Centre for Policy Studies

Pointmaker

WHY EVERY SERIOUS ENVIRONMENTALIST SHOULD FAVOUR FRACKING

RICHARD A. MULLER AND ELIZABETH A. MULLER

SUMMARY

- Environmentalists who oppose the development of shale gas and fracking are making a tragic mistake.

- Some oppose shale gas because it is a fossil fuel, a source of carbon dioxide. Some are concerned by accounts of the fresh water it needs, by flaming faucets, by leaked "fugitive methane", by pollution of the ground with fracking fluid and by damaging earthquakes.

- These concerns are either largely false or can be addressed by appropriate regulation.

- For shale gas is a wonderful gift that has arrived just in time. It can not only reduce greenhouse gas emissions, but also reduce a deadly pollution known as PM2.5 that is currently killing over three million people each year, primarily in the developing world.

- This air pollution has been largely ignored because PM2.5 was an unrecognised danger until recently; only in 1997 did it become part of the US National Ambient Air Quality Standards. It is still not monitored in much of the world.

- Greenhouse warming is widely acknowledged as a serious long-term threat, but PM2.5 is currently harming more people.

- Europe shares an ironic advantage with China – the high price paid for imported natural gas, typically US$10 per million BTU (compared to US$3.50 in the US). At those prices, the cost of shale drilling and completion can be much higher and still be profitable. Europe can therefore be the testing and proving ground where innovative technology can be tried and perfected while still profitable.

- As both global warming and air pollution can be mitigated by the development and utilisation of shale gas, developed economies should help emerging economies switch from coal to natural gas. Shale gas technology should be advanced as rapidly as possible and shared freely.

- Finally, environmentalists should recognise the shale gas revolution as beneficial to society – and lend their full support to helping it advance.

1. REDUCING PM2.5 AND GREENHOUSE GASES

1.1 PM2.5: the dirty secret

PM2.5 refers to particulate matter 2.5 microns or smaller, microscopic dust particles created directly from burning fuel but also by secondary chemical reactions from emitted sulphur and nitrous oxides (SOx and NOx). These particulates are so tiny that they penetrate deep into human lungs where they are absorbed into the blood and lead to cardiorespiratory disease. The US Environmental Protection Agency (EPA) estimates PM2.5 is responsible for about 75,000 premature deaths per year in the United States,[1] even though US measured air quality levels are typically ranked in the *good* to *moderate* categories, with an AQI (air quality index) of 0 to 100. [EPA 2010; Lepeule 2011].

To put this in perspective, yearly automobile deaths in the US in 2012 were less than half of that. European air pollution deaths were estimated at 400,000 per year by the European Environment Commissioner, more per person than in the US because the PM2.5 levels are significantly higher. [El Pais 2013].

It is not just PM2.5 that kills, but larger particles (PM10), ozone, sulphur and nitrous oxides and other pollutants. But the Air Quality Index (AQI) around the world is usually dominated by PM2.5.[2]

But US and European pollution levels are small compared to those in the developing world. In early 2013, the level in Beijing soared to an AQI of 866, far above the nominal *hazardous*[3] threshold of 300. As we write this (November 2013) the level in Delhi India is 817. On 21 October 2013, Harbin, a city in northern China with 11 million people, turned on its centralised coal system and the pollution level surged off scale at 1,000. The city's official news site said, "You can't see your fingers in front of your face." [NYT 2013]. Airport visibility dropped below 10 metres. The government shut schools, airports and many highways, and told people to stay at home.

You can look up current PM2.5 levels on the internet.[4] On the day we are writing this, most of the US is "good" (less than 50), most of the UK is "moderate" (50 to 100), Paris is "unhealthy for sensitive groups" at 114, and Vienna is "unhealthy" at 161.

PM2.5 is a horrific environmental problem. The Health Effects Institute estimated that air pollution in 2010 led to 3.2 million deaths that

---

1 The EPA number is 63,000 to 88,000 at 95% confidence. See EPA 2010, Appendix G page 2.

2 The AQI is defined separately for each pollutant, based on its estimated health effects. But, by convention, the total AQI is set to that of the leading component for the location. Recently that has almost always been PM2.5.

3 Pollution categories for air quality and the colours used to depict them on maps are

- *good*: green, AQI 0-50, PM2.5 concentration 0-12 $\mu g/m^3$
- *moderate:* yellow, AQI 51-100, PM2.5 12-35 $\mu g/m^3$
- *unhealthy for sensitive groups*: orange, AQI 101-150, PM2.5 35-55 $\mu g/m^3$
- *unhealthy*: red, AQI 151-200, PM2.5 55-150 $\mu g/m^3$
- *very unhealthy*: purple, AQI 201-300, PM2.5 151-250 $\mu g/m^3$
- *hazardous*: brown, AQI above 301, PM2.5 above 250 $\mu g/m^3$

Note: for PM2.5 above 500, AQI and PM2.5 are essentially identical.

4 For China and India, see aqicn.org (also try the map link); for Europe, see aqicn.org/map/europe/; for the US see airnow.gov (with many map choices) or commons.wikimedia.org/wiki/File:Pm25-24a-super.gif.

year, including 1.2 million in China and 620,000 in India. [O'Keefe 2013, Yang 2013]. And the pollution is getting worse as global use of coal continues to grow.

The most dramatic and compelling new result linking coal pollution to death comes from the Huai River Study. [Chen 2013]. In this investigation, scientists took advantage of a Chinese government policy that for 30 years supplied free coal north of the Huai River for heating and cooking, and forbade such coal in homes south of the river. The study determined that the 250 million people who live north of the river were exposed, on average, to an additional 184 $\mu g/m^3$ of particulates, and that they lost, on average, 5.5 years of life from the extra pollution. As a rule of thumb, they estimate that each average added exposure of 100 $\mu g/m^3$ will reduce average lifetime by three years. From this we can calculate that the level reached in Harbin, an AQI of 1000 (which for such high levels also means 1000 $\mu g/m^3$) should lead to a thousand excess deaths *from just one day of exposure.*[5]

China not only has the greatest yearly death toll from air pollution, but is also key for mitigating global warming. China surpassed the US in CO_2 production in 2006; growth was so rapid that by late 2013, China's CO_2 emissions are nearly twice those of the US. If its growth continues at this rate (and China has averaged 10% GDP growth per year for the past 20 years) China will be producing more CO_2 per person than the US by 2023. If the US were to disappear tomorrow, Chinese growth alone would bring worldwide emissions back to the same level in four years. To mitigate global warming, it is essential to slow worldwide emissions, not just those in the developed countries. And we feel this must be done without slowing the economic growth of the emerging world.

It is amazing that PM2.5 levels are not more widely addressed by environmentalists, by political leaders, by journalists, and by the general public. They should not, cannot, be ignored. PM2.5 kills more people per year than AIDS, malaria, diabetes or tuberculosis. We must do something. But what?

1.2 Energy conservation

The most effective way to keep pollution out of the air is to leave it underground, buried with the original coal. That can be done by using less energy – energy conservation – and that can be achieved without any lowering of productivity, comfort, or perceived standard of living, primarily by improving efficiency. Indeed, European nations, the US, China and other countries are working hard to do this.

China's official goal is to have energy use grow at a rate 4% slower than that of their economy. That is a challenging but realistic goal; the US improved its energy conservation by 5% per year in the decade following the 1973 OPEC oil embargo, through higher miles-per-gallon for cars, better insulation in homes and buildings, and improved efficiency in engines and appliances.

The reason that such yearly improvement is feasible is that conservation can be highly profitable. In the US, homeowners who invest in conservation typically achieve a payback time

[5] For 30 years of exposure of 100 $\mu g/m^3$, based on the Huai River study, we expect 3 years lost per person. For one *day* at *1000* $\mu g/m^3$, we expect 3x10/30/365 = 0.0027 years lost per person. For 11 million people, that is 30,000 person-years lost. If the average premature death takes place at age 35, then that amounts to 860 deaths. If the average premature death takes place at age 50 (loss of life of 20 years per affected person) then 1500 deaths are expected.

of five to ten years. If you think of it as an investment, then a five-year payback is a 20% annual return. A 10-year payback is a 10% return. And it is a tax-free return; you don't pay taxes on money not spent. Energy conservation is so profitable that it is worth doing regardless of its mitigation of air pollution and global warming [Muller, 2012].

However, if the prodigious growth rate of the Chinese economy continues, then even if they meet their conservation goals, their energy use will increase 6% per year. If they stick with coal, then their PM2.5 and greenhouse emissions will grow too. In 2013, China's economic growth slowed to between 7% and 8% per year. Even if that lower rate continues, slowing energy growth will not be enough by itself to stop the rapid rise of pollution. Energy conservation is an essential part of China's programme, perhaps the most important part, but it is far from sufficient.

1.3 Renewables

Two facts about China are often put forth to express optimism about renewables. One is that 20% of China's electric power already comes from renewables, and the other is that China's solar capability is growing rapidly: seven gigawatts (GW) capacity was added just last year. Thus China is a leader, setting an example that the rest of the world can follow.

We tend to think of renewables as environmentally benign, but according to the US Energy Information Administration (EIA), 86% of China's renewable energy in 2011 came from hydroelectric dams. The rest came from wind (9%), biomass (4%), with only 0.4% from solar.

Is more hydropower environmentally desirable? In China the recently completed Three Gorges Dam displaced 1.2 million people ("voluntarily", the government says), obliterated 1,350 villages, 140 towns, and 13 cities. China is already planning extensive new dams on the Mekong River, with disastrous ecological impacts expected, not only in China but also Burma, Laos, Thailand, Cambodia, and Vietnam.

In 2012, there were 76 GW of wind capacity in China, but because of variability, the average power delivered was 22 GW, that is, about a 29% capacity factor. That amounted to 1.5% of China's electricity generation. The intermittency can be tolerated when wind is a small portion of total power generation, but it becomes a major problem when used on a large scale. Energy storage is still expensive, and so large-scale wind is not likely to do more than supplement coal, hydro, and other more reliable alternatives.

Biomass is a renewable, good for global warming, but it too produces PM2.5. Other renewables (geothermal, tidal, wave) offer little hope of significant coal displacement in China [Muller 2012].

Solar, at 0.4% of China's electricity, is far behind other renewables. The recent addition of 7 GW solar capacity is easily misinterpreted. Capacity refers to peak power, the power that can be delivered when the sky is clear and the sun is directly overhead. Average in night and day, and you lose half the output. Grazing light at dawn and dusk halves output again. Finally, experience in US and China indicates that cloudy weather halves output yet again; it will be worse in cloudy parts of the UK and Europe. This means that in 2012 China produced an *average* solar capacity under 1 GW. And that production rate may decrease now that Wuxi Suntech Power, the major Chinese producer, defaulted on a $541 million bond and was placed into insolvency in March 2013.

Compare that 1 GW of new solar to the expansion of Chinese coal, which has added an average capacity of 50 GW per year over the past several years, a gigawatt per week, enough added each year to power seven new New York cities. Solar is being left in the dust by coal.

Nuclear power is not a renewable, but like wind and solar, it produces essentially no PM2.5 or CO_2. China is currently planning 32 new nuclear plants. But these require high capital investment, and that makes them less attractive for rapid large-scale deployment in the developing world.

The developed world has the financial resources to subsidise solar and wind, at least for peak power purposes in their own countries. But developing countries are not wealthy enough to do that, and yet their expected energy growth is too big for the developed world to subsidise. The recent retreats from subsidising renewables in Spain and Germany demonstrate how fragile and fickle government support can be. There is a general rule which is especially true for developing economies: *If it isn't profitable, it isn't sustainable.*

1.4 Scrubbers

In principle, scrubbers in coal smokestacks can remove many of the pollutants, and they are widely but not universally used in the US and Europe. US regulation requires them eventually to be installed, but retrofitting and operating such scrubbers has often proven more expensive than simply shutting down the coal plants and switching to natural gas. A 2008 report from the China Energy Group at MIT illustrates the severity of the cost problem in the developing world. Even when scrubbers have been installed, local coal power plant operators in China consistently turn them off because of the expense of operation. [Steinfeld 2008].

1.5 Shale gas

Natural gas offers a practical and relatively quick way to stem the rise of PM2.5 air pollution. At the same time, as an alternative to coal, it offers an important opportunity to significantly slow the growth of CO_2 emissions.

Shale gas is natural gas, mostly methane, tightly trapped inside shale rock. *Conventional* natural gas is the small fraction that has slowly leaked out of the shale over millions of years and became concentrated in easily reached geologic pockets. But shale gas is the *source*, and as such is much more abundant than conventional gas. Its existence has been known for a long time, but most geologists thought its extraction was economically unfeasible, until recently. Over the past two decades, geologists discovered they can release it in vast quantities by using horizontal drilling (which can follow a deeply-buried thin shale bed for over a mile) and multi-stage *fracking* (hydraulic fracturing – pumping water into the rock at pressures of a thousand atmospheres). In the US, shale gas production has grown by a factor of 17 in the last 13 years. It now supplies 35% of US natural gas.

In the US, substitution of shale gas for coal power was driven in large part by the fact that old coal plants needed to be retrofitted with expensive scrubbers; it was often cheaper to decommission them and build a new combined cycle gas plants instead. The cleanliness shale gas delivers is intrinsic. Compared to coal, shale gas results in a 400-fold reduction of PM2.5, a 4,000-fold reduction in sulphur dioxide, a 70-fold reduction in nitrous oxides (NOx), and more than a 30-fold reduction in mercury. [EIA 1999, EIA 2009]. As a result of this coal-to-gas transition, over the last 15 years, the electric power derived from coal in the US has dropped by 1/3, replaced by shale gas power. This reduction, in turn, is responsible for much of the unanticipated drop in US greenhouse gas emissions during that same period. [Hausfather, 2013].

China became a net importer of natural gas in 2007, and by 2012 the imports grew to 29% of its gas consumption. [EIA 2013]. And yet it is believed that China has enormous reserves of shale gas, perhaps 50% larger than those of the US. [EIA 2011]. If that shale gas can be utilised, it offers China a wonderful opportunity to mitigate air pollution while still allowing energy growth.

And shale gas can help address the global warming issue too. When burned to produce energy, natural gas produces typically half the CO_2 of coal (depending on the grade).[6] In addition, when the heat energy is used to produce electricity, natural gas can produce electricity with 50% higher efficiency than can coal, even when the coal is burned in the most efficient way, in a pulverised supercritical power station. The net result is that CO_2 produced per kilowatt-hour of electricity from gas is only one third to one half that of coal. And, the capital cost of such a gas-fired plant is much less than that of a similarly sized coal-fired plant.

6 The CO_2 produced in burning coal depends on the grade, that is, on how much of the coal is carbon and how much is complex hydrocarbons. Natural gas consists primarily of methane, CH_4, and when methane is burned more than half of the energy comes from the hydrogen which burns into harmless H_2O – water. (Although H_2O is a greenhouse gas, the amount produced is overwhelmed by natural H_2O.) In contrast, when carbon burns, all the energy comes from creating carbon dioxide.

2. IS SHALE GAS ENVIRONMENTALLY BENIGN?

Despite the immense potential environmental value of shale gas, the list of potential environmental negatives is also significant. We need to sort out which threats are real and which ones are based on misunderstanding; the rapid development of shale gas has been matched by an equally rapid growth of misinformation about the potential dangers. The following paragraphs go through these one by one and explain why, although all of them must be addressed, none of them are showstoppers.

2.1 Shale gas production depletes limited supplies of fresh water

A large amount of fresh water is normally used in US fracking operations, typically about a 1 gallon of water for each million BTUs of shale gas produced. (1 million BTUs of energy requires 1,000 cubic feet of gas, or about 30 cubic metres.) For a single well, that can amount to two to five million gallons of water, enough to fill several Olympic-sized swimming pools.

Yet viable alternatives exist. Virtually all of the shale gas regions have abundant resources of deep brines – salty water – well below the shallow depths where fresh water is found. This is not accidental; the same sedimentary geology that trapped shale gas provides barriers that trap rainfall. Potable water is typically found from the surface to a depth of about 100 metres; below that, the water is too salty for any commercial purpose – other than fracking. At 300 to 500 metres, still relatively shallow compared to the shale layers, abundant saline water can be extracted. Moreover, most of the water that flows back from the well can be treated and reused.

A gas and oil company named Apache has been on the forefront of reducing fresh water use. They first did this at the Horn River formation in Canada where brines proved not only practical but cheaper than use of fresh water. Then they eliminated fresh water use in fracking operations in Irion County, Texas; this year they have used only recycled produced water from fracking operations and oil fields together with brackish water obtained from the Santa Rosa formation at 800 to 900 feet depth [Reuters 2013]. In all of Apache's hydraulic fracturing operations in the Permian Basin, more than half the water is sourced from non-fresh water sources, about 900 wells.

In the US, many farmers and ranchers prefer that fresh water be used since they can make additional income by selling it. Saline water requires different additives to address viscosity, corrosion, scaling, and bacteria, but the required chemicals are not substantially more expensive than those for fresh water. In his book on shale gas, Vikram Rao, the former CTO at Halliburton, recommends that brines completely replace fresh water for fracking operations. [Rao 2012].

2.2 Flaming faucets! Fracking pollutes ground water

The famous "flaming faucets" shown in the movie *Gasland* (and on *YouTube*) were not due to fracking, despite what that movie suggests. The accounts were investigated by state environmental agencies, and in every case traced to methane-saturated ground water produced by shallow bacteria. Indeed, the movie *FrackNation* includes a clip in which the *Gasland* producer, writer, and star Josh Fox admits that flaming faucets were common long before fracking was ever tried.

Nonetheless, there have been suggestive correlations between local water contamination and well locations. In cases in which contamination has been documented as coming from the wells, it has not come from the fracking (which typically takes place at depths of two to four kilometres), but from improper wastewater disposal or from leaking shallow casings in old drill holes. Properly designed drilling, fracking, and completion regulations, coupled with effective monitoring, can ensure that shale gas production has small or zero detrimental effect on the environment.

This leakage issue is not particularly linked to shale gas wells; the same dangers occur for conventional gas and oil wells. The reason for legitimate concern is that with shale gas, the number of wells in a region can be large, so the risk of contamination is higher.

The solution lies in regulating shale at least as stringently as conventional oil and gas. If ground water contamination occurs, fine the perpetrator enough to make it highly unprofitable. Monitoring can be done both through government and community inspections; the threat of stiff fines will drive all operations to use industry best practice.

2.3 Fugitive methane – a powerful greenhouse gas

Methane, the dominant component in natural gas, is a much more powerful greenhouse gas than carbon dioxide. The initial scare of the danger of "fugitive" (leaked) methane came from mistaken use of the fact that its "greenhouse potential" is 83 times that of CO_2, kilogram per kilogram.[8] That makes it seem that even 1% leakage would undo its advantage over coal. But if you take into account the fact that methane is rapidly

[8] This value and the subsequent values are the those used in the latest report of the International Panel on Climate Change. The value 83 is for a 20 year time frame.

destroyed in the atmosphere (with a much shorter lifetime than CO_2), then the potency is reduced to about 34 times. And the fact that methane weighs less (molecule per molecule) than CO_2 means that leaked methane is only 12 times more potent for the same energy produced.[9] Because natural gas power plants are more efficient than those of coal, even with leakage rate of up to 17% (far higher than even the most pessimistic estimates), natural gas still provides a greenhouse gas improvement over coal for the same electricity produced. [Muller, 2013; Cathles et al. 2011].

How much methane leaks in actual practice? Initial analysis by Howarth [2011] suggested that it might be as high as 8%. That is well below the coal equivalent percentages, but it certainly makes natural gas less attractive from a global warming perspective. However, Howarth's original work made assumptions for parameters that were not directly measured, and many of these were "conservative estimates" – which means prejudicial against natural gas. It took two years, but finally a calibrated study of 190 wells showed that the leakage from shale gas production averaged about 0.4%. [Allen, 2013; Hausfather & Muller 2013]. If we add in leakage in pipelines and storage, the maximum is still only 1.4%, and the greenhouse advantage over coal is large. A recent report by Miller et al. [2013] suggests the rate could be twice that; but even if this new report is more accurate than the EPA value, fugitive methane is still a vast greenhouse gas improvement compared to coal.

9 A kilogram of methane produces 2.75 kg of CO_2 when burned. That means that to calculate what happens if methane leaks, we have to compare the potency of 1 kg of methane to the potency of the 2.75 kg of CO_2 that otherwise would have been put into the atmosphere. That reduces the ratio from 30 to 30/2.75 = 11.

In retrospect, that low number of 1.4% for leakage is not surprising. Any producer who leaks 8% of his gas (the Howarth number) is throwing away 8% of the revenue, and a much larger percentage of the profit.

2.4 Poisoning the ground with fracking fluid

A few years ago, one of the competitive secrets to fracking was in the choice of chemical additives to the fracking water. Environmentalists worried about the potential harm that such additives could do to the underground rocks and if accidently released to the surface and mixed with groundwater.

To alleviate concerns, over 55,000 wells in the US are now disclosing the fluids they use; the compositions are published online at fracfocus.org. Additives include friction reducers, oxygen scavengers, corrosion and scale inhibitors, and biocides. Some companies have gone further: executives of the firms have drunk fracking fluid at press conferences to demonstrate how harmless it is.

The concern of harming the ground needs to be put in perspective. The shale is already full of nasty chemicals, including the very hydrocarbons the drillers are trying to obtain (gasoline, kerosene), carcinogenic compounds known as PAHs, as well as arsenic and heavy metals including mercury and lead.

Nobody drinks the flowback water. It is bad stuff, due to what comes out of the ground rather than what was pumped down, and it must be handled appropriately. About 30% of the water injected into the ground comes back, a combination of fracking fluid and produced water from the ground. At least 90% of this water can be recycled and put back into future wells. That leaves 3% or less to be disposed of. Regulation should require that residual waste water not be released into the surface environment, but be trucked away; if liquid, then buried in disposal wells. Such practices are already in use in the US as well as in Sichuan Province of China. Southwestern Energy, one of the largest US shale gas companies, states on its website that it recycles 100% of its waste water.

2.5 Earthquakes induced by fracking

Injecting water into the ground can induce earthquakes. In 2011, a magnitude 5.6 earthquake triggered by water injection in Oklahoma destroyed 14 homes and injured two people. A good review was recently published in *Science.* [Ellsworth, 2013].

No large earthquakes have been associated with fracking but rather with "disposal wells". There are about 30,000 such wells in the US, most used for conventional oil and gas wastewater burial. Of these, most show no injection-induced seismicity; the ones that do are the ones that dispose of very large volumes or dispose of water directly into faults.

Fracking does not inject similarly huge amounts of water, and for that reason has not been the cause of large earthquakes. Typical earthquakes generated directly by fracking are magnitude one to two, too small for a human to feel although detectable by seismometers. The energy factor for a one-magnitude difference is typically 30, so a magnitude two fracking earthquake is smaller than a magnitude five disposal earthquake by 30x30x30 = 27,000 times, the same energy ratio as for a match compared to ten pounds of TNT.

We can prevent disposal earthquakes by recycling water to minimise injection volumes and by taking care in the choice of disposal well locations.

2.6 Shale gas is a fossil fuel

True. And as such, it contains substantial amounts of carbon, and eventually we need to stop injecting CO_2 into the atmosphere. But the increases in atmospheric CO_2 that we are observing is coming largely from expanding coal use in developing countries. If their increased energy needs can be met from natural gas instead of coal, we can slow global warming by a factor of two to three. That means that instead of having 30 to 50 years before we reach twice the preindustrial carbon dioxide levels in the atmosphere, we might have 60 to 100 years or more. In that time, the cost of solar, wind, energy storage and nuclear could drop to a level at which they can be afforded by the developing world; we may even have fusion energy, or something we have yet to dream of. In fact, with the hoped for economic growth, there may be little of developing world that is undeveloped in 50 years, and the whole world could afford to use zero carbon energy sources even if the cost of solar and wind were to remain high.

2.7 Cheap natural gas will slow the development of solar and wind

If natural gas is available, then it reduces the pressure to develop inexpensive renewable technologies. For some environmentalists, this is their most serious concern. With natural gas providing a cheap alternative, the pressure to produce cheap solar and wind is reduced.

Yet cheap natural gas can also make it easier for solar and wind energy to further penetrate electricity markets by providing the rapid back-up that those intermittent sources require. In addition, natural gas is the only base load fuel that can be downscaled into microgrids and distributed generation networks to provide that same flexibility and reliability for solar energy on rooftops and in buildings, expanding the market for urban solar systems. Particularly for areas focusing on distributed generation, natural gas can be an enabler of wind and solar.

And there is a real danger that if shale gas is not developed, then the main competition to solar and wind will be cheap coal. That is difficult to avoid even in the developed world. Because of Fukushima, Japan is shutting down many of its nuclear plants. As a result it expects to expand its coal use by 23% in 2014. Ironically, one of the larger coal plants it will open is in Fukushima. In Germany, also shutting down nuclear, the greatest energy expansion is coming in coal. In 2012, coal accounted for 45% of Germany's electric power, and in 2013 it has already grown to 50%. Solar in Germany is at 14%. Moreover, if it is to grow substantially and supply more than just peak power needs, solar needs good energy storage systems. Letting a perfect renewable future be the enemy of a good short- to medium-term transition from coal to gas would probably result in a world with more overall greenhouse gas emissions and deaths from air pollution.

2.8 Shale Gas Development Industrialises Rural Lands

The large-scale and long-term structures used to deliver solar and wind power are much more likely to interfere with the local environment. Many people are already complaining about "industrializing the landscape" with wind turbines. Wind farms off the coast of Cape Cod in the US have been opposed by environmentalists who considered them unsightly and worry that they interfere with sea life.

In contrast, the drilling derrick for a natural gas well is normally portable, and is in place for only one to three months. Then it is replaced with a much smaller work-over rig for a few weeks, and then replaced with a small "Christmas tree" of pipes, valves, and gas/liquid separator in a fenced platform about 30 metres square. In China, half of the concrete drilling platform is removed when production starts, and recovered land is restored to agriculture and homes. A single well can extract gas from a mile of shale, and multiple wells (different underground locations and depths) are now being drilled from a single platform both in the US and in China, and that reduces the number of platforms needed in a given area.

A serious but temporary local impact can come from the heavy truck traffic needed to bring in pumps and materials, particularly in areas where roads are poor. In China, local communities benefit from the road improvements that the gas companies make to bring in materials and equipment, and so they are tolerant of the temporary disruptions. Indeed, agreements are negotiated between the gas companies and the local communities.

3. SHALE GAS CAN BE THE SOLUTION

The argument up to now can be summarised as follows: shale gas is urgently needed to address the greatest human-caused environmental disaster of our time, rising levels of air pollution, currently causing over three million deaths per year worldwide. At the same time it can dramatically slow the rate of global warming, and, as a bridging fuel, provide the time we need to develop truly sustainable non-carbon energy sources. The main dangers of shale gas can all be addressed by regulation to ensure that development is done using industry best practice, with heavy fines for malefactors.

But why is shale gas needed in the developed world – a world that can afford to pay the premium for solar and wind? The fundamental reason is speed. Europe can develop shale gas far more rapidly than it can move to solar and wind, largely because of the low cost, the absence of an intermittency problem, and good existing gas infrastructure. To the extent that shale gas replaces coal, it will save hundreds of thousands of deaths each year, lives that will be lost if we choose the slower and more expensive transition to renewables. In addition, shale gas can enable Europe to quickly follow the US lead to lowering greenhouse gases. Coal use is still widespread in Europe. In 2009, it produced 28% of the electric power in the UK, 56% in the Czech Republic, and 42% (more recently up to 50%) in Germany.

Shale development in the US was facilitated by the fact that the US is blessed with some geologic regions in which the underground formations were most amenable to the new technology, not only in Texas but also in Pennsylvania and North Dakota. Shale layers tended to be at modest depths and unbroken by faults and other structures that complicate the shale formations in China and Europe.

It is not just the presence of shale gas that determines economic viability. Drilling a shale gas well is a complex operation. Each well typically costs between US$3 million to US$6 million; initial exploration wells can be twice as expensive. Even if they are productive, the bottom line is whether they produce enough to yield a profit. China and Europe have the "advantage" (for development) that they are importing natural gas at a high price, which makes locally produced shale gas competitive. (In the US, facilities designed to import liquefied natural gas are now being converted to export facilities.) China and Europe need inexpensive gas if they are to substitute clean shale gas energy for coal.

In fact, a number of shale formations in the US were economic failures. Many people have heard of the great successes: the Barnett, the Marcellus, the Bakken. But virtually nobody outside the shale gas community knows of the Caney in Oklahoma, the Conesauga in Alabama, the Mancos in New Mexico, the Mowry in Wyoming, or the Kreyenhagen in California. These were failed efforts, sites that were drilled but have not yet led to development.

Chinese shale gas development has been proceeding slowly, in part because their geology is complex, and in part because of their inexperience with free enterprise. China's first attempts at introducing competition, based on open bidding for shale gas leases, have been very disappointing; many of the winning companies do not have the technical or financial capability for the rapid and innovative development that was needed. China has found it difficult to decontrol prices, a key step towards making shale gas competitive. Until China masters the free-enterprise system (and it has a long way to go), rapid technological advances are far more easily achieved in the West through competition and iteration, and then exported to China.

Shale gas mining in the West is undergoing rapid technological development that is bringing down the cost. We already mentioned the use of brines in place of fresh water. Perhaps equally important is the improvement of extraction efficiency. Industry experts believe that the cubic metres of gas recovered from a given well can be doubled in the near future by better design of the fracking stages to match geologic formation characteristics. And they also believe that number could double again in the next decade. Soon that will mean four times the production for only a minor increase in cost. Such an advance is expected to turn currently difficult fields into major producers, to open up fields in China, Europe, and the US that are currently unprofitable.

The main impediment to the advance of technology in the US is the low price obtained for natural gas (under US$3.50 per million BTU, at the time of writing). As a result, few new gas wells are being drilled; emphasis is on wells that yield more valuable heavy hydrocarbons and oil. The price is still low in the US because of limited demand increase and the large number of shale gas wells already drilled and producing – over 100,000. After an initial surge of production, shale gas wells continue to produce at a low level for decades. But demand is rising as more US coal plants switch to natural gas and as the petrochemical industry moves back to the US (from places like Qatar) because of the newly low price of feedstock. We can expect the price to rise a bit (to US$4.50? US$5.00?) and that will encourage additional innovation.

As mentioned above, Europe shares the ironic advantage of China – the high price it is accustomed to pay for imported natural gas, typically US$10 per million BTU (compared to the US$3.50 in the US). At those prices, the cost of shale drilling and completion can be much higher and still be in the profitable range. That means that Europe can be the testing and proving ground where innovative technology can be tried and perfected while still profitable.

It is not just a matter of low cost and clean air, but an issue of energy security. Europe is far more dependent on Russian gas than it likes, and the Russian shutdown of the Ukrainian pipeline in 2009 clearly made Europeans recognise their vulnerability.

4. CONCLUSION

The air pollution crisis in China and in the rest of the developing world is only beginning. We observed on recent trips to China that many people mistakenly believe any level of pollution below an AQI of 250 is just "haze" and rarely bother to put on masks. When the PM2.5 levels rise above this, the government issues radio alerts and most residents mask up. The average AQI in Beijing[10] this year has been 159, in the *unhealthy* range; the US mean is 45. As the pollution grows it will soon be a mask day every day. Foreign businessmen who recently flocked to China as the land of opportunity now spend as much of their time as possible out of the country. Air pollution makes it an unattractive place to raise a family. Chinese citizens who have the capability of living abroad are doing so. The Chinese government is deeply concerned about this brain drain. And their worst fear is social disharmony, a force that could disrupt their very rule.

We must help the world switch from coal to natural gas. This is not just a public heath issue but a humanitarian one. We need to advance shale gas technology as rapidly as possible and to share it freely. We are in the midst of the greatest environmental catastrophe of modern times, but we are also in the midst of an energy revolution, comparable in significance to the 1849 US gold rush. Shale gas, with its near-total reduction of PM2.5 pollution provides a solution to the pollution. It can be a clean technology, and even though it will not halt global warming, only energy conservation offers a more affordable way to slow it. Environmentalists should recognise the shale gas revolution as beneficial to society and lend their full support to helping it advance.

---

10 The historic Beijing hourly PM2.5 record since 24 January 2013 has been recorded by Andy Young at http://young-0.com/airquality/

REFERENCES

Allen, D. T. et al, 2013, Measurements of methane emissions at natural gas production sites in the United States, www.pnas.org/cgi/doi/10.1073/pnas.1304880110

Cathles, L. M., L. Brown, M. Taam, A. Hunter. 2011. A commentary on "The greenhouse-gas footprint of natural gas in shale formations" by R.W. Howarth, R. Santoro, and Anthony Ingraffea. *Climatic Change*. DOI 10.1007/s10584-011-0333-0

Chen, Y., A. Ebenstein, M. Greenstone, H. Li, 2013, Evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River policy. www.pnas.org/cgi/doi/10.1073/pnas.1300018110

EIA 1999. *Natural Gas 1998, Issues and Trends.* Energy Information Administration document DOE/EIA-0560(98). http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/natural_gas_1998_issues_trends/pdf/it98.pdf

EIA 2009. *Modern Shale Gas Development in the United States – A Primer.* United States Energy Information Administration. April 2009. http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf

EIA 2011. *World Shale Gas Resources – An Initial Assessment of 14 Regions Outside the United States.* US Energy Information Administration report, Washington DC, April 2011, available at www.eia.gov

EIA 2013. www.eia.gov/COUNTRIES/cab.cfm?fips=CH

El Pais, 12 November 2013. English edition available at: http://elpais.com/elpais/2013/10/18/inenglish/1382105674_318796.html

Ellsworth, W.L., 2013. Injection-Induced Earthquakes. *Science* 341, 1225942 (2013). DOI: 10.1126/science.1225942 https://www.sciencemag.org/content/341/6142/1225942.abstract

EPA 2010. *Quantitative Health Risk Assessment for Particulate Matter*, report EPA-452/R-10-005.

Hausfather, Z., 2013. *Explaining and Understanding Declines in U.S. CO2 Emissions* http://static.berkeleyearth.org/memos/explaining-declines-in-us-carbon.pdf

Hausfather Z. and R. Muller, 2013, New EPA Report Reveals Significantly Lower Methane Leakage from Natural Gas. http://static.berkeleyearth.org/memos/epa-report-reveals-lower-methane-leakage-from-natural-gas.pdf

Howarth, R. W., R. Santoro, A. Ingraffea, 2011, *Methane and the greenhouse-gas footprint of natural gas from shale formations, Climate Change*, DOI 10.1007/s10584-011-0061-5. For a discussion of this paper, see http://www.yaleclimatemediaforum.org/2011/05/coal-preferable-to-natural-gas-or-not/

International New York Times, 22 October 2013, page 1.

Lancet 2012, *Global Burden of Disease Study*. This study consisted of seven Articles, which can be accessed at http://www.thelancet.com/themed/global-burden-of-disease

Lepeule, J, F. Laden, D Dockery, J Schwartz, 2012. Chronic Exposure to Fine Particles and Mortality: An Extended Follow-up of the Harvard Six Cities Study from 1974 to 2009. *Environmental Health Perspectives* vol. 120 I no. 7 I July 2012, pp 965-970.

Miller, S. A. et al., 2013. *Anthropogenic emissions of methane in the United States, Proc. US National Academy of Sciences*, www.pnas.org/cgi/doi/10.1073/pnas.1314392110 .

Muller, R. A., 2012. *Energy for Future Presidents* (Norton, New York).

Muller, R. A., 2013. *Fugitive Methane and Greenhouse Warming*, Berkeley Earth memo. http://static.berkeleyearth.org/memos/fugitive-methane-and-greenhouse-warming.pdf

O'Keefe, 2013. www.healtheffects.org/Slides/AnnConf2013/OKeefe-Sun.pdf

Rao, 2012. V., *Shale Gas, The Promise and the Peril*, 198 pages, RTI Press.

Reuters 2013. Fracking without freshwater at a west Texas oilfield. http://in.reuters.com/article/2013/11/21/apache-water-idINL2N0J514J20131121

Steinfeld, E. S., R. K. Lester, E. A. Cunningham, 2008. *Greener Plants, Grayer Skies? A Report from the front lines of China's Energy Sector*. Industrial Performance Center. http://web.mit.edu/ipc/publications/pdf/08-003.pdf

Yang G, Wang Y, Zeng Y, et al. (2013). *Rapid health transition in China, 1990–2010: findings from the Global Burden of Disease Study 2010*. Lancet 2013; 381: 1987–2015. This paper can be downloaded (after you have registered for free) at: http://download.thelancet.com/mmcs/journals/lancet/PIIS0140673613610971/mmc1.pdf?id=de2e5b4b1d461676:68d48003:142252c0c07:-26961383605243403

THE CENTRE FOR POLICY STUDIES

The Centre for Policy Studies is one of Britain's best-known and most respected think tanks. Independent from all political parties and pressure groups, it consistently advocates a distinctive case for smaller, less intrusive government, with greater freedom and responsibility for individuals, families, business and the voluntary sector.

Through our Associate Membership scheme, we welcome supporters who take an interest in our work. Associate Membership is available for £100 a year. Becoming an Associate will entitle you to all CPS publications produced in a 12-month period; invitations to lectures and conferences; advance notice by e-mail of our publications, briefing papers and invitations to special events.

Please contact Jenny Nicholson, Deputy Director, Events and Fundraising, for more details at the address below.

THE AUTHORS

Richard A Muller has been Professor of Physics at the University of California, Berkeley since 1980. He is recognised as one of the world's leading climate scientists and is the co-founder and scientific director of Berkeley Earth, a non-profit organization that re-analysed the historic temperature record and addressed key issues raised by climate sceptics. He is the author of *Physics for Future Presidents* and *Energy for Future Presidents* and six other books. He has founded two projects that led to Nobel Prizes and was named by Foreign Policy as one of its 2012 Top 100 Global Thinkers.

Elizabeth A. Muller is co-founder and Executive Director of Berkeley Earth, and founder and Managing Director of the China Shale Fund, an investment fund that brings together the best geological minds for innovation in shale gas in China. Previously, she was Director at Gov3 (now CS Transform) and Executive Director of the Gov3 Foundation. From 2000 to 2005 she was a policy advisor at the Organization for Economic Cooperation and Development (OECD). She has advised governments in over 30 countries in both the developed and developing world.

ISBN 978-1-906996-80-2

57 TUFTON STREET, LONDON SW1P 3QL TEL:+44(0) 20 7222 4488 FAX:+44(0) 20 7222 4388 WWW.CPS.ORG.UK