WILL NATURAL GAS FUEL AMERICA IN THE 21ST CENTURY?

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CONTENTS

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AGRICULTURE AND NATURAL GAS

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AGRICULTURAL CONSUMPTION OF NATURAL GAS

In the increasingly heated debate over the role of natural gas in our energy future, focus is typically paid to its potential use as an alternative to coal for electricity production or oil for transport. But natural gas plays a pivotal role in our industrial farming systems. Natural gas has many uses in the agricultural sector, both on-farm and off-farm; it has provided between one third and one half of the fossil fuel energy used by U.S. farms over the past 40 years.[1]

The vast majority of the natural gas supporting American agriculture today is used off-farm. Most of it is used to manufacture farm inputs like pesticides, plastics, and fertilizers; nitrogen fertilizer production in turn accounts for most of that. Nitrogen fertilizer use has almost quadrupled in the U.S. since 1961 while rising more than eight-fold globally (Figure 1); industrial production of nitrogen fertilizer accounts for 2-3% of natural gas consumption in the U.S., and about 5% globally.[2] A less significant use of natural gas off-farm is the generation of electricity for farms, even though electricity consumption rose from 6% of farm energy use in 1965 to 22% in 2002.[3]

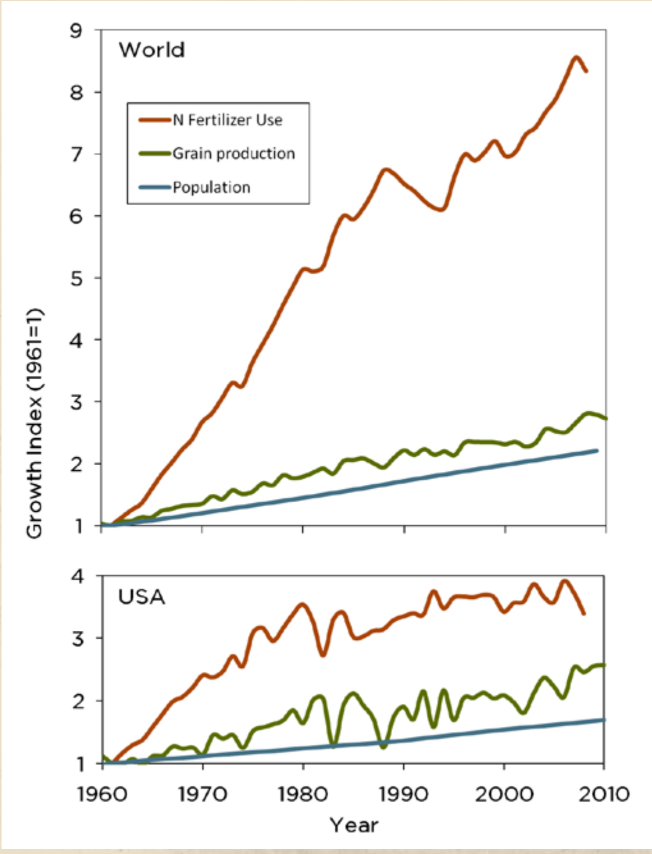


Figure 1. Index of 50 years' growth in nitrogen fertilizer use, grain production, and population globally (top) and in the U.S.[4]

The least significant use of natural gas in the farming sector is on-farm, where it is used primarily for energy: powering irrigation pumps, drying crops before storage, heating buildings and greenhouses, and other uses. Efficiency gains and fuel substitution enabled American farmers to cut on-farm use of natural gas from 8% of U.S. farm energy use in 1965 to 4% in 2002.[5]

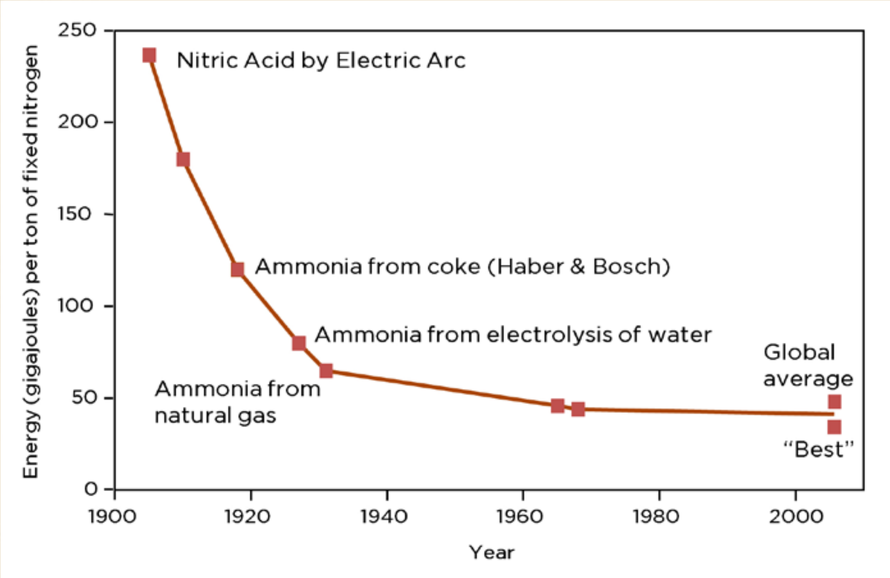
NITROGEN FERTILIZER PRODUCTION

Nitrogen is the most abundant element in the earth's atmosphere and the most important mineral nutrient for crop production. Plants need nitrogen to make proteins, but they cannot access the nitrogen in the air because it consists mainly of stable pairs of nitrogen atoms bound together by strong chemical bonds. Nitrogen fertilizer is made by combining gaseous nitrogen (N_2) and hydrogen (H_2) under very high heat and pressure to form ammonia (NH_3). Nitrogen gas comes from the air and natural gas typically provides both the hydrogen and the energy needed to maintain the temperature and pressure that enables the reaction. Although ammonia can be used to make plastics, synthetic fibers, resins, explosives, fuels, and other chemical compounds, almost 90% of it is currently used for fertilizer.[6]

It has been less than a century since people learned to make ammonia at an industrial scale. The earliest ammonia factories used coal as a source of hydrogen and energy, and were much less efficient than modern factories using natural gas (Figure 2). In contrast to European and North American fertilizer plants, China continues to use coal for 80% of its ammonia synthesis, and has doubled its output since 1995 so that it now produces about one third of the global ammonia supply.[7] Making ammonia with coal generally uses more energy and releases more greenhouse gas than making it with natural gas.[8] Researchers and green energy startup companies are exploring ammonia production methods that use renewable energy sources such as wind, hydro, and biomass.[9]

The amount of natural gas used to produce nitrogen fertilizer in the U.S. has fallen substantially in recent years. While some of the decline can be attributed to continuing efficiency improvements at fertilizer plants (Figure 2) and more efficient use of nitrogen fertilizer on American farms (Figures 1, 4, 5), the majority is due to the outsourcing of fertilizer production. Nitrogen fertilizer production in the U.S. fell by one third between 1995 and 2010, while imports rose from 15% to 43% of consumption.[10] The imported fertilizer is made in countries with plentiful natural gas, including Trinidad and Tobago (57%), Russia (15%), Canada (13%), the Ukraine (7%), and others (8%).[11] As a result, regions that use nitrogen fertilizer may be far removed from the regions that bear the environmental costs of its production.[12]

Figure 2. Energy efficiency of synthetic nitrogen fixation has improved with technological innovations over the past century.[13] Today's most efficient plants use about 36 gigajoules of energy to fix a ton of reactive nitrogen, while an average plant uses about 50 gigajoules to do the same. Making ammonia from natural gas is currently the most energy efficient method for industrial nitrogen fixation.



CHEMICAL DEPENDENCE?

The rapid increase in nitrogen fertilizer consumption in the latter half of the 20th century is often credited with keeping grain production growing faster than population (Figure 1). President Nixon's secretary of agriculture, Earl Butz, famously dismissed the idea of large-scale conversion to organic methods (which preclude the use of synthetic nitrogen fertilizer) by saying, "Before we move in that direction we must decide which 50 million of our people will starve."[14] A quarter century later, geographer Vaclav Smil estimated that "at least two billion people are alive because the proteins in their bodies are built with nitrogen that came—via plant and animal foods—from a factory [...] In just one lifetime," he concluded, "humanity has indeed developed a profound chemical dependence."[15]

More recent research has called into question the frequently-cited claims that synthetic nitrogen fixation has forestalled mass starvation. A 2007 review concluded that organic methods could not only satisfy the world's food needs without synthetic nitrogen, but would improve yields in developing countries.[16] Another extensive review, published in 2009, reached the surprising conclusion that long-term application of synthetic nitrogen fertilizer is actually reducing the nitrogen content of agricultural soils.[17] The review's authors explain that nitrogen is stored in soil in carbon-based molecules that are more prone to bacterial decomposition after synthetic nitrogen fertilizer application. Releasing this carbon and nitrogen back into the atmosphere increases the need for synthetic nitrogen fertilizer, harnessing farmers to a chemical treadmill in which more nitrogen fertilizer use creates greater need. "The long-term consequences of continued reliance on current production practices will be a decline in soil productivity that increases the need for synthetic nitrogen fertilization, threatens food security, and exacerbates environmental degradation," warns the University of Illinois team.

2003 fish kill in Narragansett Bay, Rhode Island resulting from a severe hypoxic event caused in part by excess nitrogen discharges into the bay.[18]

Whether our use of nitrogen fertilizer is essential or extravagant, it has profound ecological impact. Just 10% of the nitrogen fertilizer applied to crops is ever consumed as food; the rest must be absorbed by the environment.[19] Nitrogen fertilizer has dramatically altered global nitrogen cycles (Figure 3), polluted air and water, reduced biodiversity, and contributed to climate change. These negative effects are well-documented,[20] and are associated with the use of the fertilizer itself, not necessarily its production. If new natural gas extraction technologies further pollute groundwater and increase greenhouse gas emissions to support nitrogen fertilizer production they will be adding to an already heavy ecological footprint.

GETTING OFF THE TREADMILL

Reducing agriculture's dependence on nitrogen fixed with natural gas can enhance agricultural sustainability. Even without widespread adoption of organic methods, American farmers appear to be making some progress toward this goal. The rapid growth in nitrogen fertilizer use of the 1960s and 70s came to an end in the 1980s, and has not resumed, but yields continue to rise (Figures 1, 4). A yield response trial conducted at multiple sites in Iowa between 2000 and 2009 showed that corn grown in rotation with soybean could match typical corn yields of the 1990s without any nitrogen fertilizer application, and could match the national average of the past decade with half the nitrogen typically applied at that time (Figure 4). Increasing nitrogen applications beyond the national average offers almost no potential for yield improvement (Figure 4). American farmers seem to be getting the message: Nitrogen use efficiency of corn production in the U.S. has

Figure 3. Anthropogenic nitrogen fixation has more than doubled the amount of active nitrogen added to terrestrial ecosystems each year, and the amount that flows from terrestrial ecosystems to groundwater, rivers, lakes, and oceans. Arrow widths are proportional to annual flows except for the flow of recycled reactive nitrogen, which is much larger than shown. Reactive nitrogen typically cycles within terrestrial ecosystems for about 500 years. Figures are rounded to the nearest 5, and incorporate considerable uncertainty, reflecting rapidly evolving understanding of global nitrogen cycles.[21]

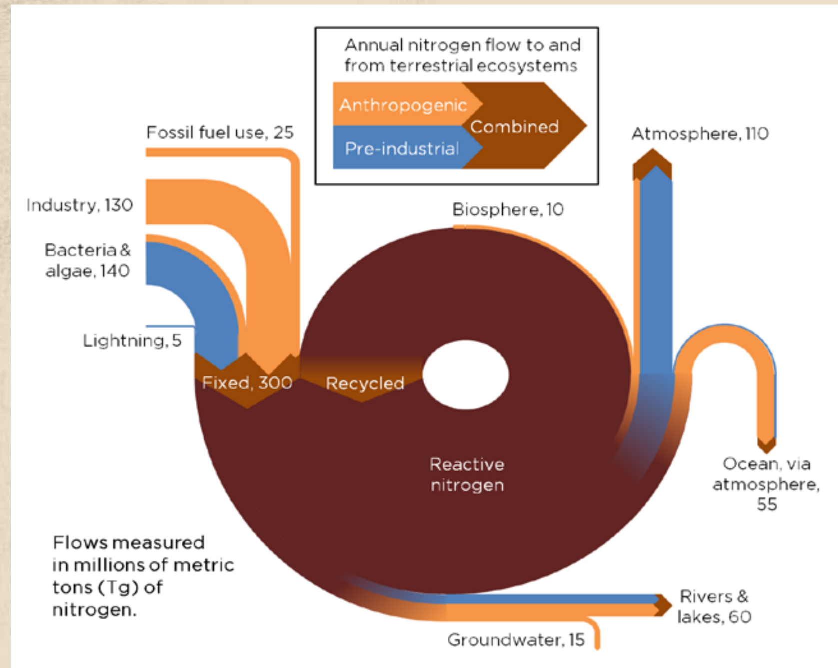


Figure 4. Corn yield response to nitrogen fertilizer applied to corn grown after soybean (green) or after corn (orange) in trials conducted in Iowa between 2000 and 2009[22]; and average U.S. corn yield and nitrogen fertilizer application for 5-year periods between 1965 and 2004 (blue).[23] Yield increases since the 1980s have been achieved without using more nitrogen fertilizer. Greater use of nitrogen-fixing crops, such as soybean, offers potential to reduce nitrogen fertilizer application without compromising yield.

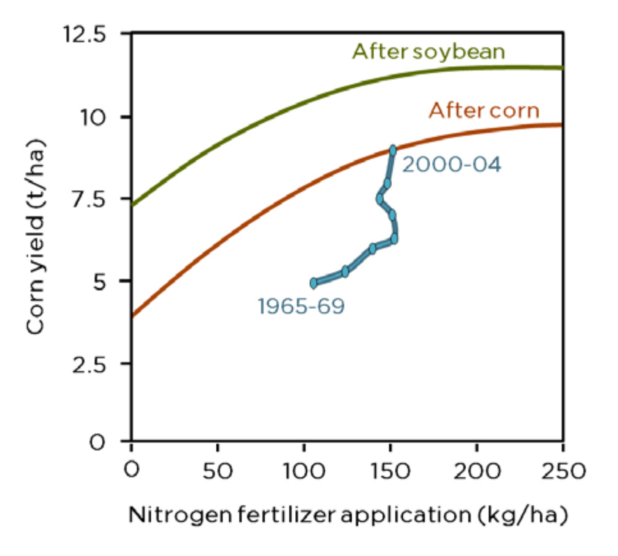
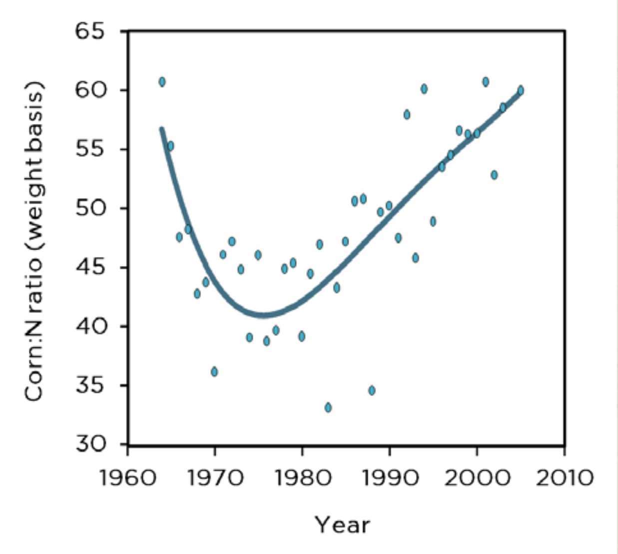


Figure 5. Efficiency of nitrogen fertilizer use for corn production in the U.S., 1964-2005[24], shown as the weight ratio of corn yield to nitrogen applied as fertilizer. Efficiency improvements since the 1980s have only recently restored nitrogen use efficiency to levels achieved in the mid-1960s.



increased steadily since the 1980s, recovering from the dive it took when nitrogen fertilizer use skyrocketed in the 1960s and 70s (Figure 5). The efficiency gains have been accomplished by improving yields without increasing nitrogen fertilizer use. The challenge of the future will be to scale back nitrogen fertilizer consumption by restoring biological processes that can satisfy plants' need for nitrogen using energy from the sun instead of natural gas.

ENDNOTES

1 J Miranowski, "Energy Consumption in US Agriculture," in *Agriculture as a Producer and Consumer of Energy*, J Outlaw, K J Collins, and J A Duffield, eds. (Oxfordshire, UK: CABI, 2005).

2 Vaclav Smil, *Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production*, (Cambridge, MA: MIT Press, 2001).

3 Miranowski, "Energy Consumption in US Agriculture."

4 International Fertilizer Association, IFADATA database, http://www.fertilizer.org/ifa/ifadata/search (accessed 4/29/11). US Census Bureau, International Data Base, http://www.census.gov/ipc/www/idb/ (accessed 4/29/11).
USDA Foreign Agricultural Service, Production, Supply and Distribution Online, http://www.fas.usda.gov/psdonline/ (accessed 4/29/11).

5 Miranowski, "Energy Consumption in US Agriculture."

6 US Department of the Interior and US Geological Survey, *Mineral and Commodity Summaries 2011*, http://minerals.usgs.gov/minerals/pubs/mcs/2011/mcs2011.pdf.

7 Gunnar Kongshaug, "Energy consumption and greenhouse gas emissions in fertilizer production," 1998, updated by Tore Jenssen for the International Fertiliser Society Meeting, London, United Kingdom (April 2003), http://bit.ly/ip8q5f. US Department of the Interior and US Geological Survey, *Mineral and Commodity Summaries 2011.*

8 Kongshaug, "Energy consumption and greenhouse gas emissions in fertilizer production."

9 D Lammers, "Minnesota plant will produce fertilizer from wind," Associated Press, June 9, 2010.

10 US Department of the Interior and US Geological Survey, *Mineral and Commodity Summaries 2011.*

11 US Department of the Interior and US Geological Survey, *Mineral and Commodity Summaries 2011.*

12 Smil, *Enriching the Earth.*

13 Adapted from Kongshaug, "Energy consumption and greenhouse gas emissions in fertilizer production."

14 Earl Butz, "Crisis or Challenge," *Nation's Agriculture* 19 (July-August 1971).

15 Vaclav Smil, "Global Population and the Nitrogen Cycle," *Scientific American* (July 1997), 76-81.

16 C Badgley, et al., "Organic agriculture and the global food supply," in *Renewable Agriculture and Food Systems* 22(2) (2007), 86–108.

17 R L Mulvaney, et al., "Synthetic Nitrogen Fertilizers Deplete Soil Nitrogen: A Global Dilemma for Sustainable Cereal Production" in *Journal of Environmental Quality* 38 (2009), 2295-2314.

18 Photo: Menhaden fish kill (cc-by) eutrophication&hypoxia. See also "Bay science: Low dissolved oxygen: the hypoxia threat," Narragansett Bay Estuary Program, http://www.nbep.org/bay-science-low.html (retrieved 5/23/2011).

19 US Department of the Interior and US Geological Survey, *Mineral and Commodity Summaries 2011.*

20 Badgley, et al., "Organic agriculture and the global food supply." J Galloway, et al., "Transformation of the nitrogen cycle: Recent trends, questions, and potential solutions," in Science 320 (2008), 889-892. Mulvaney, et al., "Synthetic Nitrogen Fertilizers Deplete Soil Nitrogen: A Global Dilemma for Sustainable Cereal Production." W Schlesinger, "On the fate of anthropogenic nitrogen," in *Proceedings of the National Academy of Sciences* 106 (2009), 203-208. Smil, "Global Population and the Nitrogen Cycle." Smil, *Enriching the Earth*. J Woods et al., "Energy and the food system," in *Philosophical Transactions of the Royal Society* B 365 (2010), 2991–3006.

21 Sources: Miranowski, "Energy Consumption in US Agriculture." US Census Bureau, International Database. USDA Foreign Agricultural Service, Production, Supply and Distribution, http://www.fas.usda.gov/psdonline/ (accessed 4/29/11).

22 J Sawyer, et al., *Energy Conservation in Corn Nitrogen Fertilization*, Iowa State University Extension, PM2089i (2010).

23 USDA Economic Research Service, Fertilizer Use and Price, Table 10: Nitrogen used on corn, rate per fertilized acre receiving nitrogen, selected States, 1964-2005, http://www.ers.usda.gov/Data/FertilizerUse/ (accessed 4/29/11). USDA National Agricultural Statistics Service, Crop Production Historical Track Records, April 2011, http://usda.mannlib.cornell.edu/usda/current/htrcp/htrcp-04-26-2011.txt (accessed 4/29/11).

24 USDA Economic Research Service, Fertilizer Use and Price. USDA National Agricultural Statistics Service, Crop Production Historical Track Records.

PROBLEMS AND OPPORTUNITIES WITH NATURAL GAS AS A TRANSPORTATION FUEL

By Richard Gilbert and Anthony Perl

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Today's transport technology and organizational arrangements require enormous amounts of oil, especially in the United States where some 12 million barrels a day fuel the internal combustion engines that power almost all land, marine, and air transport.[1] Concerned over rising oil prices, diminishing domestic supplies, and supply shocks due to political instability in the Middle East, many are looking for substitutes to fuel our growing transportation needs. A popular alternative: natural gas. In "Will Natural Gas Fuel America in the 21st Century?," David Hughes provides convincing reasons to be skeptical about the substantial future growth in natural gas supplies from shale rock or other sources that would be needed to sustain contemporary mobility arrangements by replacing oil with gas.

The documented environmental and financial downsides of shale gas are compelling. Yet despite these drawbacks, enthusiastic media portrayals of a natural gas bonanza appear frequently across North America. At the time we wrote this, a Canadian newspaper had devoted a full page to how shale gas will rescue China from its energy challenges: "... China may have more riches under its own soil than policymakers in the world's second-largest economy every dared imagine."[2] Another article suggested that the coming "gas glut" could be mopped up by fuelling North American trucks and buses with liquefied natural gas.[3]

Such thinking evokes our sense of déjà vu when observing the enthusiasm for finding ways of sustaining something close to present transport arrangements. We saw similar dreaming foster the recent preoccupation with hydrogen fuel cells. Brief consideration of that diversion in transport redevelopment can help us think more clearly about the potential of moving freight and people with natural gas.

California Governor Arnold Schwarzenegger with Hummer H2H hydrogen concept car, 2004.[4]

A decade ago, hydrogen was embraced as the miracle cure that would steadily replace oil on the road to post-carbon mobility. President George W. Bush's State of the Union Address in 2003 initiated a $1.2 billion investment towards this end.[5] In his 2006 Address, Bush candidly admitted that Americans were "addicted to oil" but promised that technology was poised to resolve this malady.[6] In April 2006, he told the California Fuel Cell Partnership, "I strongly believe hydrogen is the fuel of the future."[7] Experts had forecast that by 2011 there would be more than half a million automobiles powered by fuel cells on North American roads.[8] But according to J.D. Power and Associates, a major source of automotive data, "only a handful of fuel-cell vehicles are in use today because the technology is still in development."[9]

The promised payoff from fuel-cell development has been eroded by its poor performance, particularly the inefficiency of using renewable electricity to produce hydrogen that is then used to produce electricity, in a fuel cell on board a vehicle.[10] The available evidence points to a similar erosion of the promised payoff from investments in shale gas.

We believe that the evidence points to a far more modest role for natural gas in fueling mobility. This path to making the best use of limited natural gas supplies begins with planning not to burn this fuel directly in internal combustion engines. Rather, using natural gas in electricity generation would result in more usable energy and less pollution, particularly at vehicles.

Best available technology can transform about 45 percent of fossil fuel energy into electricity.[11] Moreover, if waste heat can be used within a few hundred kilometers of a generating station, an additional 30 percent of this energy can be applied to heating buildings and some industrial processes. Transmission and distribution losses for electricity are typically under 6 percent[12] and the efficiency of electric traction motors is typically above 90 percent.[13] Thus, when electric vehicles are connected while in motion to a grid supplied by natural-gas-fueled generation, about 40 percent of the primary energy can be used for propulsion.

If lithium batteries charged from the grid are used to store the electrical energy on board vehicles, charging and discharging losses of some 10 percent must be allowed for,[14] plus further losses resulting from having the mass of the batteries on board,[15] reducing the efficiency of the system to perhaps 30-35 percent. The efficiency of 30-35 percent may be contrasted with the comparable efficiency of internal-combustion-engine vehicles, which appears to average about 20 percent,[16] whether fueled with natural gas or gasoline.[17] Thus, natural gas consumption per kilometer—and corresponding emissions—could be much lower when the fuel is used to make electricity for traction. Moreover, these emissions can be better regulated at generating stations than in on-board engines.

Emissions from natural-gas fuelled vehicles may be underestimated. Because natural gas fueled engines can be run at higher compression ratios than gasoline engines, they can generate higher outputs of nitrogen oxides.[18] High numbers of particulates can also be emitted from natural gas engines, especially when accelerating.[19] While particulate mass is much lower than from diesel engines, the abundance of ultrafine particulates produced in natural-gas-fueled engines may penetrate bronchopulmonary passages more deeply and induce more adverse health effects.[20]

Using liquefied natural gas (LNG) as a fuel for buses and trucks presents further complications, starting with LNG's lower energy content per unit volume compared to gasoline and diesel fuel.[21] An LNG-fuelled transportation system would also require an extensive distribution and refueling infrastructure with an untested safety record. There is much experience with safely handling gasoline and diesel fuel but little experience with managing the very different properties of an extremely cold and explosive liquefied gas. The challenges posed by LNG are exemplified by the extraordinary precautions taken in and near Boston Harbor in connection with the regular visits of tankers discharging LNG at the Everett terminal. These precautions include the establishment of a five-square-kilometer security zone around each tanker, escort by armed patrol boats, and the suspension of flights at nearby Logan International Airport.[22]

A 25-foot U.S. Coast Guard boat provides a security escort for the Liquefied Natural Gas (LNG) Tanker Matthew in Boston Harbor.[23]

Our most important reason for proposing use of natural gas in electricity generation rather than in direct combustion in motor vehicles arises from our belief that a revolution in land transportation is beginning whereby electric traction will replace many internal combustion engines. Our recent book, *Transport Revolutions,*[24] makes the case for rapid deployment of electric mobility to keep ahead of oil depletion. This strategy and an energy-first transportation planning framework are summarized in our chapter in *The Post Carbon Reader.*[25]

Using available natural gas to generate electricity could help the U.S. achieve a 'soft landing' into its post-carbon transformation. Burning natural gas in internal combustion engines would do nothing to advance this transformation, and would be a diversion from the need for more fundamental changes in mobility.

ENDNOTES

1 See Annex A (Page 630) of *World Energy Outlook*, International Energy Agency, Paris, France, 2010.

2 A Chen, "Gas Lag: Facing an energy crunch, China is getting ready to unearth shale gas," *Financial Post*, April 21, 2011.

3 S McCarthy, "A solution for low natural gas prices: trucks and buses," *Globe and Mail*, April 14, 2011.

4 Photo: General Motors.

5 George W. Bush, Third State of the Union Address (speech, Washington, DC, January 29, 2003).

6 Ibid.

7 Associated Press, "Bush promotes fuel cells on Earth Day," (April 24, 2006) http://www.msnbc.msn.com/id/12436113/ns/us_news-environment/.

8 PriceWaterhouse Coopers, *Fuel Cells: The Opportunity for Canada*, (June 2002) http://www.pwc.com/en_CA/ca/technology-industry/publications/fcoc-02-en.pdf.

9 JD Power "Alternative Fuel Cars," (retrieved May 6, 2011) http://www.jdpower.com/autos/articles/Alternative-Fuel-Cars/.

10 U Bossel, *Phenomena, Fact and Physics of a Sustainable Energy Future*, European Fuel Cell Forum, (Oberrohrdorf, Switzerland, July 2007), http://www.efcf.com/reports/E22.pdf.

11 See Table 1 of Hughes, J.D., *Will Natural Gas Fuel America in the 21st Century?*, Post Carbon Institute (May 2011) http://postcarbon.org/naturalgas.

12 U.S. Energy Information Administration, *United Stated Electricity Profile*, 2008 edition (Washington D.C., March 2010) http://www.eia.gov/cneaf/electricity/st_profiles/us.html.

13 The Engineering Toolbox, "Electrical Motor Efficiency," (retrieved May 6, 2011) http://www.engineeringtoolbox.com/electrical-motor-efficiency-d_655.html.

14 MA Delucchi, MZ Jacobson, "Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies," *Energy Policy* 39(3) (2001): 1170-1190.

15 C-SN Shiau, C Samaras, R Hauffe, JJ Michalek, "Impact of battery weight and charging patterns on the economic and environmental benefits of plug-in hybrid vehicles." *Energy Policy* 37(7) (2009): 2653-2663.

16 F Creutzig, A Papson, DM Kammen, L Schipper," Hot deal or hot air? Life-cycle analysis of pneumatic cars," paper presented at the 89th Annual Meeting of the Transportation Research Board (Washington DC, January 2010).

17 Kelly Blue Book, "Natural Gas Car Lows: Cost versus Efficiency," http://community.kbb.com/blogs/greenarticles/archive/2008/07/10/Natural-Gas-Car-Lows_3A00_-Cost-Versus-Efficiency.aspx.

18 T Korakianitis, AM Namasivayam, RJ Crookes, "Natural-gas fuelled spark-ignition (SI) and compression ignition (CI) engine performance and emissions," *Progress in Energy and Combustion Science* 37(1) (2011): 89-112.

19 ER Jayaratnea, NK Meyera, ZD Ristovski, L Morawska, B Miljevic, "Critical analysis of high particle number emissions from accelerating compressed natural gas buses," *Environmental Science and Technology* 44(10) (2010): 3724-3731.

20 LD Knibbs, T Cole-Hunter, L Morawska, "A review of commuter exposure to ultrafine particles and its health effects," *Atmospheric Environment* 45(16) (2011): 2011-2022.

21 J Eberhardt, "Fuels of the future for cars and trucks," presentation at the U.S. Department of Energy's Diesel Emissions Reduction Conference (San Diego, California, August 2002) http://www.eere.energy.gov/vehiclesandfuels/pdfs/deer_2002/session1/2002_deer_eberhardt.pdf.

22 See http://www.quoddyloop.com/savepassamaquoddybay/documents/newspaper_inserts/insert-7.pdf and the sources cited therein. Also see http://www.savepassamaquoddybay.org/safety_reports.html for other sources about LNG safety.

23 Photo: U.S. Navy, public domain.

24 R Gilbert and A Perl, *Moving People and Freight without Oil*, 2nd edition (Gabriola Island, BC: New Society Publishers, 2010).

25 R Gilbert and A Perl, "Transportation in the Post-Carbon World," in *The Post Carbon Reader*, ed. R Heinberg and D Lerch (Healdsburg, California: Watershed Media, 2010), 347-360.

PUBLIC HEALTH CONCERNS OF SHALE GAS PRODUCTION

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INTRODUCTION AND OVERVIEW

The scale and speed at which shale gas drilling is proceeding in many states demands a full discussion of what is known about potential public health concerns. To date, these concerns generally have been based on a series of publicized occurrences[1] rather than rigorous evidence grounded on measurement and evaluation. With tens of thousands of wells already drilled and thousands more planned without sound government oversight in many states, the probability of a single large adverse event is of great concern, as are the cumulative environmental and public health effects of thousands of low-intensity problems. This mix of aggressive industrial development with constrained regulatory and public health oversight is a potential recipe for disaster.

METHODS TO FRAME PUBLIC HEALTH CONCERNS

The public is often most concerned with the probability of an individual person getting sick as a result of industrial activities like shale gas drilling. Also of concern, however, are the cumulative community impacts and how these can influence health, particularly given the speed and scale of current and projected shale gas drilling activities.

Old St. Nicholas coal breaker, Gilberton, Pennsylvania.[2]

Health effects occur at all scales: individual, community, regional, and global. The legacy of coal can be instructive in anticipating some of the public health concerns of shale gas drilling. Pennsylvania, the state with the largest burden of abandoned coal mines in the U.S., has experienced the public health consequences of individuals breathing coal dust and being injured or killed in mining accidents. Communities suffered from family members becoming ill from exposure to dust and chemicals brought home on clothing, as well as from worsened local air quality, the impact of acid rain on local ecosystems, the contamination of surface water and groundwater sources with acid mine drainage, and economic losses from compromised property values.

Individuals and communities near shale gas drilling operations may have similar risks of exposure to:

- air, soil, surface water, and groundwater contaminated with hundreds of undisclosed chemicals used in hydraulic fracturing fluids and cleaning of tanks and equipment;
- particles of dust, soot, and fumes from diesel exhaust and other sources that can be inhaled;
- ionizing radiation from flow back and produced waters;[3] and
- noise and air pollution from trucks, drilling pads, compressors, and power tools.[4]

Many of these exposures will be in low concentrations that do not carry significant risk at any one point in time, but the combined and cumulative effects over years and decades are not yet known. There is also the continued risk of a greater spill or event that results in large episodic exposures. Many of these have already occurred[5] and continue to do so.[6] Effects of some exposures can appear quickly while others may take years to decades to emerge.

A considerable portion of the public's health concerns have focused on the many chemicals added to hydraulic fracturing fluids, as drilling companies initially did not willingly disclose the identities or amounts of these additives. The identities of many of the possible chemicals used in hydraulic fracturing fluids have since been disclosed,[7] and some of these chemicals, when studied in higher doses, are known to cause cancer, neurotoxicity, reproductive toxicity, and systemic poisoning, among other health effects.[8] Drilling companies must continue to disclose the names and amounts of the chemicals used in hydraulic fracturing so that public health authorities can do the research required to evaluate the risk of adverse population health effects due to these additives, given that average doses incurred by community members are likely to be low.

Although there is legitimate concern that exposures to some of the known contaminants involved in shale gas production can cause asthma, cancer, heart disease, diabetes, damage to nerves and reproductive organs, and mental health problems,[9] the actual risk to any individual or community is not known. With so many existing and projected shale gas wells expected to remain in operation for years and thus leaving a legacy of contaminated air, soil, and water, the long-term and cumulative effects over space and time converge to raise the public health concerns to a high level.

Hydraulic fracturing waste liquids fill a containment pool.[10]

EXAMPLES OF SOME HEALTH CONCERNS OF PRIMARY INTEREST

- **Air pollution** from shale gas production poses a serious risk of adverse pulmonary and cardiovascular outcomes. The air pollution results from a number of sources, including diesel exhaust (i.e., from trucks, compressors), volatile organic compounds (VOCs) from evaporation of the organic chemicals in hydraulic fracturing fluids and produced waters, and the photochemical reaction of VOCs with oxides of nitrogen to produce ozone. Emerging data from drilling operations in Ft. Worth (Tex.), Garfield (Colo.), and western Wyoming suggest that air pollution from shale gas production can be high intensity and pose a serious and real threat to health of community members of all ages.[11]

- **Ground water pollution** from hydraulic fracturing additives and produced water is a big concern, the risk of which has not yet been appropriately evaluated. Despite the fact that drilling passes through well water aquifers and water-related problems with drilling are known to occur, there have been no systematic evaluations of shale gas drilling risks to ground water in a variety of geologies. The U.S. EPA has proposed research that will not be completed for several years, but the full scope of this work has been debated and Congress continues to consider putting constraints on what may be examined; meanwhile, the EPA's budget has been reduced.

- **Flow back and produced waters** are of concern because the contaminants in this water, including radioactive compounds and organic chemicals, return to the surface and must be properly managed. The dose response for the risk of cancer in relation to ionizing radiation is not thought to have a threshold; any level of radiation that is increased because of these activities will raise the risk of cancer a measurable amount, but the overall risks are likely to be low. Furthermore, much of this water is currently going to sewage treatment plants which are not designed to remove or manage chemicals and radioactive elements, although recently drilling companies have begun changing practices to reuse most or all of these waters for subsequent hydraulic fracturing, reducing the volume of contaminated water.[12]

- A final example concerns the risk of environmentally and ecologically **degraded communities**. Our work in Pennsylvania shows that abandoned coal mines are associated with a legacy of worse community socioeconomic deprivation (CSD). Higher levels of CSD have been associated with worse health outcomes across a wide range including diabetes, obesity, asthma, heart disease, mental health problems, and destructive health behaviors.[13] The significant changes in communities related to shale gas drilling have also been associated with more crime and drug use in some cases.[14] What the shale gas drilling industry leaves behind (e.g., environmental and ecological degradation, industrial development), could also lead to higher levels of CSD in these communities. Degradation, deprivation, and unhealthy individuals are possible long-lasting legacies in communities with extensive shale gas drilling.

IS SHALE GAS BETTER FOR PUBLIC HEALTH THAN COAL?

Coal use is undoubtedly the fossil fuel with the worst environmental and public health legacy. Coal miners and mining communities, communities located close to coal-fired power plants, and communities located downwind from power plants—and ultimately communities anywhere on the planet—all experience varying degrees of serious health consequences from mountaintop removal, coal dust, chemical contaminants in sludge, sulfur and nitrogen oxides, mercury, acid rain, toxic ash generation, storage, and disposal, and global climate change. There is no doubt that coal harms health and must first be used more efficiently and in less polluting ways, and then phased out as quickly as possible; moreover, the concept of "clean coal" does not hold up under scrutiny, as traditional air pollution from coal combustion continues to pose health risks[15] and carbon capture and storage is unlikely to be implemented any time soon or at scale.[16] Replacing coal with shale gas, however, could prove just as damaging to public health and the environment, because of the potential for health effects from local, regional, and global environmental exposures, as well as the significant adverse health outcomes that can be a consequence of environmentally and ecologically degraded communities.

CONCLUSIONS

The potential risks to the public's health from shale gas drilling are serious. Even though the specifics of the risks are not yet known, there is sufficient evidence for concern. The precautionary principle, invoked when the potential risks to health and well-being are severe and/or widespread, dictates that the burden of proof that shale gas drilling is not harmful should fall to those wishing to undertake the potentially harmful action. Because so much drilling has already occurred and is projected to continue occurring, the precautionary principle should be invoked to slow down the drilling of new wells, allow the EPA and public health scientists to better evaluate the risks, and determine how best to regulate shale gas production to avoid another coal-type legacy affecting the health and well-being of millions of people for generations.

ENDNOTES

1 Marianne Lavelle, "Natural Gas Stirs Hope and Fear in Pennsylvania," *National Geographic*, October 3, 2010, accessed May 3, 2011, http://news.nationalgeographic.com/news/2010/10/101022-energy-marcellus-shale-gas-overview/.

2 Photo: St. Nicholas coal breaker, (c) www.abandonedhistory.com.

3 Tom Zeller Jr., "Studies Say Natural Gas Has Its Own Environmental Problems," *New York Times*, April 11, 2011, accessed May 3, 2011, http://www.nytimes.com/2011/04/12/business/energy-environment/12gas.html?pagewanted=1&ref=politics.

4 Roxana Witter et al., *Potential Exposure-Related Human Health Effects of Oil and Gas Development: A White Paper*, Colorado School of Public Health, University of Colorado, Denver, 2008, http://docs.nrdc.org/health/files/hea_08091702a.pdf. and Roxana Witter, et al. *Potential Exposure-Related Human Health Effects of Oil and Gas Development: A Literature Review (2003-2008)*, Colorado School of Public Health, University of Colorado, Denver, 2008, http://docs.nrdc.org/health/files/hea_08091702b.pdf.

5 Rona Kobell, "Marcellus Shale: Pipe Dreams in Pennsylvania?," *Chesapeake Bay Journal*, December 2009 accessed May 3, 2011, http://www.bayjournal.com/article.cfm?article=3715.

6 Mike Lee, "Chesapeake Battles Out-of-Control Marcellus Gas Well," *Bloomberg*, April 20, 2011, accessed May 3, 2011, http://www.bloomberg.com/news/2011-04-20/chesapeake-battles-out-of-control-gas-well-spill-in-pennsylvania.html.

7 U.S. Environmental Protection Agency, Office of Research and Development, *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources* (Washington, DC 2011), http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/upload/HFStudyPlanDraft_SAB_020711.pdf.

8 Ibid.

9 Roxana Witter et al., *Potential Exposure-Related Human Health Effects of Oil and Gas Development: A White Paper*, Colorado School of Public Health, University of Colorado, Denver, 2008, http://docs.nrdc.org/health/files/hea_08091702a.pdf.

10 Photo (cc)(i)($)(=) Ari Moore.

11 Al Armendariz, *Emissions from Natural Gas Production in the Barnett Shale Area and Opportunities for Cost-Effective Improvements*, (prepared for Ramon Alvarez, Environmental Defense Fund, January 26, 2009), http://www.edf.org/documents/9235_Barnett_Shale_Report.pdf.; Joe Osborne, "Shale Gas Can Pollute the Air, Too: But Marcellus Companies Might Even Profit from Preventive Measures," *Pittsburgh Post-Gazette*, November 1, 2010, accessed May 3, 2011, http://www.post-gazette.com/pg/10305/1099670-109.stm.; and Colorado Department of Public Health and Environment, *Colorado Air Quality Control Commission. Report to the Public 2008-2009* (Denver, CO 2009), http://www.cdphe.state.co.us/ap/down/RTTP08-09fullweb.pdf.

12 Tom Zeller Jr., "Studies Say Natural Gas Has Its Own Environmental Problems," *New York Times*, April 11, 2011, accessed May 3, 2011, http://www.nytimes.com/2011/04/12/business/energy-environment/12gas.html?pagewanted=1&ref=politics.

13 M. Janghorbani, R.B. Jones, and R. Nelder, "Neighbourhood Deprivation and Excess Coronary Heart Disease Mortality and Hospital Admissions in Plymouth, UK: An Ecological Study," *Acta Cardiol* 61[3] (2006): 313-320.; M. Janghorbani et al., "Neighborhood Deprivation and Preterm Birth in Plymouth, UK," *J Matern Fetal Neonatal Med* 19[2] (2006): 85-91.; and M.

Stafford et al., "Deprivation and the Development of Obesity: A Multilevel, Longitudinal Study in England," *American Journal Preventive Medicine* 39[2] (2010): 130-139.

14 Roxana Witter, et al. *Potential Exposure-Related Human Health Effects of Oil and Gas Development: A Literature Review (2003-2008)*, Colorado School of Public Health, University of Colorado, Denver, 2008, http://docs.nrdc.org/health/files/hea_08091702b.pdf.

15 Paul R. Epstein, et al., "Full Cost Accounting for the Life Cycle of Coal," *Annals of the New York Academy of Sciences* 1219 (2011): 73-98.

16 Intergovernmental Panel on Climate Change, *Carbon Dioxide Capture and Storage*, (Cambridge, England: Cambridge University Press, 2005), http://www.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf.