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Fossil Fuel Energy and Economic Wellbeing

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About the Author

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Executive Summary

Today, fossil fuels supply better than 86 percent of the marketed energy used worldwide. The proportions of oil, gas and coal vary by region but basically these three fuels supply the great majority of energy used to produce economic output everywhere in the world.

Energy is an essential input into economic activity of every kind. More energy enables an economy to produce more output and also to grow. For example, energy is used to distribute goods throughout regions, countries and the world. If less energy were available for the purpose, trade and markets would shrink, with adverse effects on income and consumption. Further, energy is an input into the research and development of new products or new ways of making older ones, and so is a key component of technological advance. Abundant, inexpensive energy therefore provides great advantages and is highly desirable. Because fossil fuels are such a large part of the world's energy supply, they play a very prominent role in enabling people everywhere to enjoy what they have and to look forward to better times ahead.

There are several reasons why fossil fuels constitute such a large portion of the world's energy supply. They are abundant and their quantities generally have been growing, not diminishing. They exhibit high energy density, meaning they contain considerable energy in limited space or volume. And they have high value, enabling people to enjoy such things as mobility, heating and cooling, and the cooking of foods. Also, oil and gas in particular are used to fashion a variety of useful products, including chemicals, plastic goods, synthetic cloths and road asphalt.

At the same time, the production and use of fossil fuels have a number of environmental impacts, including impacts on land, air and water. The environment is not free; there are real costs associated with such impacts, and governments in most countries regulate the production and consumption of fossil fuels to reduce these costs. Usually this regulation takes the form of standards if not specific technological requirements. In advanced countries such regulation generates controversy over whether a particular measure is insufficient or excessive, with organized environmental groups arguing for stricter versions and businesses and others who bear the direct costs arguing for less strict. Generally speaking, however, there is social consensus in advanced countries that with government oversight most of the environmental impacts of fossil fuels are manageable.

There appears to be an exception, however; climate change. Despite the obvious reliance of the entire world on fossil fuels and the prospect that such reliance is likely to continue for decades, particularly in the developing world, it has become fashionable to argue that such fuels must be phased down and perhaps discarded entirely. The targets tend to be longer range, but they involve drastic proportions. For example, the European Council calls for an 80-95% reduction in CO_2 emissions in advanced countries by 2050 which, because fossil fuels account for the great majority of these emissions, almost certainly would require an enormous reduction in their use.[1] In 2009 the Obama Administration pledged the United States to reduce its greenhouse gas emissions 17 percent below 2005 levels by 2020, but made clear this is just a first step towards much more stringent goals in future years. The EPA's "Clean Power Plan," for example, is intended to reduce power plant emissions by 32 percent relative to 2005 levels by 2030.

Of course, if governments in advanced countries legally require such reductions, they will be made, with whatever sacrifice is entailed. Governments can require, for example, that renewables be substituted for fossil fuels in ever increasing amounts. But this makes little sense. If there are climate-related costs associated with fossil fuels, these can be directly reflected in their costs to consumers. If that is done, the proportion of these fuels in a nation's energy mix may change, but they are unlikely to be dramatically phased down or out. It is simply a mistake, conceptually and practically, to propose a drastic phasing out of fossil fuels. Even a relatively high cost assigned to anthropomorphic climate change does not imply such a phase-out, and given the tremendous value of these fuels to country economies everywhere, no such phase-out is likely.[2]

What does make sense is the ongoing development of energy alternatives which add to world supplies in cost effective manner. This includes cost effective renewable energy and energy efficiency technologies, the latter of which would reduce the energy needed in some applications and free it to serve in others. Technology development that increases the abundance of energy and keeps its cost low will yield increased economic output and growth everywhere.

Exactly what the optimum quantities of various forms of energy will be as time passes cannot be forecast at this point. Technical advance may help renewables play a larger role, or it may sustain or even increase the use of fossil fuels through reduced environmental impact, including fewer CO_2 emissions. Pricing to reflect the cost of emissions properly is the key, not setting goals for phase-outs. Once that is done, people will make changes in energy consumption, investment and production and we can see what results follow.[3] The sooner we rethink our objectives with respect to fossil fuels, the better off we will be.

Introduction

It is often asserted that the world needs to begin phasing out fossil fuels, replacing them with renewables in order to reduce environmental impacts, particularly future climate change. For example, the President's envoy on climate change, Todd Stern, recently stated that the world will have to forego the development of fossil fuels, leaving reserves in the ground, in order to solve global warming.[4] According to him, it is 'obvious' that fossil fuels will have to remain undeveloped in order for mankind to avoid adverse impacts from climate change.

Others have made similar assertions, and some have articulated quantitative targets for CO_2 reduction so great that they would force massive reductions in the use of fossil fuels. The Union of Concerned Scientists, for example, argues that the U.S. must reduce its CO_2 emissions by at least 80 percent relative to 2000 by the year 2050.[5] Similarly, the European Climate Foundation takes as a given that Europe and other advanced countries must reduce their CO_2 emissions by 80-95% below 1990 levels by 2050 and lays out a roadmap for doing so.[6] If these sources are taken at face value, it is inevitable that fossil fuel use, at least in the developed world, must be severely phased down if not entirely phased out. And, since the developing world now is emitting more CO_2 from fossil fuels than the developed world, it can only be a matter of time before world leaders demand that it too phase out the use of these fuels.

That the production and consumption of fossil fuels have environmental impacts is undeniable. The natural environment is not a free good; the production and consumption of fossil fuels results in pollution that has real costs. Governments have struggled for years to control the impacts of fossil fuel development and use and generally have found ways to mitigate them. Until recently, few have argued that the environmental impacts of fossil fuels and the need to control them imply the cessation of use of these fuels. Rather, arguments have centered on whether controls are sufficient or too stringent.[7] The specter of climate change seemingly has altered the situation. Now it is argued that fossil fuels are not 'affordable' at all; they must be severely phased down if not completely eliminated.

But this is incorrect, conceptually and practically. There is serious disagreement on the extent to which CO_2 on net imposes costs on the environment.[8] Further, even if it were the case that it imposes such costs, serious errors of policy would result from concluding that fossil fuels must be phased out. There is no imperative to do so, estimates of the cost of anthropomorphic climate change should it occur are too low to think in terms of such a phase-out, and any such phase-out is unlikely to happen. Instead, one might make a case that the overall energy mix should contain proportionately fewer fossil fuels. Such an assertion would rest on the notion that if all of the costs of these and other fuels are reflected in their prices people will choose a different mix. That may or may not be true. A proper balance of fuels depends on the relative costs and advantages of fossil fuels versus others, and the challenge is to reach an appropriate balance. Exactly what that balance should look like probably will vary over time as technology advances and relative costs change. Does it necessarily imply fewer of all fossil fuels, meaning less coal, less oil and less natural gas? Maybe, maybe not. That is an empirical matter.

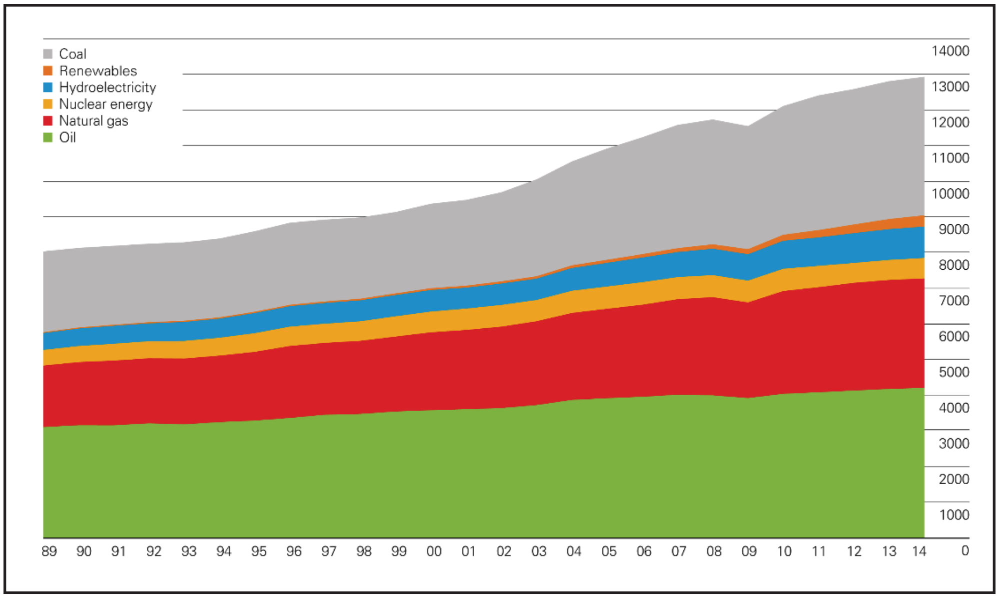
In this paper, I intend to show that, conceptually, it is incorrect to think in terms of phasing out fossil fuels, and that rather their advantages and costs need to be weighed against those of other energy sources. The relative abundance of fossil fuels and their practical advantages have great value to people and should not be arbitrarily dismissed. Even if a potential threat from climate change is considered, it will be shown that fossil fuels very likely will continue to play a prominent role in energy use. The mix of such fuels may change and various other energy sources and energy efficiency technologies may advance and obtain market share via competitive superiority; if so, that would be a positive development. But technological change may increase the viability of fossil fuels as well. The objective should be to promote low cost, not high cost energy, to encourage economic growth and citizen welfare. Fossil fuels are a great boon in that respect, and their role should be treated objectively, just as that of other energy sources should be. The sooner such thinking takes hold, the better off we will be.

Historic Use of Fossil Fuels

In 2014, according to the BP Statistical Review of World Energy, fossil fuels constituted 86.3 percent of world energy consumption, a slight decrease from 2013, when they constituted 86.7 percent.[9] For the U.S., fossil fuel consumption in 2014 also was 86.3 percent of total fuel consumption, down slightly from 86.4 percent in 2013. Clearly, fossil fuels constitute the great majority of energy consumption worldwide, with oil comprising the highest single percentage, coal next and natural gas third. Marketed renewables gained between the two years, from 2.2 percent to 2.45 percent, but they still make up a very small percentage.

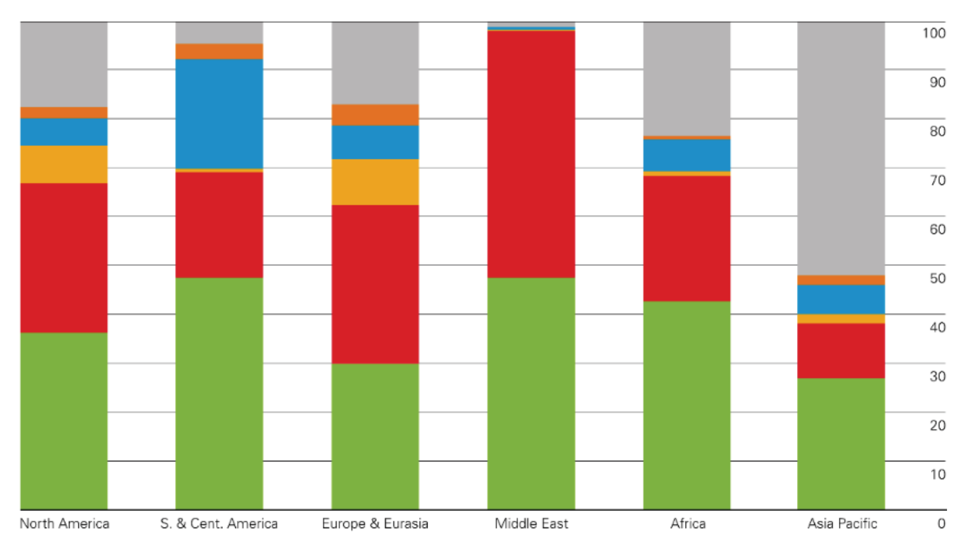
Nothing in this fuel makeup is surprising since fossil fuels long have dominated worldwide energy consumption. The chart below, taken from the 2015 BP Statistical Review of World Energy, shows energy consumption by year, by fuel, from 1989 through 2014. Over that period, worldwide energy consumption grew by over 60 percent, from about 8 billion tonnes of oil equivalent annually to about 12.9 billion such tonnes,[10] and so too did consumption of each of the three fossil fuels. Hydropower, nuclear and renewables also grew, but not enough to much change the overwhelming proportion provided by the three fossil fuels.

Figure 1. World Energy Consumption, 1989 – 2014 (million tonnes of oil equivalent)



Interestingly, fossil fuel use varies by region, with oil and gas dominant in most areas but coal more important in Asia. This is shown in Figure 2, again taken from the BP Statistical Review. The chart shows varying percentages of oil, coal and natural gas by region, and also varying percentages of nuclear, hydropower and renewables. Each fossil fuel has advantages in some areas relative to others, likely related to resource bases and transport costs.

Figure 2. Primary energy regional consumption pattern 2014 (percentage)



Why are fossil fuels in such widespread use?

Prior to the age of fossil fuels, most energy was provided by wood and by human exertion. Wind and hydropower also contributed. But the industrial age was based first on the use of coal, burned directly or used to make steam, and later on oil and natural gas as well. The enormous surge in world economic output that has occurred since the19th century has utilized mostly fossil fuels.

What is it about fossil fuels that make them such attractive resources in most areas of the world? For one, there is their relative abundance. Despite past fears that the world will soon run out of oil and natural gas, worldwide proved reserves of these resources have generally risen over time, not diminished. At the end of 2014, for example, estimated world proved reserves of crude oil were almost exactly 1,700 billion barrels whereas at the end of 1994, twenty years earlier, they were about 1,118 billion. The increase occurred despite worldwide oil consumption of about 30 billion barrels annually, or about 600 billion barrels over the period. The 2014 figure was about 52 years of worldwide consumption at present rates.

Similarly, estimated proven world natural gas reserves rose from 119 trillion cubic meters to 187 trillion over the same time period and constituted about 54 years of consumption at the end of it. Yet over those 20 years, consumption was on the order of 50 trillion cubic meters.

As for coal, estimated proven reserves *decreased* from 1994 to 2014, from 1,039 billion tons to 891.5 billion, but the 2014 reserves represented 110 years of world production at current rates. Likely, exploration for coal was deterred by such a high inventory of reserves relative to the demand.[11]

How can fossil fuel reserves be so abundant when worldwide consumption increases every year and the earth's resource base of these fuels is finite? The answer lies in the economics of the fuels and in the role of technological advance. Producers seek to maintain reserves at some multiple of production, enough to assure several years of future production including consideration of consumption growth. When reserves get below this number their prices tend to rise and there is economic incentive to explore for more. Conversely, when reserves exceed the intended number their prices tend to fall and less exploration takes place. This concept has led some to believe the world has only limited quantities of fossil fuels left to burn, but the notion of holding limited inventories is standard practice among businesses of many types.

In addition, there is constant investment in research into how to unlock previously uneconomic fossil fuel reserves. The recent technique of combining horizontal drilling with hydraulic fracturing provides a particularly striking example of technical advance in the oil and gas industry that has made economic billions of previously uneconomic resources, but it is not the only example. Oil and gas exploration and drilling has become ever more sophisticated via a variety of technological improvements, with the result that far more of the world's petroleum resources are available to be developed and sold into the market than ever before. There is little reason to doubt that the trend will continue; that is, that even more such resources will be unlocked as people try new methods to extract them, some of which prove successful.

What matters too is the productivity of these energy sources. The ability of fossil fuels to power machines has resulted in much reduced time to produce products and therefore greater amounts of product within a given time. Early engines powered by steam, for example, reduced the time necessary to transform raw cotton or wool into finished cloth and much expanded the numbers and types of cloth goods available to consumers.

Fossil fuel use to transport goods also is key to the establishment and extent of markets everywhere. When horses, oxen or bicycles had to be used to transport goods to a marketplace, the extent of trade was very limited. But with trucks, planes and trains powered by fossil fuels, trade between localities and geographic regions has become ubiquitous throughout the world, enabling a far higher quality of life and much greater productivity than otherwise would be possible. Whether this productivity is attributed to fossil fuels or to the resources which make the products, it is clear that without such fuels the potential output of any economy would be much more limited.

But fossil fuels themselves are highly productive. A gallon of diesel fuel can propel an automobile containing passengers some 30 miles. A thousand cubic feet of gas will supply an average home in the U.S. for about five days. And one ton of bituminous coal will supply about two months' worth of electricity to an average U.S. home. Computers, cell phones, IPads and other modern communication devices rely principally on fossil fuel energy to provide the power needed to run them. Renewable sources also supply such power, but as the devices directly consume power or are recharged to do so, the great majority of power they use is generated by fossil fuels.

Speaking broadly, then, fossil fuels are relatively attractive worldwide because they are inexpensive, relatively easy to move about, and provide considerable value. In Appendix A of this report, we further explore what each of the three fossil fuels accomplishes as well as some of the more widely used alternatives.

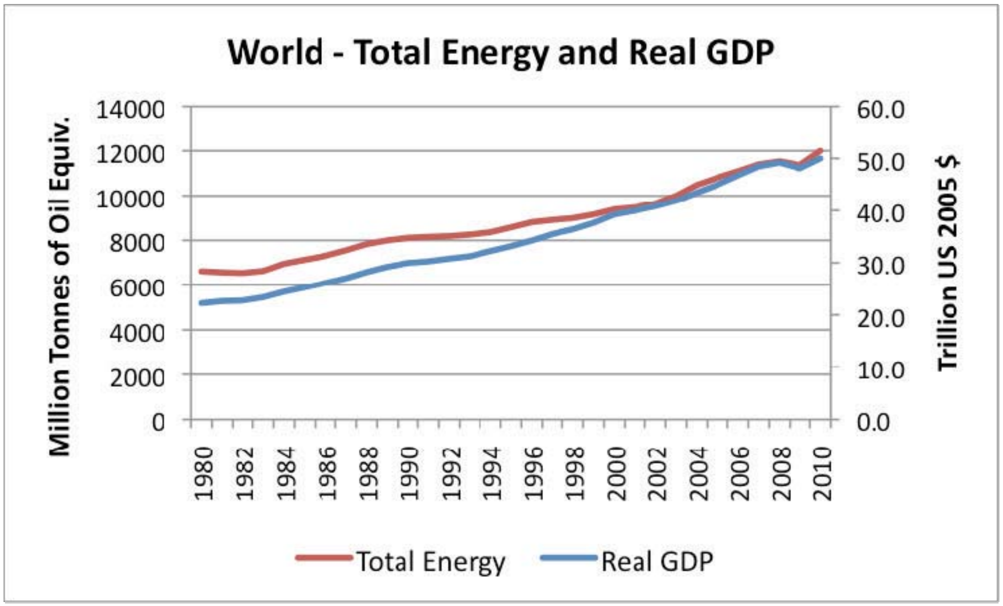
Energy, fossil fuels and economic activity

In this section we argue that high levels of economic activity throughout the world depend on the continued use of fossil fuels. The key point is that the relative abundance of these fuels and their high productivity make them a relatively attractive choice despite their environmental shortcomings. Substitution of other fuels that are cost effective will add to people's wellbeing, whereas substitution with more costly fuels is likely to subtract from it.

Consider how a modern economy operates. In general terms, inputs such as labor, capital and energy are transformed into outputs via the performance of work.[12] Energy in particular is needed to perform work, by powering machines to produce goods, or vehicles to transport these goods to markets. This energy can come from a variety of natural resources, but as we have seen, fossil fuels provide the great bulk of the energy used worldwide. Without them, the amount of work accomplished and the goods and services available would be a small fraction of what actually is produced.

The long term relationship between energy and world economic output is shown on Figure 3. Over the 30 year period 1980-2010 GDP grew faster, but energy consumption grew steadily too. Evidently energy consumption is strongly associated with economic activity and that relationship likely will continue.

Figure 3. Long term relationship between GDP and Energy Consumption



A key to understanding the relationship between inputs and outputs is that low input prices reflect relative abundance, which encourages production and output. An easy way to picture this relationship is through the recognition of constraints. If production requires a certain amount of each input, then less of a given input imposes tighter constraints on the production process, just as more of the input relaxes these constraints so that more output can be produced.[13] Certainly there can be substitution among inputs, using more of those in abundance to substitute for those that are scarce, but such substitution implies that a portion of the abundant input must be utilized merely to replace another one, reducing the amount directly available to produce output. Also, the composition of output can be changed to require less energy, but to the extent this change is driven by a growing scarcity of energy it likely means a less preferred set of outputs.

In an open economy, prices tend to reflect the relative scarcity of resources. Thus, if an input is abundant its price will be relatively low, whereas if it is scarce its price will be relatively high. With abundant resources output will be higher than when resources are scarce. Thus, energy whose low cost reflects its relative abundance will stimulate output whereas high cost energy will result in less.

The point is that, if more economic output is desirable, then relatively inexpensive energy also is desirable. We assume herein that people and their governments desire high and growing output. In that context, abundant, inexpensive energy is of great value, and to the extent that fossil fuels are the principal source of such energy, they are not only desirable but surely will continue to be widely used.

Energy and economic growth

How does economic growth occur? We can add more labor or capital, which generally will result in more output. Or we can add more energy, which enables more work to be done and also generally results in more output. If we only add capital or labor, the rate of growth will be less than if we add energy as well. Energy particularly is a complement to capital in the sense that more energy makes capital more productive, meaning that we obtain more output from the capital we have the more abundant is the energy available to us.

Economic growth also results in a greater demand for energy, say to power industrial processes or goods and services purchased by consumers. This implies that cause and effect can go in either direction, from more energy to more growth or vice versa, from more growth to more use of energy. Hannesson for example tested the relationship between energy and GDP for 171 countries and finds that growth is associated with more energy consumption for all countries and for several different subsets of countries, including rich, medium rich, poor, market oriented, centrally planned, oil exporting and oil importing.[14] Thus, the relationship between economic growth and energy use appears to be robust with respect to the type of economy examined.

However, such association does not prove causality. Separating cause and effect statistically is difficult, but Stern reports that while the relationship is complicated the causality from energy to GDP has been established. The complications arise from changing energy input quality, substitution and complementarity with other inputs, and changes in technology and in industrial composition, but once these are isolated the causation emerges.[15] Further, we know from events in which energy suddenly became scarcer that output can be strongly adversely affected.[16] However, the suddenness of these events and the fact that they were largely unanticipated contributed to why many economies were so strongly affected.

Economic growth is related to the availability of inputs but it also can occur through technological change, which may involve the production of new goods and services or finding ways to produce existing goods more cheaply, thus freeing resources to produce other things. Usually energy is used in the process of researching and developing new technology and later to power a new discovery. In that sense it is a necessary input to such technological advance.[17] Can we imagine the Wright Brothers experimenting with and eventually proving the feasibility of powered air flight without access to energy, for example?

From a human perspective, greater quantities of energy, available at lower prices, enable more work to be done. If energy is extremely scarce and hence very expensive, there will be fewer energy using machines and humans will perform some of the work that energy-using machines otherwise could do. Ample energy, on the other hand, tends to encourage investment in machines, which in turn results in greater output for a given labor input.

This is a key point in understanding the value of fossil fuels. Their relative abundance is a great boon to people because they reduce the cost of energy, enabling economies to produce more and also to expand more rapidly. This is true whether an economy is advanced or developing, the less the cost of energy the better from an output and growth perspective. This is why it is necessary to seek balance with regard to the use of fossil fuels even as we seek to control their environmental impacts.

The growth of GDP over the past decade in China offers a striking example of how economic growth is fueled by, and results in, the use of greater quantities of energy. Between 2004 and 2014 the Chinese economy grew in real terms by 158 percent. Over the same period primary energy consumption in that country grew from 1573 million tons of oil equivalent to 2972 million tons, or by 89 percent. The amount of energy per unit of output declined, but there still was very substantial energy consumption growth.

A large part of this consumption growth took the form of coal, which the country also produces in large quantities. Between 2004 and 2014 coal consumption increased from 1125 million barrels of oil equivalent to 1962 million, meaning that in 2014 coal made up about two thirds of China's energy consumption.

The Chinese leadership has promised to further reduce the country's amount of energy used per unit of GDP and to invest in the expanded use of renewables. However, it also has indicated that the country will continue to increase its total energy use for at least another 15 years, presumably because it intends to continue to encourage economic growth. This total energy growth may involve different proportions of fossil fuels and renewables in future, but it almost certainly means that the consumption of fossil fuels will continue to grow in China for at least the next 15 years and probably longer.

Nor is China the only developing country that will use more energy in the future. The BP Statistical Review indicates that most developing countries have been steadily increasing their annual energy consumption, some of them at quite high rates (e.g., India, Indonesia, Vietnam, Turkey). Presumably these countries will seek further economic growth, and to do so they almost certainly will require more energy.

The point is that developing countries, as well as developed, want and expect economic growth, and are likely to increase their energy use as this growth occurs. They may encourage the use of renewables, but given their past behavior they also will take advantage of the many positive qualities that fossil fuels possess.

Fossil fuels and the environment

It is widely understood that the production and consumption of fossil fuels can have significant environmental impacts on air, water and land. For example, the burning of these fuels results in emissions of what are known in the U.S. as criteria pollutants, mainly sulfur oxides, nitrogen oxides, particulate matter and carbon monoxide. All of these are controlled in one fashion or another by EPA, usually through direct regulation but in a few cases through setting a limit on total emissions and allowing emitters to trade emission permits among one another as a way to reduce compliance costs.

The criteria pollutants are emitted into the air, but the extraction of fossil fuels also can impact water and land. For example, oil and gas exploration and production involve water use and disposal while coal mining can involve significant impacts upon land. In the U.S., various federal and state agencies regulate fossil fuel production activity to reduce impacts on human health and the natural environment and to restore natural resources where possible. Usually this control is exerted through minimum standards in the form of specific limits that must be met, and generally these standards have become tighter in the U.S. over time.

Almost all environmental regulation is controversial because different interests have different objectives and try to influence government regulatory agencies and the courts to bend in their direction. For example, environmental organizations tend to want very strict limits on environmental impacts and are less interested in cost, whereas fossil fuel producing or using firms want lower, less costly standards. However, with few exceptions, there is agreement that regulation of this sort is necessary to achieve appropriate social outcomes.

Are regulations with respect to fossil fuels sufficient to adequately control the impacts of their production and consumption on land, air and water? That is difficult to judge because the U.S. rarely tries to cost out such impacts and then force firms to internalize these costs through taxes or other economic instruments. Because of this, the costs of controls may vary greatly from the costs imposed by the pollution being controlled.[18]

Generally speaking, however, the U.S. environment has improved over time, the technology of pollution control has advanced, and firms often are forced to pay fines for accidental spills or other releases, inducing them to exert preventive care. It may be that in some instances regulatory controls still allow pollution-related costs that exceed the benefits tighter regulation would yield, but in others, particularly applications of the Clean Air Act where costs cannot legally be considered, the regulations are more likely to be excessively tight. In any case, in the U.S. at least, there has been no movement to phase out the use of fossil fuels because of their environmental impacts until recently, when climate change has become an issue. We next examine whether this phase-out approach makes sense.

Climate change and fossil fuels

The issue of climate change appears to have caused massive confusion even among those who are normally thoughtful about the benefits and costs of environmental improvement. The entire notion of phasing down or phasing out fossil fuels appears to be based on the idea that the planet cannot survive the use of these fuels, so that the sooner they disappear the better. But it is one thing to posit that the burning of fossil fuels may be causing adverse changes to the climate, quite another to argue that the solution involves phasing them down or out, no matter how valuable they may be.

A moment's thought should yield doubt about the entire notion. First, there is considerable uncertainty surrounding climate change and the extent to which human sources are contributing to it. Though some argue that the science of humans' contribution to climate change is "settled," by its nature science is never settled, and even the Intergovernmental Panel on Climate Change acknowledges significant uncertainties about climate processes. The empirical evidence to date is mixed, and the models constructed to predict future climate change have not been accurate. Further, many have pointed out that CO_2 has beneficial effects on plant life, acting as a fertilizer, so the relevant question is whether the gas is a net plus or minus as it affects people and the environment worldwide. Also, there is a time dimension to benefits and costs, with some arguing that in the near term the benefits of a warmer climate outweigh the costs while the opposite is more likely in the longer term.

For our purposes, however, there is an even more important point to be made. Let us assume for the sake of argument that climate change indeed poses a net threat. How big is this threat and what costs would it impose? Unless these are infinite or nearly so, it makes no sense to radically alter our way of life in drastic and unprecedented manner.

Social Cost of Carbon

Economists have tried to capture hypothesized threats from climate change via estimates of the cost of such threats should they materialize. This is usually termed the social cost of carbon (SCC), and many estimates of this cost have been made. These are further described in Appendix B to this report. Suffice it here to indicate that most of the estimates are fairly low, in the range of $12 per metric ton of carbon at a 3 percent social discount rate. However, the Administration has estimated this cost at $38 per metric ton, more than three times as much. While that number seems high in light of most other estimates, the point here is that even if the agreed cost were somewhere between $12 and $38 per metric ton, and that cost were internalized to consumers of fossil fuels via a tax or some other mechanism, it would not imply the phasing out of these fuels. In other words, there is a stark inconsistency between the estimated cost of climate change, even by those who think it poses a serious problem, and the notion of phasing fossil fuels out.

To see this, consider a tax set equal to $12 per metric ton of carbon, about the level the literature would support. Such a tax would raise the cost of gasoline by only about 12¢ per gallon (and diesel fuel by 13¢ per gallon), hardly enough to significantly affect demand. At a 3 percent rate of growth, such a tax on gasoline would reach 24¢ per gallon in about 24 years (26¢ per gallon on diesel), still much too low to imply any kind of phase-out of these fuels.

The same tax would amount to $.66 per thousand cubic feet (Mcf) of natural gas and $23 per ton of coal. If fully passed through, they would raise the price of gas-fired electricity by about 0.66¢ per kWh and that of coal-fired by about 1.2¢ per kWh. These price changes would induce more investment in other forms of power generation as well as the substitution of natural gas for coal, but they are not large enough to cause the wholesale abandonment of either fossil fuel. Further, even if the tax were increased by 3 percent per year, natural gas likely would be viable for many decades while coal would only slowly be phased down.

Of course, a higher tax would change relative energy prices by more. One set to equal the SCC that the Administration has proposed would add about 38¢ per gallon of gasoline, slightly more on diesel. If fully passed through, this would add about 14 percent to the present price per gallon of gasoline. Subsequently, if the tax rose by 3 percent per year, it would reach 76¢ per gallon by around 2039. But many people around the world purchase transportation fuels at far higher rates of tax than this. Thus, even a rate of tax at the Administration's estimated SCC does not imply the phasing out of gasoline or other petroleum products.

With respect to natural gas, a tax of the magnitude of the Administration's SCC estimate would be about $2.11 per Mcf. Natural gas at the residential retail level sells on average for about $10.40 per Mcf, implying an increase of about 20 percent. At the commercial building level the price is lower, about $8.00 per Mcf, so the percentage increase would be higher, about 26 percent. These are not sufficient to imply the wholesale abandonment of this fuel in either sector.

For coal, a tax at the Administration's estimate of the SCC would add approximately 3.8¢ per kWh to the cost of power generation. Such a rate would discourage coal use. But, because of its lower carbon content, such a tax would add less to the cost of generating electricity with natural gas, about 2.2¢ per kWh. In other words, the price of natural gas would fall relative to the price of coal. The net effect would be to induce the substitution of natural gas for coal as well as the increased use of non-carbon fuels to generate power.

These results assume that the pricing of carbon would result in no other effects than higher prices for fossil fuels. But such a price also would induce people to find ways to use carbon productively. Instead of a waste product, carbon or carbon dioxide might become a useful resource.[19] If so, the value of fossil fuels would rise, with captured CO_2 one of the benefits of burning them. A policy to phase out fossil fuels would prevent such a phenomenon from occurring.

Abundant, inexpensive energy is desirable

We've now described two social objectives, one to encourage economic output and growth and another to properly control the impacts of economic activity on the environment through measures that internalize the costs to those imposing such impacts. We've also pointed out that abundant, inexpensive energy helps increase output and produce economic growth whereas scarce, high cost energy discourages both of these. Are we faced with the dilemma that we cannot control fossil fuel environmental impacts without making energy frightfully expensive and hence discouraging output and growth?

The answer is no. Environmental controls make fossil fuel more expensive, but as we have seen, most of their impacts already are controlled and even if there were agreement that there is a SCC and it were included in fossil fuel prices, these fuels would remain solidly in the mix.

Indeed, they might compete better than many people now expect. Environmental advocates sometimes assert that private sector firms tend to overestimate the costs of environmental controls, finding ways to meet standards with technology not contemplated at the time they were set. Accordingly, should there be a tax on carbon, firms might find ways to curb emissions or capture and use them productively more cheaply than now expected. This implies higher proportions of fossil fuels in the world mix than many people now expect. If so, such a development should be welcomed because it would mean a greater supply of energy available to generate economic growth than otherwise.

This is a central point. The social objective should be to cost resources properly so as to make good use of them, not to make energy expensive or forego the use of certain forms. We should be trying to find ways to make the amount of energy available for productive use greater, not less. This objective includes the development of energy efficiency technology, since that frees energy from some uses to others and reduces its cost. As for fossil fuels, the idea is to properly cost whatever environmental effects they have and then encourage as much production of them as possible. Exactly what that implies in terms of future use is uncertain, but it does not imply a policy of phasing them out. The latter is simply wrongheaded thinking, with no regard to value and only to cost. It is time to clear our heads and look to what can be done to maximize the use of these fuels, subject to proper controls, not minimize it.

The optimum use of social resources

Our society's objective should be to utilize our resources wisely, without preconditions as to which should survive and which not. Fossil fuels in particular provide huge benefits to societies worldwide and should be cultivated, subject to appropriate environmental controls. Exactly what mix of fuels this implies in future years is far from clear. That depends on which are the lowest cost and which provide the greatest value, when all considerations are taken into account. These include direct effects, such as energy services provided, and indirect, such as the trade promoting capabilities of transportation fuels.

Because energy is so key to economic activity, it should be clear by now that what's to be desired is an expanded set of energy choices, not a diminished one. This does not imply disregarding the environment; the expanded use of energy should take environmental impacts into account. Non fossil sources of energy have certain advantages but most have environmental impacts of their own and tend to be high in cost. To the extent these sources can competitively contribute to the abundance of energy in the economy they will enhance human welfare. Any source of energy that contributes to worldwide abundance in cost competitive manner will do that. But forms of energy that cost more to harness and use than the value of product they contribute will have the opposite effect. The challenge for non-conventional forms of energy is to reach cost competitiveness with fossil fuels so that, along with whatever reduced environmental impacts they bring, they enhance economic output and growth rather than diminish it. All fuels should be judged by these standards, including fossil fuels. So far, they have met the test.

Appendix A – Contributions of Individual Fuels

Oil

It is difficult to overstate the contributions that products fashioned from crude oil make to life around the globe. Everyone is familiar with transportation fuels, which include gasoline and diesel used in cars, trucks and trains, aviation fuels, and bunker fuels used in ships. These fuels dominate the transport market, by which is meant that there are few substitutes at present.

In the U.S., daily consumption of gasoline runs about 375 million gallons. If on average a gallon of gasoline propels a car 25 miles, then this 375 million gallons results in about 9.375 billion miles of travel per day, just in this country. Worldwide gasoline consumption is at least 2 ½ times U.S. consumption, so we are speaking of at least 25 billion miles traveled every day worldwide. This mobility enables people to take jobs they otherwise would find hard to access and to move about more within those jobs as needed. It also enables them to access more goods and services, visit family and friends more, etc. The result is that people are more productive than they otherwise would be, and are able to experience a higher quality of life. It is hard to overstate how important mobility is to people around the globe.

Gasoline however is only one transportation fuel. In the U.S., trucks consume about 60 million gallons of diesel fuel per day plus a portion of the gasoline supply. For the most part, these trucks are transporting goods from one place to another, often from where they are made to where they will be consumed. As heavy trucks average about six or seven miles per gallon, the diesel-burning portion of the U.S. fleet travels about 400 million miles each day, mostly carrying loads such as food, machinery, household goods and other consumables. The wide distribution of products encourages economies of scale in manufacturing and a greater variety of consumer items everywhere.

Jet and bunker fuels are used to provide massive transport services in the U.S. and elsewhere. In the U.S., the consumption of jet fuel is about 1.5 million barrels per day and worldwide consumption between three and four times that total. Different planes get different fuel mileage but with an average load of passengers a Boeing 747 (not a very fuel efficient plane) will transport a single passenger about 100 miles per gallon.[20] Using that as an example, 1.5 million barrels per day would imply 6 billion passenger miles per day just in the U.S., and some three to four times that worldwide. A world in which oil were phased out might find alternative ways to transport people long distances, but it is hard at present to see how air travel would be as extensive as it is today.

Oil and natural gas provide the chemical building blocks for fertilizers and for pesticides and herbicides, all very important contributors to the agricultural productivity of land. Also, petroleum fuels are used to run tractors and other farm equipment, replacing horses and mules and freeing land previously used to feed them. Thus, oil is a key input to agricultural productivity, enabling people to consume higher quantities of food than otherwise would be possible.

There are many other uses for oil as well. In some areas of the world oil is used to generate electricity, though very little is used for that purpose in the U.S. Gasoline and diesel are used in a variety of machines such as generators, which provide backup power or power in remote locations, and in garden implements such as chainsaws and leaf blowers. Diesel and in some cases kerosene are used to heat homes. Crude oil also is transformed into asphalt used to build roads, and into petrochemicals which in turn are transformed into many common products such as plastics and synthetic cloths. The truth is that oil products are ubiquitous in modern life and it isn't easy to perceive at this point how they could be phased out without a considerable drop in people's standard of living.

It's also true, however, that exploration for oil and its development, transport and consumption have environmental impacts. Accidents involving the spillage of oil have adversely impacted oceans, beaches and other natural landscape, and unsafe disposal of drilling fluids and waters pumped to the surface during production have adversely impacted land and water. The burning of oil products results in air emissions, including toxic substances, and therefore is regulated by governments in most countries. As we shall see, however, *all* forms of energy have some adverse environmental impacts, and the challenge is to control these while still enjoying the benefits they provide.

Natural gas

Natural gas is used worldwide to generate power, for industrial purposes, for home heating and cooking, and in some places for transportation. There has been steady growth in the worldwide use of this fuel over the past 25 years and longer, and that growth has been occurring almost everywhere. In the past 10 years, for example, worldwide consumption has risen from 2,700 billion cubic meters to about 3,400 billion meters, or by 26 percent. Consumption growth in the U.S. over that period was about 20 percent, in Latin America about 43 percent, in the Middle East 80 percent, in Africa 48 percent and in Asia and the Pacific 80 percent. Only in Europe did the consumption of natural gas drop during the period, by about 6 percent, as the production of North Sea gas declined and political difficulties with Russian gas intervened.

In the U.S., gas heats approximately 50 percent of all homes. Yet only about 20 percent of domestic supply is used for that purpose, with another 14 percent used to heat, cool or heat water in commercial enterprises. A small amount is used to propel vehicles, of which there are about 142,000 in the U.S. currently running on this fuel.

The biggest uses, however, are for power generation and industrial application. Natural gas fired power generation now comprises about 27 percent of total U.S. power generation, and that proportion is projected to grow over time.[21] Gas is considered desirable for power generation because investment can be made in plants of varying sizes, because waste heat from gas burning often can be captured and used productively, and because relative to other fossil fuels used for power generation it is environmentally benign.

Natural gas is an important industrial fuel, where it is used either as an input or as a source of heat to make such things as steel, glass, clothing, cement, fertilizer and petrochemicals. In particular, the use of gas to make fertilizers has vastly increased the amount of produce that can be obtained from a given amount of land, freeing labor from farming and enabling a higher per capita level of food intake.

The recent surge of gas production in the U.S. has been something of a boon to these industries, enabling them to compete more favorably internationally and encouraging additional investment and employment. Also, gas in the ground often includes liquids such as propane, ethane and butane, which are stripped out and used in the manufacture of various chemical and petrochemical products.

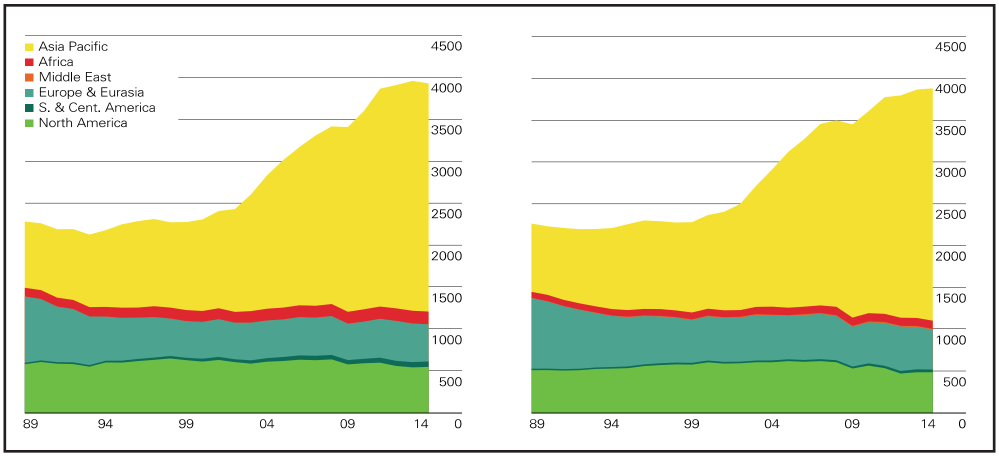
Gas is a relatively clean fuel as it contains little sulfur or other potentially toxic substances and its carbon content is only a little more than half that of coal. However, the burning of gas produces nitrogen oxides, and methane itself is a greenhouse gas. Leaks of gas into the atmosphere therefore are said to contribute to climate change, as does the flaring of gas which sometimes occurs in conjunction with the production of crude oil.

Coal

Coal is mostly used to generate power, though in some countries it is burned by individuals as a heating fuel. It also is used as a source of heat in some industrial processes and can be used to produce fertilizers and other chemical products. Particularly in developing countries, coal has proven a relatively inexpensive means of gen-erating electricity to both power industrial development and satisfy rising consumer demand.

According to BP's Statistical Review of World Energy, world coal consumption has risen over the past 10 years from about 2.9 billion tonnes of oil equivalent to 3.9 billion, an increase of about one third. This growth has not been uniform geographically, however. Figure 3 below shows the growth of production and consumption of coal by area of the world.

Figure 4. Production and consumption of coal by world region, 1989-2014 (million tonnes oil equivalent)



Almost all of the growth has been centered in the Asia Pacific region, the section of the globe exhibiting the fastest economic growth. Within this region, China, India, Indonesia and South Korea in particular have increased their consumption substantially, with China now consuming about half the world's production. The first three of these and Australia also were able to increase their coal production dramatically over the period.

Elsewhere growth was minimal or negative. An important reason is that the mining and burning of coal has important health and environmental effects, which economically advanced countries have sought to control more tightly over time. Still, on a worldwide basis in 2014, coal comprised about 30 percent of total energy consumption, second only to oil.

The environmental impacts of coal include land disruption from strip mining and health and environmental impacts from its burning. The latter in particular have led to regulatory controls in advanced countries, and increasingly are doing so in the developing world as well. Such controls include scrubbers, electrostatic precipitators and selective catalytic reduction systems on coal burning power plants to curb sulfur and nitrogen oxides and several other pollutants. Efforts have been made to control CO_2 emissions from coal plants, but so far these efforts are in the experimental stage only.

Other fuels used for transport or to generate power

Oil so dominates the transport market that we need pay little attention here to substitutes such as ethanol or other biofuels, and to electricity. Though biofuels play an important role in a handful of countries (e.g., Brazil), generally they compete only through mandates or subsidies and for now are inconsequential in terms of worldwide market proportion. In addition, the production of biofuels involves land use, which comes at the expense of food products and also can involve the clearing of otherwise natural areas. The former tends to put upwards pressure on world food prices while the latter has environmental impacts of its own.

Battery powered cars are an option, but so far have advanced more slowly than hoped.[22] One problem is the limited energy density of batteries, which translates to limited range; battery powered cars as yet are impractical for longer trips. Another is cost; despite large federal subsidies, battery powered cars are unaffordable for most people. Until the range and cost issues are more fully resolved, the widespread deployment of these types of cars remains a future hope.

Though there are few viable substitutes for fossil fuels at present in the transport market, the same is not true of the power generation market. There nuclear, hydro, and to a rising extent renewables such as solar and wind are contributors.

Nuclear and hydro, like fossil fuels, provide baseload power. In the U.S., nuclear provides about 20 percent of the country's total electric power, hydro about seven percent.

Nuclear and hydroelectric power are frequently cited for the fact that they emit no CO_2, though the construction of either type of plant will yield such emissions on a one-time basis. Hydro generally is a clean source of power; the problem is that there are limited sites where new dams can be built. Also, the construction and operation of new dams can result in threats to species habitat that in the U.S. render such construction difficult if not impossible. Therefore, the proportion of power provided by hydropower in the U.S. is unlikely to much increase over time.

Nuclear power poses environmental problems of its own, namely the disposition of nuclear waste. Such disposition also raises safety issues, namely the possibility that terrorists or others might obtain a sufficient supply from utility-generated waste to make a nuclear weapon. Further, the capital requirements for a modern nuclear plant are so great that few companies are willing to build them. In the U.S., substantial federal subsidies are offered to induce the construction of new plants, but even with these subsidies few companies have been willing to do so. The future of nuclear power therefore remains in considerable doubt, and until the economics and waste disposal issues are better resolved it seems unlikely that this energy source will provide a significantly larger share of U.S. power than it now does.

This leaves solar and wind, two sources of power that have been growing rapidly over the past few years. These sources have a number of environmental advantages and their economics have been improving with time. Once production facilities for these sources are put in place, they emit no criteria pollutants nor CO_2 or methane, and thus are seen as a chief means to mitigate anthropomorphic climate change. Further, a great deal of work is underway to improve the efficiency with which they supply power and also to cost effectively store the power they produce during peak hours for hours when they produce little or none.

However, in the U.S. as in most countries, these energy sources require government subsidies to be widely applied, and because of their intermittency the quality of power they produce is below that of baseload sources. A despatcher must adjust other generating plants to accommodate such intermittency, increasing or decreasing the draw from these plants as power from solar or wind sources varies over time, and by so doing imposing costs on these other plants. The intermittency of output from solar and wind effectively puts limits on how much of these resources can be utilized within an overall grid system, rising amounts putting greater pressure on existing plants, with consequent higher costs and a need for increased per unit subsidies.

Another problem with both centralized (concentrated) solar and wind is that, because of their low energy density, they require large amounts of land to produce commercially useful amounts of power. In that respect, they are inferior to fossil fuels. Also, solar farms and windmills often are located far from their markets and hence can require considerable transmission capacity to be built to reach consumers. Where this transmission capacity is paid for by all of a utility's consumers, which is usually the case, there is effectively a subsidy to the solar or wind facilities.

In addition, windmills pose threats to raptors and to bats, killing a few hundred thousand of the former and several hundred thousand of the latter per year in the U.S.[23] Also, they are considered unsightly by many because of their size and the fact that they often are located in otherwise naturally attractive areas.

Distributed solar via photovoltaic cells offers something different from centralized solar, namely the opportunity for individual homes and businesses to supplement the power they draw from the grid with power that is self-produced. In several countries such power has expanded rapidly, but to date it has had to be heavily subsidized because the capital costs exceed the expected returns in most applications. Though these capital costs have been dropping and the efficiency of the cells increasing, the intermittency of their power production implies for the present that baseload power remains a necessary component of their practical use.[24] Indeed, a rising challenge is how to pay for that baseload power even as the production of intermittent power increases.

Appendix B – The Social Cost of Carbon

Estimates of the social cost of carbon

How big are the estimated costs of climate change? A large literature has developed to estimate what is known as the social cost of carbon. Because all greenhouse gases can be expressed in terms of their CO_2 equivalent, this amounts to the estimated cost of anthropomorphic climate change. Since carbon emissions are at the heart of the case against fossil fuels, we can focus on the SCC as the climate-related cost from burning these fuels. How big are estimates of these costs?

As noted in the text, some would argue that these costs are non-existent, or even that they are negative; i.e., that the emitting of carbon dioxide generates more value than cost. However, a survey of SCC estimates published in 2007 indicated that the average was about \$12/tonne of CO_2.[25] Others have surveyed the literature and concluded that the median estimate is lower, no more than about \$7 per tonne of CO_2 at a 3% social discount rate (about \$26/tonne of carbon).[26] Other estimates are somewhat higher. One of the more prominent economists writing on climate change, Richard Nordhaus, estimates a SCC of \$12/tonne of CO_2 in \$2005, which adjusted for inflation would be about \$15/tonne today.[27] All of these suggest a fairly modest social cost.

On the other hand, some believe the SCC is much higher, possibly even several hundred dollars per tonne. Most estimates in this range posit relatively high probabilities of catastrophic outcomes or else assume a very low social discount rate, even a zero rate. While catastrophic outcomes are theoretically possible, there is little historical empirical evidence to support them. As to very low discount rates, these are said to take account of the interests of future generations. But putting capital to use generates growing wealth, which is available to these future generations, enabling them to better adapt to if not mitigate climate change. Once the productivity of capital is considered, it is difficult to rationalize very low discount rates.

Even the U.S. government has weighed in. The present Administration has publicly estimated the social cost of carbon at \$38/tonne of CO_2 as of 2015, and is using the estimate in regulatory proceedings such as the Power Plant Rule. This estimate is considerably higher than median estimates in the literature and calculates cost impacts worldwide, not just in the United States, though it is being used as a benchmark for domestic policy actions. A number like \$38/tonne of CO_2 does not imply the phasing out of fossil fuels, however.

Why a social cost of carbon does not imply a phase-out of fossil fuels

In the text we argued that the price increases from internalizing estimates of the SCC into fossil fuel prices are too low to result in the phase-out of these fuels. In Table B-1 below we show the immediate impact and that after 24 years if the SCC rises by 3 percent per year.

With some exception, these price effects do not imply phasing out the consumption of petroleum, natural gas or coal. Of the three fuels, oil products would hardly be threatened, natural gas use might decrease somewhat, and coal would be phased down. However, the phasing down of coal might well be accompanied by the substitution of natural gas to produce power. So gas consumption overall could increase rather than decrease. According to Resources for the Future, at a relatively low carbon tax gas use probably would be encouraged on net, while at a high level of tax gas use might fall as non-carbon fuels were substituted.[28] However, RFF also points out that a high tax would stimulate efforts to capture and store if not productively utilize CO_2 from

Table B-1. Effects on gasoline and fossil fuel electricity prices of a fully passed-through carbon tax						
	Gasoline		Natural Gas		Coal	
Rate of tax	Initial	After 24 years at 3%/yr	Initial	After 24 years at 3%/yr	Initial	After 24 years at 3%/yr
$12/tonne	12¢/gal	24¢/gal	.66¢/kWh	1.34¢/kWh	1.2¢/kWh	2.4¢/kWh
$38/tonne	38¢/gal	76¢/gal	2.2¢/kWh	4.3¢/kWh	3.8¢/kWh	7.6¢/kWh

the burning of both coal and natural gas, and that success in these ventures could restore their economic viability.

Even if a carbon tax were applied worldwide to reflect a SCC, would the consumption of coal or any other energy resource fall absolutely? Perhaps, but what if worldwide economic growth resulted in steadily increasing demands for energy? It seems very unlikely that people around the globe will accept a state of affairs in which their incomes are stagnant or falling; rather, the opposite is more likely. To accommodate this growth, more energy is going to be demanded. And even if gas and coal became more expensive, where they were still *relatively* cheap, they would be chosen. In the end, the proportion of coal and natural gas would fall in a worldwide regime in which the SCC was fully internalized, but it is unclear that their use would fall absolutely unless other energy sources became competitive in very large quantities or the pricing of fossil fuels made energy so expensive overall that economic growth was discouraged.

Endnotes

1. In the U.S., for example, carbon dioxide accounted for 82 percent of all greenhouse gases (GHGs) in 2013.
2. The notion of phasing out fossil fuels is reminiscent of Richard Nixon's "Project Independence," which was aimed at phasing out U.S. oil imports. Once the benefits v. costs of that approach were widely understood, the project was quietly shelved.
3. This has been the approach taken in the U.S. towards sulfur dioxide via a cap and trade program affecting the nation's power plants.
4. "Obama's Climate Change Envoy: Fossil Fuels Will Have to Stay in the Ground," The Guardian, November 24, 2014.
5. "A Target for U.S. Emissions Reductions," Accessible at *http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/emissions-target-fact-sheet.pdf*

6. See “Roadmap 2050: A practical guide to a prosperous, low-carbon Europe.” The document cites the European Council as having set the 80-95% goal in 2009.
7. For example, there is considerable controversy at present whether EPA should set the national 8-hour standard for ground level ozone at .07 ppm or .065 ppm or even lower. The present standard is .075, which some have argued is already sufficient to protect human health and the natural environment.
8. This topic is explored further below. CO_2 provides sustenance to plant life, which is a benefit. To the extent it contributes to global warming, it has positive benefits in some geographic areas, negative in others. And the science of such warming is subject to continuing inquiry, with more learned as hypotheses concerning climatic effects of greenhouse gases are formed and data collected to test them.
9. “Consumption by Fuel,” BP Statistical Review of World Energy 2015, p. 41.
10. A tonne is a metric ton, or 2200 lbs.
11. Proved reserves are an inventory in the sense that they represent known amounts of a resource that are technically and economically recoverable. Generally, the incentive to add to reserves is related to how big this inventory is; an inventory of 110 years of current coal production would provide little such incentive at present.
12. Land is often identified as a separate input, but for simplicity it is treated as a form of capital here.
13. See David I. Stern, “The Role of Energy in Economic Growth,” CCEP Working Paper 3.10, October 2010. Stern’s work indicates that scarce energy imposes strong constraints on economic growth.
14. Rognvaldur Hannesson, “Energy and GDP Growth,” *International Journal of Energy Sector Management*, Vol.3, No. 2, pp. 157-170.
15. See David I. Stern, “Economic Growth and Energy,” *Encyclopedia of Energy*, Volume 2, Elsevier, 2004.
16. For example, the oil shocks of 1973-74 and 1978-79 had clearly negative effects on the U.S. and other economies.
17. Sometimes technological progress involves the use of less energy to produce a given quantity of goods (greater energy efficiency), which then frees energy to do other things. Even in such cases, however, energy often is used to experiment with new energy efficiency devices and to perfect them, in which case it remains a key input to the R&D process.
18. In *Whitman v. American Trucking Association* (531 U.S. 457 – 2001) the Supreme Court ruled that the setting of national air quality standards should not take costs into account. However, EPA is empowered to take costs into account in how such standards are implemented. Nevertheless, the setting of standards without regards to costs suggests these standards sometimes will be tighter than justified by a comparison of social costs with benefits.

19. See for example Wei Xiong et al, “The Plasticity of Cyanobacterial Metabolism Supports Direct CO_2 Conversion to Ethelene,” Nature Plants: Letters, Article No. 15053, April 27, 2015. Accessible at: *https://www.nrel.gov/energysciences/sites/default/files/embedded/files/Nature-Plants-Article.pdf*
20. A Boeing 747 can carry up to 568 people. For purposes of the example, a load of 500 people is assumed.
21. In its short term Energy Outlook, the Energy Information Administration (EIA) projects that the proportion will rise to 31 percent by 2040. If the Administration’s new Power Plant Rule goes into effect, the increase probably will be greater.
22. In 2011, for example, President Obama set a goal of 1 million electric cars on American roads by 2015. However, by that year only about 280,000 had been sold.
23. Rose Eveleth, “How Many Birds do Wind Turbines Really Kill?” Smithsonian.com, December 16, 2013.
24. Storage capacity and cost may improve with time such that it will be possible for buildings to become self-sufficient in power supply, but the costs of this approach today are prohibitive.
25. Attributed to G.W. Yohe et al on Wikipedia. Accessible at *https://en.wikipedia.org/wiki/Carbon_tax.*
26. Richard S. J. Tol, “Targets for Global Climate Policy,” University of Sussex, Economics Department Working Paper Series No. 37-2012. Tol points out, though, that there is vast uncertainty about the SCC, and that the number depends crucially on the discount rate used since so much of the expected cost occurs far in the future.
27. Nordhaus, Richard. “Estimates of the Social Cost of Carbon: Background and Results from the RICE-2011 Model,” Cowles Foundation Discussion Paper Number 1826, Yale University, October 2011.
28. See “Considering a Carbon Tax: Frequently Asked Questions,” available at *http://www.rff.org/centers/energy_and_climate_economics/Pages/Carbon_Tax_FAQs.aspx*

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