1.7% and 6.0% for the conventional gas lifecycle. This yields total fugitive emissions for conventional gas that range between 22.7 and 80 TgCH4/GtC, a footprint that exceeds fugitive methane emissions from coal between 3.2 and 11.3 times. As shown in Table 1, methane is a much more powerful driver of global warming; therefore, even the smallest of changes matter. Howarth et al. (2011) were the first to show that the conventional gas lifecycle comes with an only slightly smaller GHG footprint for the 100-years interval than coal. For the 20-years frame, conventional gas and coal actually level off. In other words, an increase in conventional gas accelerates global warming almost as much as an increase in coal would do.

Third, Howarth et al. (2011) estimated fugitive methane emissions from the shale gas lifecycle to be 30% to 50% higher than the ones from conventional gas. Leakages increase from 1.7% - 6.0% to 3.6% - 7.9% and are partially caused by early stage venting to find the best gas flow rate. A portion of the chemical fluids that were pumped into the well to fracture the low permeable shale beds also releases methane to the atmosphere when the fluids return to the surface. After the fracturing took place, the drill out phase leaks methane, too (Howarth et al. 2011). In the 20-years interval, methane emissions from shale gas exploitation are 1.4 to 3.0 times higher than CO2 emissions (Wang et al. 2011). Compared to coal, the shale gas GHG footprint varies from 15% to more than 100% bigger over the 20-years footprint. The 100-years interval brings them closer together again because methane dissolves faster.

These numbers are, though, debated. If Howarth et al. (2011) are right in their investigation, a shift from coal to shale gas would not slow down but rather accelerate global warming, unless the methane leakage rate of the shale gas lifecycle is kept below 2-3%. A recent study of the NETL (2011b), however, provides a more nuanced assessment. It conclusively shows that Howarth et al.'s basic assumptions, that 100% of the drilled shale gas is actually also delivered to the end user, is not accurate because 11% are used for powering well engines and other purposes. Second, the fugitive emissions are estimated to be 1.1% for the extraction and 1.7% for the entire lifecycle only. This means, p actually ranges below the crucial threshold of 2-3%. Thus, shale gas has a smaller GHG footprint than the coal lifecycle. Over the 100-years interval, the GWP of the shale gas extraction (32.3 lb CO2_e/MMBTu) ranks only slightly above the national GWP average of gas extraction (25.2 lb CO2_e/MMBTu). Over the 20-year interval, the shale gas extraction GWP (76.6 lb CO2_e/MMBTu) does not exceed the domestic gas average of 56.8 lb CO2_e/MMBTu by much either. Coming back to the core question, shale gas, over the course of its entire lifecycle, performs better than coal. This can be seen in Table 3.

Table 3: GWP Estimates

	Avg. Coal	Avg. Conv. Gas	Avg. Unconv. Gas
20-years horizon (lb CO2_e/MWh)	2,661	1,484	1,613
100-years horizon (lb CO2_e/MWh)	2,453	1,140	1,179

Source: NETL (2011b).

To sum up, Howarth et al. (2011) find that a shift from coal to shale gas would not bring benefits to the GHG footprint, but the NETL rebuts them by more nuanced modeling. Certainly, the subject needs further investigation. Today, it seems though that shale gas comes with a leakage rate of 2-3%. As a consequence to the high sensitivity of the footprint towards methane, the shale gas has a bigger GHG footprint than conventional gas but a smaller one than the coal lifecycle.

2.1.2 Quality of Life – Is Shale Gas a Boon to Public Health?

Our focus now turns from the macro (global climate change) to the micro (individual wellbeing) level. The exploitation and combustion of coal and gas emits not only GHG but also criteria air pollutants that harm the quality of life for people living close to a well, mine, or power plant. Some chemicals, such as neurotoxic mercury, travel. Thus they also affect the health of people living further away. Coming back to Table 2, natural gas clearly performs the best. The coal lifecycle emits more NOx, SO2, black carbon, CO, mercury and particulates than the conventional gas and the shale gas lifecycles at a mass per energy base. A shift from coal to gas thus reduces the overall likelihood of heath problems affecting the nervous system, inner organs, and the brain (Kargbo et al. 2010). Less sulfur in the atmosphere can also free cities from smog and thus fight lung cancer. In the U.S., 23,600 premature death and approx. 500,000 cases of illness were caused by soot in 2010. A mineworker is twice as likely as an oil worker to die at a work related accident (The Economist 2011c).

Various studies (Epstein et al. 2011, Greenstone and Looney 2011, Levy et al. 2009, and most broadly Stern 2006) attempted to internalize the "social cost" of pollution into the cost of an energy unit. The studies have been imperfect, to put it mildly, because the cost of externalities such as the harm caused by smog are not easily calculable. Nevertheless, even rough estimates indicate that the externalities caused by the deployment of coal outweigh the external costs of gas. Greenstone and Looney (2011) of the Brookings Institute estimate 3.4 cents/kWh of health related costs on top of the average coal electricity price of 3.2 cents/kWh. Levy et al. (2009) focus on health costs from coal related NOx, SO2 and PM2.5 and reveal a highly unequal geographic distribution of cost in the United States. The median of their 407 plants sample ranges at 0.14 cent/kWh. This means, coal can seriously affect public health, and people are indirectly paying for these externalities. The magnitude of the effect, and thus the variance of the distribution, depends on the distance to the next coal plant, the plant's air quality control system, and wind direction. Epstein et al.'s (2011) best estimates of health costs are even higher (17.84 cents/kWh).

On the individual side, the private valuation of pollution has been analyzed from the perspective of its effects on real estate values, focusing on electricity generation (Davis 2010). This benchmark of comparison is not useful to separate the tradeoffs between coal and natural gas, because the overwhelming majority of new plants have been combined cycle natural gas, and therefore the number of coal plants is not high enough to draw a significant conclusion. Given the decision to advance exploration in large areas of Pennsylvania, the private valuation of property can be analyzed with the help of newly released data from this area, but this is out of the scope of this article. Overall, there is evidence that people incorporate some information from pollution into their value appraisals (Sanders 2011), and therefore this would give a bound on the airborne effect of shale gas exploration vs. coal. Nevertheless, the private valuation of airborne contamination derived from shale gas and coal, both from direct sources like extraction activities, and indirect sources like electricity production will depend on the direct comparison of the effects of gas versus coal. The lack of data to correctly estimate these effects calls again for the need for more research on this. There are ongoing efforts initiatives to analyze other health effects and its effects on private perception (UPitt 2011).

Focusing then on the social valuation of pollution, the gas price would only rise by 4% (Greenstone and Looney 2011). Shale gas drives up the health costs a little bit because CH4 emissions are higher. Furthermore, the well pad construction and initial fracturing stages contribute additional PM. Sporadic flaring also causes additional CO as do diesel engines (NETL 2009). Comprehensive before-and-after assessments are needed to make decisions on a more detailed base. The larger point, though, should remain unshaken; conventional gas and shale gas rank first and second. Coal comes third.

2.2 Water

2.2.1 Withdrawal and Consumption – How Much is too Much?

The U.S. uses 410,000 million gallons of water per day (460,000 thousand acre-feet per year). 85% is freshwater and 15% is saline water (Kenny et al. 2009). 39% of the freshwater is withdrawn to cool the turbine generators for thermoelectric power generation. 1% is used by the mining sector. A large portion of the withdrawal re-enters the water loop, thus the actual consumption of freshwater for thermoelectric systems and mining accounts for 3% and <1%, respectively (NETL 2008). Table 4 presents water intensity metrics for the shale gas, conventional gas, and coal lifecycles.

Table 4: Water Metrics

Average

Water Consumption (litres/MWh) [1]	**Coal**	**Conv. Gas**	**Shale Gas**
…for extraction	11-53	negligible	29.4
…for processing	0-109	57.5	57.5
…for transport	negligible	28.8	28.8
…for combustion	1970 - 3940	490-1,900	

Plant Specific

Water Usage (gpm/MW) [2]	**SCPC***	**SCPC w CCS***	**NGCC***	**NGCC w CCS**
Consumption	7.7	15.7	3.3	6.3
Withdrawal	9.7	20.4	4.3	8.4

Source: [1] Grubert and Kitasei (2011), [2] NETL (2011a), NETL (2008), * SCPC: Supercritical Pulverized Coal, NGCC: Natural Gas Combined Cycle plant, CCS: with Carbon Capture and Storage.

Keeping in mind the considerable fluctuations due to technology, location, season, and researcher biases, conclusions can still be drawn. Coal has an advantage in transportation. Natural gas consumes less water for combustion because NGCC plants run almost twice as efficient as coal plants. The processing stage comes with too much facility specific variation to make an overall statement. Finally, the first phase of the lifecycle (extraction) strongly depends on whether the gas is drilled conventionally or unconventionally.

Shale gas extraction requires 50 to 100 times more water than the extraction of conventional gas. This is because one of the additional steps, hydraulic fracturing, uses significantly more water upfront to unlock gas from the resource rock. Drilling in the Marcellus Shale needs 80,000 gal of water per well. The fracturing adds another 3,800,000 gal. Total water use per well sums up to 2,700,000 gal in the Barnett Shale, 3,060,000 gal in in the Fayetteville Shale, 3,700,000 gal in the Haynesville Shale, and 3,880,000 gal in the Marcellus Shale (NETL 2009).

To sum up, the shale gas lifecycle estimate for water consumption is higher than for conventional gas. However, shale gas needs less water than coal (Grubert and Kitasei 2011). As mentioned above, the estimates vary greatly from well to well. Therefore, a statement about the performance of water consumption should always be well specific.

2.2.2 Public Safety – How Many Flaming Water Faucets are there?

One of the main reasons for the moratorium declared for New York stems from the perils of water contamination. There are three major public safety concerns with respect to shale gas production and water. First, the fracturing fluid could contaminate groundwater aquifers. Typical fracturing operations add 3 to 12 chemicals (see details on fracfocus.org), or 2% to 98% of water and sand and pump this cocktail under high pressure into the well. The main purposes of the acids and other toxics are the reduction of friction and to prop open the rock fractures (NETL 2009). Second, methane could seep into the water supply system if the underground cement casing of the borehole does not completely isolate gas from soil. Third, naturally occurring radioactive material (NORM) can be carried to the surface as part of the flow-back. The background radiation is very low, but the sludge can cumulate in the vessels and thus threaten the health of workers (NETL 2009). Radium can also cause cancer when contaminated fish or water enters the food chain.

In fact, the possibility of water contamination has already shaped many of the practices adopted by industry, like the cement casing of the annulus of the wells (Harrison 1985). Whenever possible, well operators use non-potable water, with total dissolved solids greater than 10,000 and up to 30,00 thousand ppm. In general terms, it is more cost effective to re-use the flow back water used in the hydraulic fracturing process than to clean up to the levels necessary for surface discharge. The flow back fluids have increased levels of salinity, as well as some metals (barium, strontium), low level radionuclides and some volatiles (Burnett 2009).

The industry has taken the practice of recycling the water used, and as of now around 70% of the injected water is reused in further explorations. While it is possible to clean up to 80 % of the flow back water using reverse osmosis and advanced membranes, this process is very energy intensive, and therefore not widely usable (Pickett 2009). Another consideration for the fracturing process is the management of the waste-water that is not recycled into the process. The available alternatives include injecting it into disposal wells, under the underground injection control program (UIC) administered by the Environmental Protection Agency (EPA), or deliver the waste water to treatment facilities, sometimes managed by the municipalities (API 2010). While the UIC programs are regulated, there is a risk that municipalities do not have the infrastructure or the technical capabilities to treat the waste-water (Arthur et al 2008). A proper oversight by the state agencies is needed in this case, or having EPA as the agency in charge at the federal level.

Even though, industry has taken these decisive steps, various incidents have drawn public attention. Next to a Chesapeake facility in LA, cows drank fracturing water and died. Arsenic was found in drinking water (Epstein et al. 2011). Cabot Oil & Gas Corp. had to supply residents in PA with bottled water after a well explosion caused contaminated groundwater. *Gasland* was nominated for an Academy Award by showing flammable tap water. Residents in CO, OH, PA, TX, and WV have reported methane enriched drinking water, too (Urbina 2011c). In Dimoch, PA, gas leaked into a water well and exploded (Kerr 2010). Just recently, EPA stated that from analysis done in Pavillion, Wyoming "the data indicates likely impact to ground water that can be explained by hydraulic fracturing", the first time such direct link has been suggested by the federal agency (DiGiulio et al. 2011).

The question whether these threats are rare events (caused by poor completion and human error for instance) or systematic problems (without quick technical fixes) ultimately decides the public safety aspect of the shale gas vs. coal debate. As pointed out in subsection 2.1, decision-makers need rigorous scientific analyses that prove if there is a causal relation between the likelihood of such events and fracturing activities. Osborn et al. (2011) is one such study for the Marcellus and Utica Shales in PA and NY. They frequently found methane in the groundwater within a 1.0-kilometer annulus around fracturing operations. The magnitude increases sharply closer to the well. In comparison, significantly lower CH4 concentrations were recorded in geologically similar areas, which lead to the conclusion that the link is causal. The study did not reveal robust evidence for the other hazard, fracturing fluids contaminated water, though (Osborn et al. 2011). To use the words of Susan Tierney, "The issues of hydraulic fracturing are less about the fracturing than they are about drilling through the aquifer" (Powell 2011).

There have been only a few reports on NORM because shale gas plays are not required to monitor radium concentration. The New York Times cited a confidential 1990 study from the American Petroleum Institute that finds "potentially significant risks" from radium in wastewater in Los Angeles (Urbina 2011c). Further, wastewater samples from the Marcellus Shale exceeded radium-226 safety standards as much as 267 times (Kargbo et al.

2010). It is a political objective to close the so-called “Halliburton-Loophole” that exempts hydraulic fracturing from the Safe Drinking Water Act (Howarth and Ingraffea 2011).

Altogether, there have been few reports of major violations and environmental damages caused by operation of the wells (Considine et al. 2011), as is usually the case in pollution studies (Gamper-Rabindran and Finger 2011). The major categories of observed damages are major spills, cement and casing violations, blowouts and venting, and stray gas, affecting all three of the dimensions considered (air, water and land). The increased exploration in the Marcellus shale has increased the number of violations, though in percentage terms it remains relatively low. Nevertheless, the potential effects this can have on ecosystems need to be taken into account for proper management of the system.

To sum up, methane leaks systemically into groundwater at an annulus of 1.0 kilometer. This is a significant local disadvantage for shale gas production, like local air pollution for coal mining examined in subsection 2.1.2. While other dimensions (water withdrawal and consumption) tend to favor natural gas over coal, solutions to secure drinking water supplies for people living close to shale gas plays are needed.

2.3 Land

Besides capital, labor and mineral resources, coal and natural gas production also utilizes the factor of land. Mining and drilling affect landforms, watersheds, habitat quality, soil, vegetation, biodiversity, and can even cause small-scale earthquakes. Used land can mostly be restored but reforestations can take up to 300 years. Direct land use embraces land transformation caused by mining and drilling zones and electricity generation. Indirect land use is related to secondary steps in the fuel lifecycle such as transportation infrastructure, and the land used caused by the energy inputs into mine and well processes (Fthenakis and Kim 2009).

A closer look at the stages of the lifecycles reveal the unequal distribution of land use from extraction to combustion. Since it is problematic to weigh intensity against the size of land use, these figures are debatable. Fthenakis and Kim (2009) find that average surface and in-situ coal (bitumen) extraction in the U.S. uses 400 m2/GWh and 200 m2/GWh of land, respectively. Most intensive is the removal of entire mountain-tops for coal mining. Natural gas needs less land, 110 m2/GWh, on average.

An additional impact caused by the gas exploration effort is the disruption of natural habitats, and the effects such disruption have on ecosystems and indigenous species. An indirect effect of the water management problem is the possible influence it can have on forests and its decimation in polluted areas (Adams et al. 2011). With the current exploration under way in Pennsylvania, a range of between 34,000 to 82,000 acres could be cleared for shale gas exploration. This development could then lead to threats to rare animal species, as well as a decrease in the amenity value these forests have, in areas that were relatively untouched (Johnson 2010). Since the area needed for extraction of horizontal gas is much smaller than those required by conventional gas and coal, the relative comparison favors shale gas exploration. Yet, the absolute magnitude of the exploratory effort, the ecological value that the lands where this effort is conducted have for rare species, and the fact that in many cases the target exploration areas overlay riparian areas, streams, and wetlands, adds to the land effects.

The picture changes when the fuels are transmitted. (Jordaan et al.2009) introduce edge-effects, the width of the pipeline plus a buffer zone around, to fully cover the disturbance caused by natural gas pipelines. Incorporating edge-effects cumulate to 130 m2/GWh of land use for gas transmission in the U.S., which is the biggest portion of the gas lifecycle (Fthenakis and Kim 2009). 70% of coal in the U.S. is shipped on railroads. Assuming average distances to power plants, and 1600 TWh total coal power production, coal transportation uses 30 to 80 m2/GWh, or 23% to 61% of gas transmission. Land use for electricity generation accounts for the smallest part. Less land transformation, approx. 5 m2/GWh, is needed for NGCC plants because of higher efficiency rates and less storage space than coal (6 to 18 m2/GWh) (Fthenakis and Kim 2009).

The boom-bust cycle effects characteristic of the extraction of non-renewable resources, like is the case of shale gas, leads to other effects on the land usage, more related to human geography, and is the development of infrastructure that will be used for transmission of both products (pipelines for gas), and by-products (e.g. pipelines transporting water for the process, Christopherson and Rightor 2011). The construction of indirect infrastructure supporting the shale gas exploration activity will have additional effects to similar endeavors for the coal industry. While some of this construction effort, for example the development of housing facilities and amenities for workers moving to the exploration areas, have similar impacts to those observed in coal exploration, the pipeline infrastructure for water treatment is specific to the shale gas industry. The infrastructure will be divided between sourcing pipeline infrastructure, carrying water to be used for the exploration effort, and pipelines transporting used water for treatment in appropriate facilities (King and Webber 2008), adding to the total dedicated physical stock necessary for shale gas development.

The shale gas lifecycle promises to use less land in the exploration site than both other lifecycles. One reason is that multiple horizontal wells can be drilled from a single well pad, thus reducing the land intensity of a well. For instance, in the Fayetteville Shale, four horizontal wells can deliver the same amount of gas as 16 vertical wells while land disturbance is only 10% that of the 16 vertical wells. As a consequence, fewer infrastructures are needed which in turn reduces surface disturbances. Furthermore, shale gas explorations have often returned to former oil and gas rich areas, such as the “oil patch” states. Thus, the net effect of shale gas operations can be kept lower if existing land uses are subtracted. Still, shale gas plays turn large areas into industrial zones. Well pads range from 80 acres in New Albany, to 160 acres in Marcellus and Barnett, to 560 acres in Haynesville and 640 acres in Woodford (NETL 2009). As always, the impact is a matter of perspective. What may be a small share of total U.S. land transformation for natural resource exploitation can be a challenge to a local community that neighbors a new well pad.

To sum up, lifecycle analyses found shale gas production using least land, conventional gas more, and coal most. Land use for natural gas ranges around 200 to 300 m2/GWh depending on location and pipelines and is similar to the land use of solar PV systems over a 30-years time interval. Land use for surface coal production is as high as 950 m2/GWh in Kansas (Fthenakis and Kim 2009).

3 Discussion

The assessment showed that the conventional gas lifecycle performs better than the shale gas lifecycle in all but the land usage dimension. This comes as no surprise because hydraulic fracturing and horizontal drilling, the two additional extraction stages upfront, make shale gas production a more emission and water intensive endeavor. Drilling multiple horizontal wells from one pad, however, reduces overall surface disturbances.

With conventional gas supply on a steady decline, the key question is whether shale gas should replace coal, “the devil we know.” Locally, shale gas emits fewer criteria air pollutants than coal. Therefore, a shift from coal to shale gas would benefit public health, local environmental protection, and the safety of workers. Globally, the GHG footprint of shale gas is likely to be smaller than the coal footprint. Thus, a shift would slow global warming and decrease related cost for climate change adaptation measures – assuming all other factors remain constant. Water front-loading makes shale gas extraction more water intensive than coal production. Over the entire lifecycle, however, power from coal consumes more water than power from shale gas because coal-fired plants are less efficient than NGCC. Shale gas drilling also causes less surface disturbance than coal mining. However, it must be noted that the hazard of methane leaking into groundwater aquifers does affect the safety of drinking water supply.

A drawback of shale gas exploration still lies in the lack of information available, including health cases, specially related to vulnerable populations like infants and elderly people. Such a problem claims for the need to collect data that helps to assess the possible health effects of shale gas exploration. Since the adoption of shale gas has been a precipitous event, in which states either opt in rather quickly or delay their decision to join, there is no way to assign treatments in a controlled way. Therefore, for a long-term assessment of the health effects of shale gas exploration, a data collection effort using the local outlets available (e.g., health centers, retirement communities) can be undertaken for evaluation of these effects (Lauver 2011). The collection of such data would require the inclusion of basic information that helps to point out the cause of the ailment (airborne, water related, food consumption, etc.).

Despite the risks associated with shale gas, this article advocates for more shale gas and less coal due to the severe impact of coal on the quality of life and environmental protection. We of course acknowledge that most of the quantifications come with considerable degrees of uncertainty because stringent peer-reviewed investigations are rare. With increasingly more attention on shale gas – in the addition to the fact that the EPA is expected to publish key assessments of hydraulic fracturing in 2012 and 2014 – this situation is likely to improve.

Besides closing the uncertainty gap, it is useful to answer two logic questions that help solve our puzzle. First, are there technical solutions available to minimize negative impacts on air, water, and land in the short term? Second, can shale gas be a bridge fuel for renewable energies in the long term? America should invest in more shale gas and less coal, if problems can be fixed and shale gas does not significantly divert investment from allocating for renewable energy systems.

3.1 Technical Fixes – How to Minimize Environmental Impacts?

Air. There are technical solutions to mitigate GHG emissions and air pollution. Reduced emission completion (REC) technologies can lower the methane leakage rate by 90%. New wells should always incorporate REC while old facilities are barely feasible to upgrade. Still, infrared cameras can monitor fugitive emissions even for older wells in order to spot leakages and fix engines and storage tanks (Howarth et al. 2011). Natural gas can drive engines at 85% less VOC pollution than diesel (Kargbo et al. 2010). Over the long term, Wang et al. (2011) suggest to link shale gas wells to CCS technology. When operations come to an end, captured CO2 from coal-fired plants could be injected into “empty” shale gas wells to store CO2 under the low permeable seal rock.

Water. Available technology can combat the perils of water contamination and reduce overall fresh water consumption. Current well construction technologies allow to reduce the risk of water contamination. Flow-back water can be re-used as seen in the Marcellus Shale, where 90% of water returns to the water loop. Fracturing water can also be partly recycled into fresh water. In that case, specialized water treatment facilities can better cope with the large-scale influx than local and municipal facilities. If flow-back water cannot be recycled, underground injection can be an alternative for disposal (DOE 2011a). In the first place, fracturing fluids can also be produced from soy and palm oil to reduce the usage of chemical additives. In Canada and the Marcellus Shale, liquefied petroleum gas and liquefied CO2 were used instead of water intensive fracturing fluids to transport the propane into the well, thus minimizing the portion of water needed for hydraulic fracturing (Kargbo et al. 2010). There are technologies also available for the management of the salty residual water and its return to groundwater (Myers 2009).

Land. Shale gas already holds a land use advantage in comparison to conventional gas and coal. Still, even more wells can be drilled from fewer pads. Sound walls around the well pad reduce noise and smell for residents and wildlife. Replacing trucks by pipeline helps to minimize drilling related traffic, dust, and street erosion (NETL 2009). Finally, wastewater should not re-enter the water cycle without previously being checked for radioactivity (Kargbo et al. 2010). The use of spatial analysis tools and current information on species inventories can also help to track the effects on natural environments and the biodiversity associated to it (PANHP 2011).

3.2 Trade-Off – From a Golden Age of Gas to a Golden Age of Renewables?

It is often argued that shale gas is just more of the same from a pool of conventional resources that harm public health and environmental protection. Howarth and Ingraffea (2011) and many environmentalist groups have successfully pointed out that shale gas bears the potential to distract politicians and investors from boosting renewable energy deployment, setting up sustainable energy portfolios, and fighting global warming. But will shale gas actually postpone the day for renewable energy to achieve grid parity (i.e. produces power at market price level) and for storage technology to counterbalance intermittency gaps?

Politics. The first assumed trade-off between political attention for renewable energies and political attention for shale gas does not stand up under scrutiny. First, there has not been evidence that the capability or willingness of regulatory agencies, such as the EPA or legislative bodies, to support renewable energies has been cut back and shifted to shale gas. Initiatives, such as stricter ozone controls, a cap-and-trade system for CO2 emissions, or further subsidies for solar PV developers, have faced challenges. We can ascribe these difficulties however to the slumping economy and the beginning of the election cycle.

Second, renewable energy policies have not been affected by shale gas. The Renewable Portfolio Standard (RPS) in 30 states + D.C. is the most widespread and most effective tool to increase power generation from renewable energy sources in the U.S. today (Yin and Powers 2009). The target margins became even more ambitious in recent years, not less (DSIRE 2011). Shale gas is not eligible in any of the states to fulfill the quota, thus utilities are not allowed to replace renewable energies by shale gas to meet their requirements. Since NGCC can quickly ramp up and down, shale gas is best equipped to serve as the fill-in power for renewable energies (MIT Energy Initiative 2011). Further investment in both renewable energies and shale gas may thus actually go hand in hand.

Third, from a game theory perspective, advocates of shale gas may find it easier to argue for renewable energy subsidies. Shale gas can thus be a bargaining tool in negotiations enabling the negotiator to offer a balanced portfolio, a backup for intermittent renewable energies, and, if taxed properly, a revenue to subsidize renewable energies.

Investment. The second assumed trade-off between investment in renewable energies and investment in shale gas does also not stand under scrutiny. The hypothesis that investment flows are diverted from renewable energies and benefit shale gas production instead implies that the production factors capital, labor, and land are scarce and also equally applicable for both shale gas and renewable energy production. First, none of these production factors is limited to such an extent that renewable energy installations cannot be built because factors are already bound to shale gas operations or vice versa. There is actually a surplus of labor from depleting coal and oil branches who would choose to work for shale gas companies over unemployment.

Second, the assumed competition over land is not likely either, because renewable energies are decentralized sources of energy; therefore, they do not necessarily occupy the same space as shale gas plays. Further, shale gas drilling often returns to conventional gas and oil areas and thus re-uses land instead of taking it away from renewable energies.

Third, assuming that shale gas diverts capital from renewable energies also neglects that the current capital flow (USD 30 billion in 2010 (REN21 2011)) is mainly policy-driven. In other words, unless the command and control schemes remain ambitious, this investment flow is not sensitive to shale gas investment. Instead, shale gas may compete for capital from other market competitive fuels that are not eligible to meet the RPS quota, e.g. coal and petroleum. In the end, investment into shale gas transmitting pipelines and their open-access rule today may even foster biogas tomorrow. Biogas can be blended into natural gas, thus lowering transmission cost of renewable gases because infrastructure is already in place.

Prices. Low gas prices make renewable energy relatively less competitive. That is a peril for further market penetration of renewable energies. Still, it is not certain that gas prices remain low if shale gas must meet tighter regulatory standards. Moreover, the ultimate price competitor in the power sector is coal (and nuclear and hydropower for base load capacity), not gas. Thus, the crucial challenge to achieve grid parity is to meet the coal price. This objective can be approached from two sides: increased cost effectiveness of renewable energies and storage solutions by further technological innovation; or internalization of the cost of carbon into the price of coal. Both ways are relatively independent from the shale gas issue. To sum up, shale gas holds the potential to smoothen the transition to an age of renewable energies but we must be aware of the potential of low gas prices to cause temporarily a spike.

Generally, the movement towards a low carbon economy requires changes in the management of the current generation assets (Varaiya et al. 2011). While the marginal cost of generating electricity using renewable energies equals zero, there are impediments to the extent to which this renewable energy is able to be used in load centers. On the one hand, and for the Northeastern portion of the U.S. where shale gas will play a role, the changes in electricity load are mostly negatively correlated with the availability of renewable resources, leading to large amounts of spillage of the renewable energy whenever this energy is available (GEEnergy 2010, NREL 2010). Moreover, the congestion in transmission lines that builds up during high demand periods (e.g. summer afternoons in New York City) leads to the creation of load pockets, that further decrease the ability to use this cheap energy (Lesieutre et al.2005). On the other hand, renewable resources are not dispatchable at will, leading to sudden decreases in the availability of usable energy available. In both cases, the need for generation assets that can operate continuously at low emission levels and ramp quickly when needed is pivotal to the stability of the system and the better use of the available renewables without harming reliability (NERC 2011).

Locations with congested transmission systems and limited opportunities for lines expansion are usually served by legacy generators that can be replaced by cleaner sources of energy (DOE 2009). While the implementation of RPS allows for optimal selection of the renewable of choice, given the geographical characteristics of the North Eastern U.S., wind turbines are the technology that more economically serves this purpose.[5]

A collateral damage of the Japan's nuclear crisis was the increased support for phasing out aging nuclear plants, and an idiosyncratic case for New York State is the projected closure of the Indian Point Nuclear plant. This plant provides 2,000 MW of base load capacity for the area of New York City and Westchester, and with its shutdown, besides a possible rise in prices of energy, there is a need for increased generation capacity (The New York Times 2011). A possible alternative is the use of transmission lines from Canada (Hydro-Quebec), but the time required to obtain permits and build such lines limits the short-term viability of this project. The impact of this closure, and the future constrained availability of nuclear sources further exacerbate the need for enough adequacy in the system.

Focusing then on supply side mechanisms, with a constrained transmission system, fast ramping generation plants will be needed and a good option is the use combined cycle natural gas turbines, with efficiencies close to 60% (Siemens 2011). Beyond the tradeoff between shale gas development and wind energy, the question from the supply side is the capacity of the pipelines to transmit gas to urban centers (NYSERDA 2009), and the tradeoff between gas for heating and gas for electricity. This question is actually more relevant during the winter season, when the use of gas for heating purposes competes with the gas used for electricity generation. But gas is more a complement, necessary to firm the wind resource, rather than a substitute. The system still needs the development of clean sources of gas and expanded infrastructure, replacing aging coal capacity. In fact, better load management (Callaway and Hiskens 2011), and specifically the temperature-sensitive load, can lead to better usage of the available resources, including renewables, and decrease in the congestion in the transmission system, and subsequent elimination of load pockets in urban areas. Such mechanisms are more demand oriented, and while we advocate for those, they are not relevant to the question of gas vs. coal on the supply side.

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[5] Green rooftops and solar energy can play a role in urban environments. Still, the bulk of the RPS is likely to be covered by wind resources.

3.3 Regulation – How to Achieve Compliance?

This bridge is not being built unless shale gas operators actually implement the solutions outlined in subsection 3.1, Jackson et al (2011), or the First and Second Ninety Day Reports of the SEAB Shale Gas Production Subcommittee (DOE 2011a, 2011b). Their compliance requires political action in the form of market interference. Without clear signals, some operators will keep on free-riding on the public goods of health, safety, and environmental protection.

What should be done? Some, e.g. the Texas Governor Rick Perry in his "Energy Plan", would like to expand drilling as soon as possible. Others, e.g. the State of New York, have a moratorium in place (Oppel 2011). The solution lies somewhere between these extremes. Economic theory usually suggests legislation that internalizes both actual cost of production and external cost borne by the public and the environment into the producer's cost-benefit calculation. Therefore, the optimal tax equals the marginal external cost. As has been mentioned at multiple points throughout this article, such a "Pigouvian" tax would always be imperfect because social and environmental costs are difficult to quantify. Another obstacle lies in the current state of American politics since many politicians sharply oppose any kind of taxation. From a theoretical point, though, a carbon tax would be an efficient tool to divest in old coal plants and replace their capacity by new shale gas fired plants.

Since raising taxes is not likely, regulation emerges as the second best solution. The full lifecycle of the shale gas process needs to be analyzed to properly target the efforts required to allow for a sustainable development of the industry. The infrastructure for sourcing and disposal of waste water in the business-as-usual operation can be managed to minimize the impacts on the areas and ecosystems affected (Rahm 2011), and at the same time, targeted regulation can be used to deal with eventual impact of spills and unexpected failures in the system. A less regulatory approach would be the encouragement to implement preventive management practices, with reporting of key indicators (dashboard metrics) and contingency planning (Riha and Rahm 2011). We cast a shadow of doubt on the effectiveness of self- regulating mechanisms for companies, as evidence from voluntary emissions reduction in the manufacturing sector show (Gamper-Rabindran 2006).

The case for hybrid regulation is compelling. First, gas extraction does not yet fall under the EPA's Toxic Release Inventory. But public trust can be won (back) by disclosing chemicals used for fracturing and other steps. Increased transparency and information can also educate people about the risks and benefits of shale gas extraction (Powell 2011). Second, the Halliburton Loophole mentioned above should also be closed quickly to monitor NORM. Third, tripartite organizations, such as STRONGER, reduce transaction costs by coordinating dialog and cooperation between stakeholders from industry, society, and government. Fourth, more data should be collected to help researchers work on the crucial lack of peer-reviewed lifecycle assessments (Kerr 2011). Public and private R&D

can help to explore the few high return innovations in a strongly tailed distribution of technological ideas (DOE 2011b). Fifth, sanctions for non-compliance or contamination of the environment are too low to be effective and a greater emphasis should be put on well construction and integrity. The New York Times found that a profit of a single day for some of the companies often exceeds total annual fines for harming the environment (Urbina 2011c). Sixth, if drilling permits are auctioned by the state, an environmental performance record could be demanded from any bidder, thus excluding the free-riding operators. Seventh, the industry could learn from the Deepwater Horizon disaster and set up a fund to insure collectively against high impact, low frequency events. Generally, the framework should respect the subsidiarity principle in order to appreciate fully special local expertise, the already existing regulatory infrastructure at the state level, and state-by-state learning. Regulatory federalism still allows an issue to elevate to the federal level if a county or state level is unable to cope with it (Fitzgerald 2011).

3.4 Conclusion – Should Shale Gas Power America?

Section 1 illustrated the benefits in economics and energy independence that result from the extraction and deployment of domestic shale gas reservoirs in the United States. Section 2 showed that a shift from coal to shale gas would also benefit public health, the safety of workers, local environmental protection, water consumption, and the land surface. Most likely, shale gas also comes with a smaller GHG footprint than coal. However, shale gas extraction can affect water safety. Section 3 presented two related aspects that exemplify how shale gas can be more beneficial in the short and long term. First, there are technical solutions readily available to fix the most crucial problems of shale gas extraction, such as methane leakages and water hazards. Second, shale gas is best equipped to smoothen the transition to an age of renewable energies. Finally, section 3 recommended specific regulation that can incentivize companies to follow accepted protocols, without taxing their operations.

This article then goes along with Engelder (2011), the MIT Energy Initiative (2011) and others to recommend more shale gas and less coal. Less efficient coal-fired plants should be replaced by shale gas powered NGCC. Still, tighter regulation is decisive to minimize environmental costs. As Robert K. Sweeney, the chairman of the NY Assembly Committee on Environmental Conservation, remarked: “The gas isn’t going anywhere, so what’s the rush? If we do it, we should do it right” (Schmidt 2011).

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