Amherst, NH – Pipeline Task Force Working Document

Environmental Concerns Regarding Fossil Fuel Pipelines v. 1

Executive Summary:

The use of fossil fuels such as coal, oil, and natural gas causes emissions of greenhouse gases including carbon dioxide (CO2) and methane (CH4). These gases, even in trace amounts, cause trapping of heat in the climate system of the Earth, leading to climate change in general and overall warming in particular. Already, emissions have driven CO2 levels far higher than anything seen in the last 800,000 years, and the atmospheric concentration continues to rise quickly.

The global climate has warmed significantly since the beginning of industrial emissions around 1750, and continues to do so at a rate that is unprecedented in any available record of past climate. Even if emissions are curtailed or stopped altogether today, the Earth will continue to warm for many decades, and will not return to pre-industrial levels for thousands of years. Continued emissions will directly increase the severity of climate change and its damaging impacts.

These conclusions are supported by rigorous science, reflecting an overwhelming consensus among the world's climate scientists, and the scientific articles they write in peer-reviewed journals. Substantiated reservations regarding the central issues are now very rare in the science community, and the most important elements of the science related to climate change are already well settled.

Despite this consensus, the scientific conclusions regarding anthropogenic (human-caused) climate change remain politically controversial, particularly in the US. Unfortunately, politically motivated opposition to these conclusions takes the form of attempts to cast doubt on the science of global climate change, using arguments that lack any scientific merit, yet which sound plausible to the general public.

Assertions of scientific controversy in the media and online are highly exaggerated and distorted. For in-depth coverage of the currently accepted scientific understanding, the 5th Intergovernmental Panel on Climate Change (IPCC) report is the definitive source. A more accessible yet still trustworthy source of information is a website maintained by the UK Royal Society and the US National Academy of Sciences.

For those who may have heard specific challenges to the science of climate change that sounded convincing, we suggest:

http://www.skepticalscience.com/argument.php?f=percentage

This web site lists more than 150 of the most frequently mentioned challenges to the science, and addresses them, often with links to other resources.

The Northeast Energy Direct (NED) pipeline would carry compressed natural gas, which is nearly pure methane. Current extraction and distribution methods for natural gas are characterized by substantial leakage, and since methane is itself a potent greenhouse gas, natural gas is worse for the climate than is generally assumed. It is a fossil fuel and its continued widespread use will aggravate the climate problem. It is somewhat better than coal and oil, but far worse than low-carbon alternatives.

The remaining, readily-accessible deposits of fossil fuels are vast, dwarfing what has already been burned. Correspondingly, their use would result in CO2 emissions that dwarf those already profoundly changing the climate. The incentive to use them is large, due to the extraordinary amounts of money to be made from them (the current global fossil fuel industry

is a ~$5 trillion per year enterprise), compounded by the lack of fiscal accountability for the eventual economic cost of global environmental damage. It is projected that the global imposition of a realistic price on carbon emissions, while politically difficult, would stimulate transition to other energy sources, and drive a sharp reduction in future CO2 emissions in coming decades.

A second way of driving emissions lower involves innovation that makes alternative sources of energy more competitive. Greater investment in the basic and applied research that drives the innovation engine would accelerate the penetration of low-carbon energy sources into the market. The potential for game-changing breakthroughs is high, as accelerating technological progress on a broad front facilitates more efficient energy research. A third path to reduced emissions is energy efficiency, which also is highly amenable to technological innovation. A fourth option, posing major technical challenges, is capture and sequestration of carbon from the atmosphere.

However, permanent measures that maintain or increase supplies of fossil fuel, in the absence of a financial incentive to limit emissions, work in the opposite direction. They perpetuate emissions of CO2, drive up the total amount emitted, and increase the severity of climate change. The construction of pipelines, like NED, that facilitate the extraction of oil and gas from reserves that will last decades, at low marginal cost, increases the economic incentive to emit CO2 over the long term, with potentially devastating consequences.

Such considerations are not among those used by the Federal Energy Regulatory Commission (FERC), and will not be a factor in the determination by FERC whether or not to permit the building of NED. The decision by individual citizens to support or oppose such projects on the basis of environmental concerns will benefit from access to the reliable, factual information that this document seeks to provide.

Overview:

The purpose of this document is to provide a readable, accessible account of the global consequences of fossil fuel use in general, and the construction of fossil fuel infrastructure, similar to the NED pipeline, in particular.

The topic is complex, and to compound the problem there is a lot of chaff to be sorted through before one gets to the wheat. This aspect is well stated by the Wikipedia entry on the politics of global warming: "*Although there is a consensus on the science of global warming and its likely effects - some special interests groups work to suppress the consensus while others work to amplify the alarm of global warming. All parties that engage in such acts add to the politicization of the science of global warming. The result is a clouding of the reality of the global warming problem.*" Consequently, the document is necessarily quite lengthy in order to provide the needed clarity. To assist the reader, a short summary paragraph is provided at the end of each section.

This document specifically does not address the question of nuclear power despite its great potential relevance to the issues, in order to simplify the discussion.

The document comprises the following sections, which together are intended to provide a broad overview of the pertinent issues governing the question of whether or not continued investment in fossil fuels is advisable.

1. **A primer on greenhouse gas and climate change** – how this works at a basic level
2. **The IPCC report** – a compilation of everything known about human-generated climate change, the scientific credentials of that report, and its main conclusions
3. **The problem with natural gas** – it is not as clean as it is advertised to be

4. **The exploitation of fossil fuels** – some basic facts about how much remains to be extracted and burned, the incentives for doing so, and what the results of that would be
5. **The future of energy generation** – a summary of energy generation projections, and the potential of disruptive technologies
6. **Policy choices and consequences** – putting it all together, and the choice that pipelines like NED represent

1. A Primer on Greenhouse Gas and Climate Change

A brief account of the physical mechanism underlying climate change due to greenhouse gases is appropriate.

The Earth receives energy from the sun in the form of electromagnetic radiation that warms the surface of the earth, which in turn warms the air above it. Roughly half of the radiation arrives as visible light, and the other half is in the form of near infrared radiation, along with a small amount of ultraviolet. The sun radiates a lot of energy because it is hot, but all bodies in space radiate energy at some level as long as they are above a temperature of absolute zero (no thermal motions, corresponding to -273.15°C, or -459.67°F), and our planet is no exception. The temperature of the Earth's surface, on average, is 290°C above absolute zero, and therefore it radiates energy into space, but primarily in the invisible mid and far infrared regions of the spectrum.

Sunlight is brightest in the visible part of the spectrum, and air is generally transparent at those wavelengths, so, apart from clouds, much of the energy reaches the surface, which heats up. The rest is either directly absorbed by the atmosphere, or is reflected back into space. The reflection can be from clouds, snow and ice (efficient reflection), or darker land and water (inefficient reflection).

The story is quite different for the mid and far infrared radiation emitted by the earth. This is the mechanism that causes cooling at night, and one often hears TV meteorologists referring to "radiational cooling" in the winter when warning of extremely cold overnight lows. To be effective in cooling the earth, that infrared radiation must be able to escape into the cold of space. Clouds can get in the way of the cooling (which is why clear winter nights get colder than cloudy ones), but so can other things in the atmosphere, the so-called "greenhouse gases".

The above account is a significant simplification, and the true situation involves various forms of energy transport in the lower atmosphere. There is a complex interplay between the way that water, carbon dioxide, methane and other atmospheric constituents absorb and re-radiate energy at infrared wavelengths. The broad picture described here is, however, adequate for the purposes of this document.

The greenhouse gases of greatest concern to our society are carbon dioxide and methane, both of which have risen in concentration sharply since the industrial revolution, and these rises are directly caused by human activity. Along with water vapor, these gases absorb infrared radiation very efficiently, even when present in very low concentrations. To understand how this happens, consider adding ink to a large glass of water. Just a few drops of concentrated ink can cause the water to turn completely opaque. In other words, the glass of water efficiently absorbs visible light when only a trace of certain substances is added, at concentrations comparable to those of greenhouse gases in our atmosphere. In the same way, very low concentrations of carbon dioxide and methane, measured in parts per million, can dramatically affect how much infrared radiation escapes from the warm ground into space. When less energy escapes through radiation because of trace greenhouse gases, more stays in the atmosphere, and our planet gets warmer.

Of course things are far more complicated than this in practice. For example, higher temperatures cause the air to hold more water vapor, which is itself a greenhouse gas, so the warming effects of carbon dioxide and methane are amplified – the magnitude of that amplification is well constrained. When there is more water vapor there may be more clouds, which reflect sunlight back into space during the day but reduce radiational cooling at night. Taking these and many, many other effects into account, there is a very solid understanding of the global warming effect of increased greenhouse gas concentrations. The manner in which this happens, through radiated energy, is called ***radiative forcing*** of the climate.

There are few more stark illustrations of this relationship than the record of temperature and carbon dioxide concentration over the past million years or so. Scientists have developed robust and reliable methods of measuring past temperature and carbon dioxide, independently of each other, leading to the reconstruction of prehistoric variations shown in Figure 1. Over the past 800,000 years there have been a series of planet-wide glaciations and interglacial periods. These have fundamentally been triggered by the slow but predictable interactions between the orbit of the earth around the sun, and the tilt of the spin axis of the earth, leading to the so-called Milankovitch cycles, after the Serbian astronomer Milutin Milanković. This is called ***orbital forcing***, and is fundamentally different from radiative forcing.

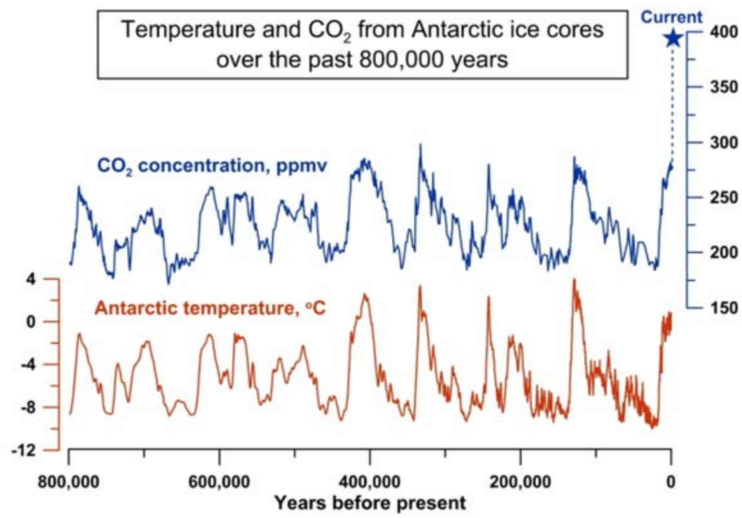

Figure 1 - Nearly a million years of temperature and CO_2 data. These two things are tightly coupled, providing compelling evidence of "positive feedback". Note that throughout this span of time, the CO_2 hovers between about 180 and 280 parts per million by volume (ppmv). On a timescale far too short to even see on this graph, it has shot up to its current 2015 value of 400 ppmv, directly and unambiguously due to fossil fuel burning and deforestation by humans. The temperature has only just started to respond to this massive injection of CO_2. Image credit: Jeremy Shakun, Boston College.

The fact that the temperature and carbon dioxide concentrations track each other so closely is powerful evidence of a phenomenon known as positive feedback. As the planet warms due to a phase of the Milankovitch cycles, the complex physical and biological mechanisms constituting the climate system respond, notably including carbon dioxide release from the oceans, causing much more warming until an equilibrium is reached. The reverse occurs during a cooling phase. Written unmistakably in a reliable record from deep ice cores over hundreds of thousands of years is an account of how carbon dioxide levels and global temperatures are tightly related to each other.

In summary: climate and carbon dioxide are tightly linked through the greenhouse effect, because the gas stops heat from radiating back out into space. It takes time, but higher carbon dioxide concentrations lead to higher temperatures and a changed climate.

2. The IPCC Report

But what can we expect in the future as gases that affect the climate continue to be emitted and continue to accumulate in our atmosphere and dissolve into our oceans? This is a very complicated question to answer with precision, and it is the subject of intense, urgent, and scientifically rigorous study by some of the world's most knowledgeable and capable scientists. A comprehensive account of the current state of the art in understanding the climate system of the Earth can be found in the fifth report of the Intergovernmental Panel on Climate Change (IPCC), published in 2013 and available for download at:

http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_ALL_FINAL.pdf

This report consists of 1,552 pages of in-depth study covering all aspects of climate change, driven by both natural and human-caused (anthropogenic) phenomena. It is a careful, objective study, based on rigorously peer-reviewed work, and constituting the most authoritative and comprehensive view of climate change available. Careful attention is paid to uncertainties in measurement and modeling. Instead of proclaiming results with certainty, the report provides the background information that allows the level of uncertainty to be understood, if it cannot always be accurately quantified. The science is often attacked for lacking certainty, but that is the nature of science. For the key, central results the level of uncertainty is low, and is clearly documented.

The report has been contributed to by over 800 climate scientists from 32 countries, and critically reviewed by an even larger group. Of the 1,552 pages, roughly 200 pages are devoted to over 9,200 references to scientific articles, most of which were published in highly respected peer-reviewed professional journals, comprising literally hundreds of thousands of pages of highly technical research reports. Peer reviewed journal articles are subjected to close and critical independent scrutiny to ensure quality of the research before they can be published. The IPCC report itself was subjected to two rounds of expert peer review, generating 54,677 independent comments by 1089 reviewers from 55 countries. Egregious errors and misrepresentations are extremely unlikely to survive such a rigorous critical examination.

The credentials of the report, despite many politically motivated attacks are, quite simply, ***unimpeachable*** from a purely scientific viewpoint. It is not a politically motivated document; it is not designed to milk a governmental grant gravy train for any specific individuals, nor is it part of some mythical environmentalist conspiracy to undermine anybody's way of life. It is instead ***an extraordinarily informative distillation of the accumulated knowledge of humanity regarding one of the most important topics for the future of our planet and our species.***

OK, the IPCC report is a fact-filled and highly credible document, so what does it say?

In a nutshell, humanity is driving the planetary climate away from the pre-industrial equilibrium, mostly because of the burning of fossil fuels, namely coal, oil and natural gas. The rate at which this is happening is much faster than has ever occurred naturally, as far back as we can see (meaning thousands to millions of years). The consequences as our planet's physical and biological systems respond to the sudden, large change in climate will be profound.

Let's look at a few key indicators of this.

- The climate has been warming swiftly since 1950, and the last 30 years period has been the warmest in at least 1400 years, bringing a host of clearly observed changes on a global scale. There is high confidence that extreme weather events have increased in frequency due to this warming.

- More than 90% of the excess heat from greenhouse gases has gone into the oceans, and is accumulating mostly in the upper 700 meters of the oceans.
- Dramatic changes are being observed in the cryosphere (polar regions and mountain glaciers). Ice is being lost at rapidly increasing rates from glaciers worldwide, and from the Greenland and Antarctic ice sheets. Arctic sea ice is experiencing rapid and drastic shrinkage, snow cover on land has decreased, and permafrost temperatures have increased.
- Sea levels have been rising for many decades, and the rate of rise has recently accelerated. This is well understood in terms of melting ice and thermal expansion due to warming.
- Carbon dioxide, methane and nitrous oxide levels in the atmosphere are higher today than at any time over the last 800,000 years. They exceed pre-industrial levels by 40%, 150% and 20% respectively, due unambiguously to human activities. The rate of change of these concentrations is greater than at any time in the last 22,000 years, and probably much longer than that.
- Humans have caused roughly 2000 billion tons (gigatons) of carbon dioxide to be released into the atmosphere since 1750, mostly from fossil fuel burning, and mostly in the last few decades. A bit less than half has accumulated in the air, and the rest is split between dissolving in the oceans, and being taken up by land-based ecosystems (mainly plant growth).
- The carbon dioxide that has been dissolving in the oceans is making the water more acidic, which will have major consequences for marine life, not discussed in this document.
- We are currently releasing roughly 35 gigatons of carbon dioxide every year, and another 3 gigatons from land use practices (i.e. deforestation and the like) for a total of roughly 38 gigatons per year. This greatly exceeds the capacity of natural mechanisms to absorb and is causing continued rapid rise of atmospheric CO_2 concentrations.
- The observed rate and character of temperature rise is well measured, and is consistent with current understanding of greenhouse gas trends and a wide range of feedback mechanisms. By and large, we know what humanity is doing, and we understand why it is having the effects we observe.

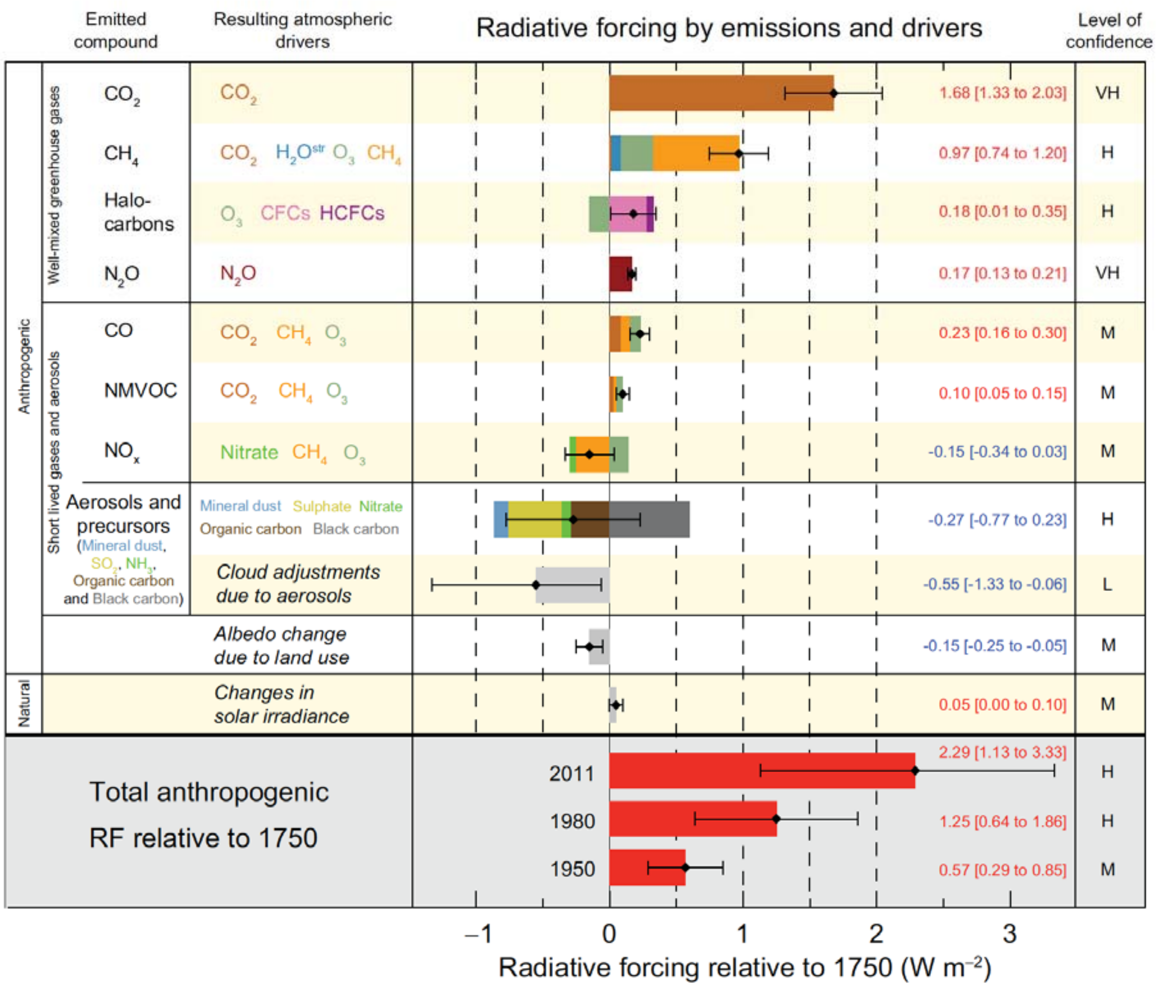

Figure 2 - For the more technically-minded. This is a simplified summary of the various factors contributing to radiative forcing (RF) in the atmosphere, including error estimates (source: IPCC report). Some are positive (warming effect) and some are negative (cooling effect). All except changes in solar output (the tiny one at the bottom) are due to human activities, and the sum of them all (red bars at the bottom) represents the overall effect of human activities on how much solar energy gets trapped. The takeaway from this is that when you take everything into account (the full report has much more information than this, and the supporting scientific studies have more still), we are clearly causing our planet to heat up.

With high confidence, the bottom line is that these numerous and profound changes have not stopped as some falsely claim, they are not due to solar variability, volcanoes, cosmic rays or other common scapegoats found in blogs and the popular press, and they are much larger and more rapid than "natural" variability in the climate system. ***They are caused by us, and what happens next depends on us.***

This document is not the place to rebut the many criticisms of climate research in the mainstream media, online forums, and politically partisan environments. For those who may have heard a challenge to the science of climate change that sounded convincing, the following link may be useful:

http://www.skepticalscience.com/argument.php?f=percentage

This web site lists more than 150 of the most frequently mentioned challenges to the science of climate change, and addresses them in some detail, often with links to other resources.

It is also the case that global warming alarmism exists, and further clouds the debate. Examples of common misconceptions found in popular media are:

- *"Rising sea levels will flood cities soon."* In reality, the timescale for large rises in sea level is quite long because ice sheets melt slowly even when it's warm, and even pessimistic estimates call for only a 3-foot rise, on average, by the year 2100. This is certainly costly, but not beyond the capacity of society to adapt to on those timescales.
- *"The permafrost will soon melt, decay, and release enormous amounts of carbon dioxide, producing a runaway greenhouse situation."* The reality is that over the next century this will be a rather small effect, and again the timescales involved are long.
- *"The Gulf Stream will stop any day now and northern Europe will freeze."* This is not going to happen, although in the second half of the 21st century the Atlantic meridional overturning circulation (AMOC) of which the gulf stream is a part will likely weaken somewhat, with significant regional climate consequences.

In general, the best unbiased and detailed account of the status of, and prospects for the climate is to be found in the IPCC report. Another trustworthy source of useful and readily digestible information is a website maintained by the Royal Society in the UK and the National Academy of Sciences in the US. A good starting point is the Q&A page at http://nas-sites.org/climate-change/.

In summary: The IPCC report is a very thorough, scientifically sound document representing the accumulated wisdom of humanity on the question of climate change. It concludes that human activity is causing rapid climate change, on a scale and at a speed not seen in thousands or millions of years, depending on the phenomenon in question. It accurately reflects an overwhelming consensus in the climate science community regarding the dominant role of human activity in the observed changes.

3. The Problem with Natural Gas

The discussion to date has focused on the primary culprit, namely carbon dioxide. This gas dominates the public debate on climate change, but as can be seen from Figure 2, methane (chemical formula CH_4, second bar from the top) also makes a large contribution to the total radiative forcing (the greenhouse effect).

Conventional wisdom tells us that burning methane, which is the main constituent of natural gas, generates significantly less carbon dioxide than oil or coal for a given amount of energy released. Therefore, the argument goes, switching from oil, and especially from coal to natural gas is a positive step for the climate and for the planet. Unfortunately it is not that simple.

Natural gas extraction, transport and use cause methane to leak into the atmosphere, and methane is a potent greenhouse gas. The most recent and thorough analyses of natural gas leakage from wells and pipes indicate that more methane escapes than has typically been assumed (e.g. see Brandt et al., Science magazine, volume 343, page 733, February 2014). Methane is removed from the atmosphere by natural processes, with a characteristic timescale of 10 years or so, in contrast to carbon dioxide that persists for centuries. Therefore, methane affects climate most strongly within a few decades of being emitted, and accounting for it in climate calculations needs to take this fact into account.

Recent studies have developed more accurate and justifiable ways of assessing the climate impact of methane, for example see:

http://mitei.mit.edu/news/assessing-climate-impacts-energy-technologies

The conclusion is that expansion of the use of natural gas in the coming years will be far less beneficial than is typically assumed, unless effective steps are taken to sharply reduce leakage rates from the natural gas extraction and distribution systems.

It is true that among the various fossil fuels, natural gas produces far fewer harmful byproducts of combustion such as particulates, radioactive materials, constituents of acid rain and the like. As such it has been heavily promoted as a clean fuel.

Sadly, from the point of view of climate change, natural gas is only slightly better than other fossil fuels, resulting in large-scale emissions of potent greenhouse gases. Switching to natural gas on a massive scale as many advocate would provide little relief, while perpetuating structural dependence on fossil fuel in our energy systems.

It should be noted that identifying and fixing methane leaks is likely to be a highly cost-effective way of reducing harmful emissions on a short timescale, though it would provide only modest amelioration of the overall problem.

In summary: Natural gas is seen by many as better for the environment than coal or oil. However, despite burning cleaner, it still emits carbon dioxide in large quantities, and its main constituent, methane, leaks from natural gas production and transport facilities. Methane is bad too, and the overall result is not much better than oil.

4. The Exploitation of Fossil Fuels

Fossil fuels are worth money – lots of money. If they can be extracted and shipped inexpensively, fossil fuel companies can make large profits by bringing vast fuel resources to market. For example, if run at capacity, the proposed NED pipeline would transport gas valued anywhere between $2B and $12B per year. This wide range reflects both time and location in a highly volatile market over the past few years, with the lowest prices at the major Henry Hub terminal in Louisiana, and much higher prices in some international markets such as the Far East, reflecting liquid natural gas (LNG) imports. The NED pipeline would be fed by gas from the Marcellus shale in Pennsylvania, which contains ample resources to keep many such pipelines operating together at capacity for 50 years or more. This implies that just this one pipeline, one of many, could end up transporting $100B to $600B worth of natural gas in current dollars, a major source of sustained revenue for the pipeline operator. Note that at likely long-term Henry Hub gas prices, the Marcellus shale formation alone contains gas worth $1-2 trillion, so the financial incentive to extract and burn it is powerful.

It's worth asking, how much fossil fuel exists that can be found and extracted? The short answer, from the perspective of environmental impact, is "far too much".

As we have seen in section 2, humanity has added roughly 2,000 gigatons of carbon dioxide to the atmosphere, about half of which has accumulated in the air, and the rest has been absorbed by land and sea. Of those 2,000 gigatons, roughly 1,400 gigatons have come from burning fossil fuels, since 1750, with the rest mostly from deforestation. These levels of emission have initiated climate change on a scale not seen in hundreds of thousands of years, and at a speed that may be unprecedented in millions of years. The changes take time to reach their endpoint, and even if greenhouse gas concentrations were stabilized at current levels, the world will still change dramatically over the coming decades and centuries, just as a ship will continue moving forward for a long time after the engines are shut down. In other words, what we have already done will make the changes we see around us today pale into insignificance compared to what our descendants will experience.

Based on what we currently know (see McGlade and Ekins, Nature, vol. 517, p. 187, January 2015), and not counting new discoveries of fossil fuel deposits, it is estimated that burning everything we expect to be able to get at will add **11,000 gigatons of CO_2** to the atmosphere. This is five and a half times what we have already added since 1750, and if we were to do it, the climate consequences would be catastrophic and permanent, virtually guaranteeing global ecosystem collapse and mass extinctions on a scale not seen since the dinosaurs were wiped out 65 million years ago. The credibility of this dire statement is enhanced by the fact that the species extinction rate observed today is on the order of 1000 times greater than that prevailing before human civilization (S.L. Pimm et al., Science vol. 344, no. 6187, May 2015 - estimates both lower and higher than this exist, but there is clear consensus regarding a very high current extinction rate), and many of the extinctions occurring today are due to the as yet modest climate change we have so far experienced.

Global warming to date has amounted to about 0.8 degrees Celsius since 1880, with three quarters of that occurring in the last 50 years. In order to limit warming to 2.0 degrees by 2050, a widely endorsed target, and based on the McGlade and Ekins paper, we must limit emissions of CO_2 to about 1000 gigatons between 2011 and 2050, corresponding to an average rate of 25 gigatons per year. In other words, to limit the changes to only 2.5 times greater than we are currently experiencing, we have to reduce our emissions drastically from current levels, which are at about 38 gigatons per year, almost all from fossil fuel use. This will be difficult at best, because of economic pressures and incentives to maintain or increase fossil fuel use.

There has been talk of “sequestering” carbon, an expensive and as yet immature technology to capture and bury carbon emissions from fossil fuel burning. The carbon, however, is already sequestered and has been for tens or hundreds of millions of years.

One can work the numbers any which way, but the bottom line is the same, and is inescapable. We as a civilization cannot afford to extract and burn all the fossil fuels we can get our hands on. This is in direct conflict with the profit motive of the multi-trillion dollar global fossil fuel industry of today.

Putting a price on carbon dioxide

The economic cost of climate change is real, but particularly hard to quantify. In economics theory, this type of cost is associated with what is known as a “negative externality”, meaning a bad side effect that is not directly accounted for in the normal buyer/seller supply and demand forces that govern prices and consumption. This has led to discussion of taxes to account for this cost – taxes on the fuels themselves creating a competitive advantage for low carbon alternatives, taxes based on actual emissions creating an incentive, for example, to capture and store carbon dioxide from smokestacks, and less direct methods such as “cap and trade”.

A justifiable price on carbon dioxide emissions is difficult to estimate, but many attempts have been made. An accurate value, and a uniform global tax on emissions equal to that value, in theory should permit free market forces to find an optimum balance between continued emissions, energy efficiency measures, and investment in research, development and implementation of low carbon alternatives. A March 2013 presentation by an official of the U.S.

Energy Information Administration included a projection for the mix of energy sources used for electricity generation through the year 2035, assuming carbon taxes of $15/ton of carbon dioxide and $25/ton, with striking results. The nominal 2035 mix of fuels for U.S. electricity generation is projected to be 38% coal, 28% natural gas, 18% nuclear, 15% renewables and 1% oil and other liquids. With a $25/ton carbon dioxide fee, the mix changes to 38% nuclear, 34% natural gas, 23% renewables and just 4% coal, representing a ***decrease in emissions by nearly 60%***. The presentation can be found at:

http://www.eia.gov/pressroom/presentations/sieminski_03142013_iea.pdf

It is likely that consistent global application of a realistic price on carbon dioxide emissions would result in a sharp reduction in emissions. However the political feasibility of this is highly questionable.

In summary: There is so much cheaply accessible fossil fuel that if we were to burn it all, the climate consequences would be quite literally catastrophic. Sound economics means that the price of fossil fuel should reflect more than just the cost of getting it out of the ground. By including a realistic cost of attendant climate change, market forces can operate more efficiently. Estimating such a cost with precision is challenging, and implementing it is politically difficult.

5. The Future of Energy Generation

In this section we consider energy generation technologies and fuels relevant to the next few decades. This means that we ignore technologies that may eventually have great promise, but are expected to require many decades of development, such as nuclear fusion, solar power satellites, ocean thermal energy conversion, and a few others.

Two Studies and a Consensus

Energy use projections are of great interest to diverse groups, prompting in depth study of energy use trends, emerging technologies, market forces, and global economic shifts. In this section, we draw from two such studies, one from British Petroleum (BP), a major energy company, and the other from the International Energy Agency (IEA), an international organization dedicated to energy security and economic growth in conjunction with environmental responsibility. The projections of these two very different entities, from now into the 2035-2040 timeframe, closely track each other in many aspects, enhancing confidence in the main points, given the starting assumptions.

Shares of primary energy

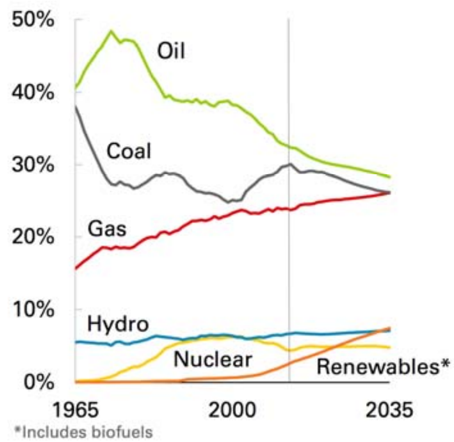

Figure 3 - Relative shares of energy sources from 1965 to 2035, taken from "Energy Outlook 2035", BP p.l.c. 2015. This shows fossil fuels still accounting for over 80% of the total 20 years from now.

Both studies agree that fossil fuel use will grow significantly, worldwide, in this time frame. There will be proportionally more gas and less coal, but fossil fuels will continue to dominate, accounting for 80% of the overall energy use. Annual carbon dioxide emissions will thus grow, reaching 25% above current levels by the end of the period. This is in alarming contrast to the ~35% ***reduction***, starting now, required to limit global temperature rise to 2 degrees (2.5 times the temperature rise we have seen so far), noted in section 4.

In other words, business as usual, allowing market forces and gradual innovation to drive replacement of fossil fuel use, will miss the 2 degree target for carbon dioxide emissions by a wide margin, potentially assuring severe global environmental consequences.

What actions might prevent this bleak future from coming to pass? Two such actions are discussed, one by BP and the other by IEA.

In a notable section of its report, BP identifies a number of options for reducing carbon dioxide emissions, and states “A meaningful global carbon price would provide the right incentives for the most cost effective decisions and investments to be made”, with respect to those options. In other words, a major fossil fuel company is responsibly noting that the environmental consequences of climate change have a price, and that price should be levied on carbon emissions in order for free market forces to work properly.

The IEA takes a somewhat different approach, focusing on the potential of transformative innovation to create the economic incentive for weaning the global economy from fossil fuels. The recommendation of this group is to triple worldwide governmental investment into renewable energy research, thereby accelerating the displacement of fossil fuels by cost-effective alternatives.

So two different approaches to reduce emissions have been identified. First, place a sensible cost on greenhouse gas emissions to allow market forces to do their job, and second, invest heavily in research and development of effective, or possibly even disruptive technologies.

The Disruptive Potential of Innovation

A common assertion among energy industry representatives, policy-makers and informed citizens is that renewable energy of various kinds cannot meet real world energy demands any time soon, and therefore we must rely on fossil fuels for decades to come. This assertion bears closer scrutiny in an era of rapid and broad technological progress.

For illustrative purposes, and for space constraint reasons, let's look at just one of a number of potentially transformative developments, specifically in the area of photovoltaic power generation – converting sunlight directly into electricity. Photovoltaics are notable in that the fundamental resource, sunlight, is abundant and inexhaustible. If costs could be brought down sufficiently, ***and*** if the energy thus generated could be stored cheaply then released when needed, solar panels could readily supply a major fraction of the energy needs of the world, on a relatively short timescale. They can be flexibly deployed on a utility scale, replacing fossil fuel power plants, and also on an individual consumer scale, as in the recent swift boom in rooftop solar systems, particularly in Germany, Italy, and other European countries.

Most cost projections are based on incremental improvements in conventional, known technologies. However the pace of innovation in many fields is accelerating, increasing the chance of so-called "disruptive" technologies emerging. They are termed disruptive in part because they upset the predictability that businesses and governments routinely use for their decision- and policy-making; such decisions and policies include things like construction of fossil fuel pipelines that will operate for decades.

Most projections call for only a 10-15% share of total energy production from photovoltaics by 2050, far too little and too late to meaningfully address the climate problem. Among the numerous competitors for the photovoltaic Holy Grail, the solar cell of the future, is a very recent newcomer – the perovskite solar cell. Only in the past 2-3 years has this material shown the potential for very low cost, high efficiency cells, with a wide range of potential mass production paths. In contrast to present day silicon cells, manufacture of perovskite cells would not require costly high temperature processes, and furthermore the raw materials are abundant and cheap. Laboratory units have demonstrated efficiencies rising from a few percent to 20 percent in just a few years, gains that required decades of research for more conventional materials. Obstacles still exist for perovskites, primarily material stability and the achievement of long lifetimes for the cells, but strong disruptive potential clearly exists. Multiple companies are eyeing the possibility of mass production as early as 2017.

Meanwhile, on the energy storage front, Tesla recently made a splash with its battery based products, and global research is accelerating into utility-scale energy storage solutions. These systems are designed to store 10 kWh, which serves the average household during nighttime hours until the sun rises and begins to recharge the batteries. Furthermore, the battery pack has been priced at $3,500, which is reasonably affordable for many who would be interested in purchasing such technology.

Disruptive change is almost always ignored in the projections on which major investment decisions are made, due to the inherent unpredictability of such change. Nevertheless, the accelerating pace of innovation makes disruptive change on the timescales associated with pipeline operation (many decades) increasingly likely.

In summary: There is consensus that current policies and energy industry practices will lead to carbon dioxide emissions much higher than is prudent, given our increasingly solid understanding of climate change. Two effective actions that could be taken are placing a realistic price on greenhouse gas emissions, and increased research into low carbon technologies. The projections are potentially pessimistic in that they do not account for the likely emergence of disruptive low carbon energy generation technologies.

6. Policy Choices and Consequences

The Challenge Posed by the Status Quo

As we have seen, there is compelling evidence that unrestrained use of fossil fuels will have damaging environmental consequences. Because carbon dioxide remains in the atmosphere for centuries to millennia it accumulates steadily, thus the emissions from fossil fuel use today will stick around and continue to have their effects felt for many generations. Kicking this particular can down the road and delaying mitigation actions makes the problem worse permanently and irreversibly, with corresponding adverse consequences.

Reducing fossil fuel use requires some combination of pricing the harmful emissions, bringing alternatives to market, and improving energy efficiency. International negotiations (e.g. the upcoming Paris climate conference in late 2015) seek to implement such actions in a coordinated way across the globe.

But even if these negotiations were to succeed, the global energy industry has inertia. It takes time and money to change the way energy is generated and used, due to a huge installed base of fossil fuel infrastructure, and the relative lack of such infrastructure for any replacement. Policies in effect today, aimed at mitigating climate change, are uncoordinated and relatively weak across the globe. At the same time, fossil fuel production and consumption is collectively subsidized by governments worldwide in the amount of $550 billion annually, according to the International Energy Agency (IEA).

The industry itself has a strong incentive to slow down and delay any transition away from coal, oil and gas, simply because there is a very large amount of money to be made. By building wells and pipelines for natural gas and oil now and reducing marginal costs of production, fossil fuel companies can compete with future renewable energy projects more effectively, for decades to come. This is entirely appropriate in a free market economy, unless there are externalities that have not been accounted for, as in this case. Unless carbon emissions are appropriately priced, the fossil fuel industry has a free hand in actions to ensure the continued large-scale exploitation of fossil fuel resources, turning those resources simultaneously not just into money but also into carbon dioxide.

Natural Gas as a “Bridge” Fuel

Many have advocated the rapid expansion of natural gas as a more environmentally benign “bridge” fuel to buy time while we wait for price-competitive, low-carbon energy sources. In particular, the replacement of coal-burning power plants with cleaner and lower carbon emitting natural gas plants is seen as strongly beneficial, as is reflected in state, national and international policies. At the US regional and Federal government levels, this is one of the drivers of projects like NED.

The total amount of carbon dioxide emitted is what will determine the climate-related challenges that must be faced by future populations, both those now living and those yet to be born. There is obvious merit in using a bridge fuel to achieve somewhat lower emissions in the near term. Total emissions, however, are determined not just by the type of bridge fuel, but also by the length of the bridge (total emissions = rate × duration). If a transition to natural gas postpones the adoption of low-carbon energy sources, even by a decade or two, any benefit is illusory. Yet investments in natural gas infrastructure are, by their nature, long-term. Without a clearly defined timeframe for the end of the bridge to be reached, the transition to natural gas is not a “bridge” but, rather, a transition to a different fossil fuel.

Therefore, to be effective in helping to mitigate climate change, any transition to natural gas must be accompanied by the political commitment to nurture the development and adoption of low carbon energy sources as early as possible, thereby establishing the endpoint of a bridge whose length is minimized. While natural gas supplies are plentiful and cheap, while the infrastructure is humming and the lights are on, and while great financial wealth flows from the wells and pipelines, such political commitment is likely to prove elusive.

Consequently, the rapid expansion of permanent natural gas infrastructure to build a "bridge" is fraught with peril, and should be viewed with great caution.

The US and the Rest of the World

While the United States has been and continues to be one of the world's largest emitters of greenhouse gases, only recently overtaken as number one by China, this problem is global, not national. A potent argument against draconian domestic measures on carbon dioxide emissions is that even if implemented, climate change would not be mitigated very much, because the rest of the world will carry on burning fossil fuels with abandon. Such sentiments mean that only near unanimity combined with genuine, enforceable commitment in international negotiations is likely to yield effective global action, which is unlikely.

Is there nothing, then, that the US can do to address this formidable problem of climate change? Encouragingly, the answer is a resounding "yes". Greenhouse gas emissions in the developed world are stable, and even declining in many countries, due largely to low population growth coupled with energy efficiency measures and growing adoption of renewables. Almost all of the growth in the rate of emissions that is projected comes from developing nations and their economies, which require rapidly growing access to energy.

Just as developing nations have been able to forego the costly installation of an extensive wired communications infrastructure (telephone lines etc.) due to the advent of wireless systems, so too can they forego the installation of fossil fuel energy infrastructures that pollute the planet, provided viable alternative technologies are available. Advanced nations like the US are ideally positioned to develop such technologies. For example, these may include locally generated electricity from wind and solar, with local storage capacity, reducing the need for a complicated, lossy and expensive long-distance electrical grid system. Where a grid system is necessary, it can be designed from the ground up with supply variability in mind, allowing much easier and cheaper management of nontraditional and potentially intermittent power.

With the appropriate vision and political will, the unmatched innovation potential of the US can be harnessed to accelerate the development of low carbon energy sources and create lucrative new markets for US industry across the developing world. Such action would simultaneously limit the emissions of developing nations without encroaching on the rights of their citizens to economic progress, and shorten the bridge to a low carbon future for the rest of the world.

This highly desirable outcome demands a long-term view and a sustained commitment. It is not compatible with the short-term business interests of today's energy industry, and instead lies firmly in the domain of stable and enforceable government policies and regulations. While this may not be seen as a politically neutral conclusion, the physics of climate change and the behavior of CO_2 molecules in the atmosphere of our planet are wholly indifferent to politics. As the late great physicist Richard Feynman famously remarked during the Challenger disaster inquiry, "reality must take precedence over public relations, for Nature cannot be fooled"; the predicament of our changing planet is a reality that humankind cannot ignore.

The Advisability or Otherwise of the NED Pipeline

The decisions of regulatory agencies such as FERC are not influenced by the global climate considerations laid out in this document, and instead are based on comparatively short-term assessments of costs and benefits.

It is therefore accurate to state that a decision to proceed with construction of the NED pipeline through New Hampshire and the Town of Amherst would be taken without regard to the associated long-term global environmental consequences of this and similar projects, consequences that are judged by the best scientific evidence available to be grave.

Incorporation of global environmental concerns into decision-making on infrastructure like this is the domain of national policy. In democracies, such policy is ultimately influenced by the views of an informed and concerned citizenry. Whether individuals favor or oppose a project like NED, for whatever reasons, an opportunity to cut through the politicized debate on climate change and get access to the facts is of value and has been the primary goal of this document.