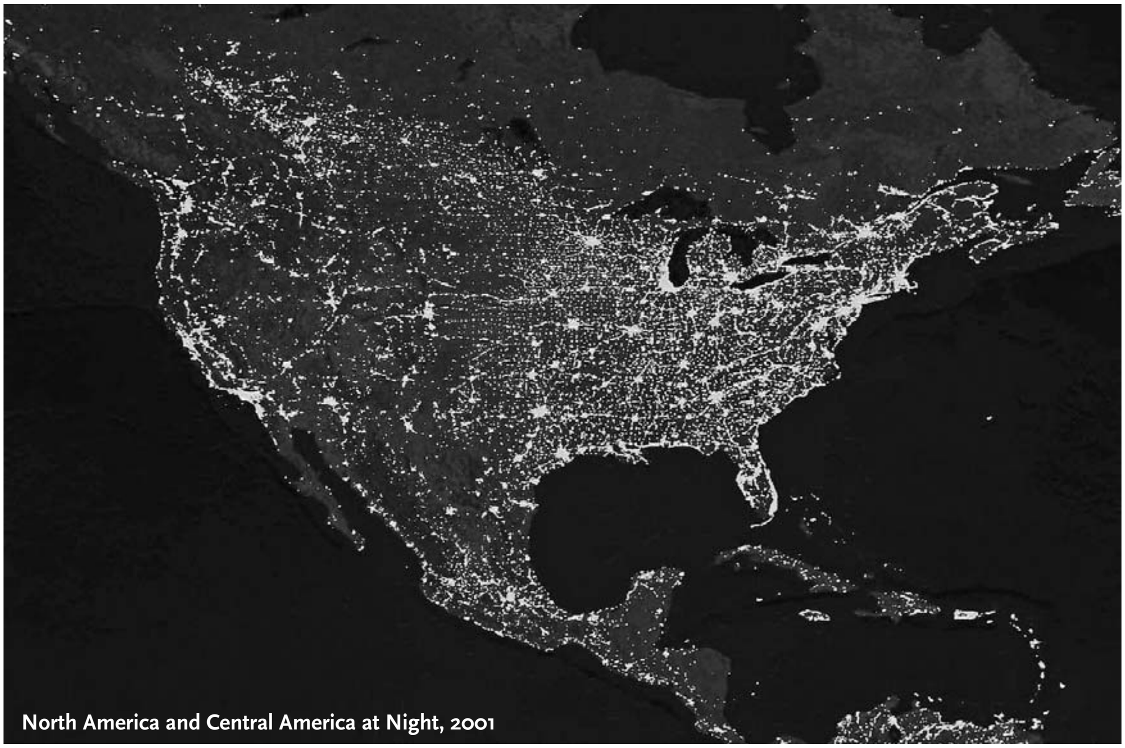
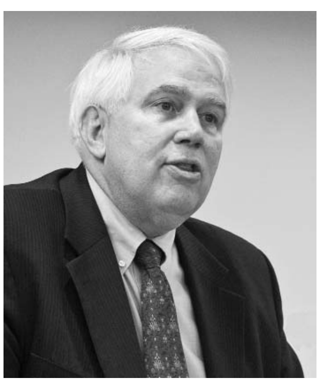

North America and Central America at Night, 2001

On the Future of Energy

Steven E. Koonin, John W. Rowe, Paul L. Joskow, and John Doerr
Richard A. Meserve, Moderator

This panel discussion was given at the 1947th Stated Meeting, held at Harvard University on October 11, 2009.



Richard A. Meserve

Richard A. Meserve is President of the Carnegie Institution for Science. He was elected to the American Academy of Arts and Sciences in 1994 and serves as a member of the Academy's Council and Trust. He also serves on the advisory committee of the Academy's Global Nuclear Future Initiative. He was recently appointed to the U.S. Department of Energy's Blue Ribbon Commission on America's Nuclear Future.

The study of issues relating to energy has been an important and long-standing part of the American Academy's work. Fifty years ago the Academy's journal *Dædalus* published an issue that is widely credited with establishing an intellectual framework for the then fledgling field of nuclear studies. In fact, President Kennedy referred to that issue as the bible on arms control. Today the Academy continues that tradition with a multipronged initiative on The Global Nuclear Future. This project is generating an integrated set of policy recommendations for balancing the growing global demand for civilian nuclear power with the need to strengthen the regime for safety, security, and nonproliferation. This week the Academy published volume one of a two-volume special issue of *Dædalus* on the global nuclear future. We hope that it will be as influential and groundbreaking as its predecessor.

Today's panel will discuss the even broader topic of the global energy future. As President Obama has stated, the choices we need to make to deal with our energy needs will play a significant role in determining future prosperity and the overall quality of life around the globe. But we face many difficult challenges in connection with energy. Energy is the foundation for economic and so-

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cial well-being, and we must somehow satisfy the growing demand for energy around the world in the years ahead. The problem arises from the fact that much of the demand for energy is and will be satisfied by fossil fuels. For example, 85 percent of the energy produced in the United States is derived from fossil fuels. The harsh reality is that the use of fossil fuels, at least in the manner we use them today, is not sustainable. The growing concentration of the resulting greenhouse gases threatens the planet. We face the need to transition to an entirely new energy infrastructure.

Energy policy is connected not only to environmental concerns but to a cluster of difficult security challenges.

Energy issues are also tightly connected to national and economic security. This is most obvious in the case of petroleum. We have near total reliance on petroleum to meet transportation needs around the world, but much of the world's supply comes from politically unstable areas through vulnerable supply chains. Energy policy is thus connected not only to environmental concerns but to a cluster of difficult security challenges. The problem is made even more complicated by the fact that our energy infrastructure is large and permeates every aspect of our lives. To transform that system will be a difficult and hugely expensive undertaking. Significant change will take time, require vast amounts of money, and demand sustained effort in a period in which we must confront many other challenges. And the change must occur across the entire globe if we are to make headway on the climate problem.

In short, our energy problem is both hugely important and nearly impossibly difficult. In today's panel we will hear from four distinguished Fellows of the Academy, each with special expertise and a unique vantage point to help us understand our energy future. I hope they will help us define a path to resolve the complicated set of issues that surrounds energy.

The first speaker is Steven Koonin, Under Secretary for Science in the U.S. Department of Energy (DOE). Steve is a theoretical physicist. He was the provost at Caltech and more recently was the chief scientist for BP. At DOE Steve oversees the single largest source of support for basic research in the physical sciences in the United States. He has been a member of the Academy since 1991.

Our second speaker is John Rowe, Chairman and Chief Executive Officer of the Chicago-based Exelon Corporation. Exelon is the nation's largest electric utility and the largest operator of nuclear power plants in the United States. John serves on the advisory committee of the Academy's project on The Global Nuclear Future and was inducted into the Academy yesterday.

Paul Joskow, President of the Alfred P. Sloan Foundation, will speak next. Paul has been a Fellow of the Academy since 1991. He is on leave from his position as the Elizabeth and James Killian Professor of Economics and Management at MIT, where he has served on the faculty since 1972, including eight years as the director of the MIT Center for Energy and Environmental Policy Research. Today he leads one of the nation's preeminent foundations supporting science policy, education, and workplace issues.

Our final panelist is John Doerr. John is a Partner in the Silicon Valley venture capital firm Kleiner Perkins Caufield & Byers. John has provided support for the creation and growth of numerous companies, first in information technology and more recently in green technology. He is an expert on carbon trading and has brought that expertise to his role as a member of the President's Economic Recovery Advisory Board. John was inducted into the Academy yesterday.

Steven E. Koonin

Steven E. Koonin is Under Secretary for Science in the U.S. Department of Energy. He was elected a Fellow of the American Academy of Arts and Sciences in 1991.

The United States is faced with two energy problems, largely separable. The first is associated with energy security, with providing a stable and economic flow of liquid hydrocarbons to power transport. Urgency in addressing this problem is driven by economics. We are sending roughly $700 million a day offshore for oil imports. In response to this challenge the administration has set a goal of reducing oil imports or reducing oil consumption by 3.5 million barrels a day, which is roughly the amount that we import from the Middle East and Venezuela each day and is about 25 percent of what we use to run our automobiles every day.

The United States is faced with two energy problems. The first is associated with energy security. The second is greenhouse gas emissions.

The second challenge we face is greenhouse gas emissions. We need to reduce the threat to the climate system by reducing our emissions. This is mostly about stationary sources generating electrical power and providing heat. The urgency here is driven by the cumulative nature of the CO_2 concentration in the atmosphere. It is also driven by the need to take geopolitical leadership in addressing this problem, by the great buildout of infrastructure that will happen in the next several decades in the developing world, and also by the need to rebuild the U.S. energy infrastructure, which we need to do at the same time as creating jobs. This implies a major and reasonably rapid transformation of the ways in which we produce, transmit, store, and use energy in this country.

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So what do we do about this? I like to joke that governments can pretty much do anything they want as long as they don't violate the laws of physics and as long as they have the political and economic capital to pay for the changes. The question is really one of identifying the optimal path. We get to do this only once, and so we should do it right. Anyone who studies the situation realizes that we need to filter technologies according to their economics, their readiness, and their ability to impact at scale. When we apply these considerations to transport, we realize that the first step we need to take is to increase the efficiency standards of automobiles. CAFE (corporate average fuel economy) standards are set to increase from 27 miles per gallon to 35 miles per gallon, and we need to do much better than that. Fortunately, significant technical headroom remains for improving the internal combustion engine before we have to start thinking about alternative ways of powering automobiles, and we need to capitalize on that.

The effort to improve CAFE standards needs to be supplemented by a gradual electrification of the transport system, a move from ordinary automobiles to hybrids to plug-in hybrids and eventually to battery electric vehicles. The pace of that transformation and the end point will be driven by how well we do in battery technologies. Given the systems nature of energy, if we are to get to full electrification of transport we will need to worry about where that extra electricity will come from. That is a nontrivial problem. Finally, we need to be rapidly pursuing advanced biofuels. The intersection between biology and energy holds great possibility, and we need to capitalize on that both in research and deployment.

To address the second problem, greenhouse gases, we need to start with efficiency in the end use. Appliance standards are important. So is building efficiency. Roughly half of the world's energy gets used in buildings. We have the technologies now to make buildings much more efficient. We simply need to stimulate their deployment. Also important is to set a price on greenhouse gas emissions, particularly carbon dioxide. That price needs to be predictable, it needs to be long-term, it needs to be material, it needs to be high enough to induce change, and it needs to be universal. When we set a significant carbon price in this country, we will see a shift from coal-fired power to gas, of which the United States now has significant resources, recently expanded as a result of technologies developed in the private sector to tap into shale gas and tight gas. We will also see a deployment of wind. Perhaps by 2030 roughly 20 percent of electricity generation will be from wind. To get beyond that, however, we will need to deal with issues of intermittency and transmission.

Fission has to be a significant part of the country's energy future if we are going to address greenhouse gases with reasonable economics and at scale. Finally, we need to develop, demonstrate, and deploy carbon capture and storage. Fifty percent of the country's electricity now comes from coal. We can't instantly rebuild all of those plants, so we need to figure out a way to capture the carbon from existing plants, and newly built plants need to have carbon capture and storage built in. Lest you think that the country has abandoned coal, you should know that about 15 gigawatts of coal capacity are in the permitting or construction process, and many more plants have been announced. We also need to improve the electrical grid in order to integrate intermittent renewables, efficiently match supply and demand, and ensure robustness of the grid against catastrophic failure.

Those of us who aspire to transform the energy system are both informed and somewhat sobered by the history of the U.S. energy supply (see Figure 1). At the time of the Civil War most of the country's energy came from wood. As the Industrial Revolution set in, coal became important. The mobility revolution of the early- to mid-twentieth century made oil important. Gas occupies an increasingly important wedge of the country's energy profile in the middle of the century, and nuclear forms a smaller wedge in the last three or four decades, followed by a tiny wedge for renewables beyond hydropower (namely, wind and solar). The good news is that energy technologies do change. They change in response to technology, economics, and politics.

We have the technologies now to make buildings much more efficient. We simply need to stimulate their deployment.

The bad news is that they change slowly, on a decade scale at least. Compared with the evolution of energy technology, IT technologies change far more rapidly. Consider that in less than one decade personal music and video technology went from CDs and tapes to predominantly MP3s and flash memory (see Figure 2).

So energy is different from other spheres in which we have seen great technical evolution. Clearly, we cannot continue with business as usual and make the kinds of transformations we expect in the energy system. We need to find the right path to accelerate development and deployment. We need to put all the players together – including academia, the national labs, and the private sector – much more intimately than we have before. Doing so poses many challenges, however. For example, the universities shy away from significant commercial involvement. Ownership of intellectual property is often a source of tension. Businesses must seek differential advantage if they are to be successful, but government cannot grant such advantages. The scale of capital required for meaningful energy demonstra-

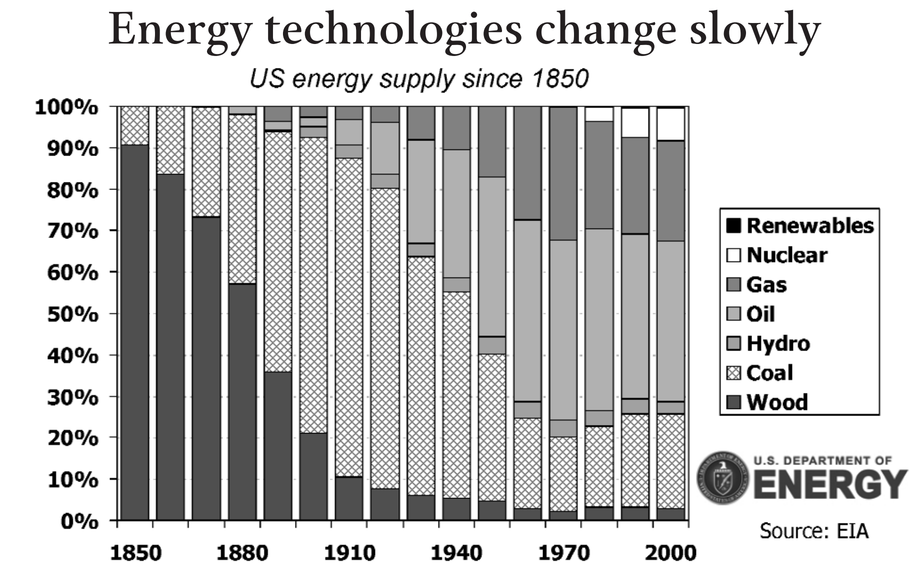

Figure 1

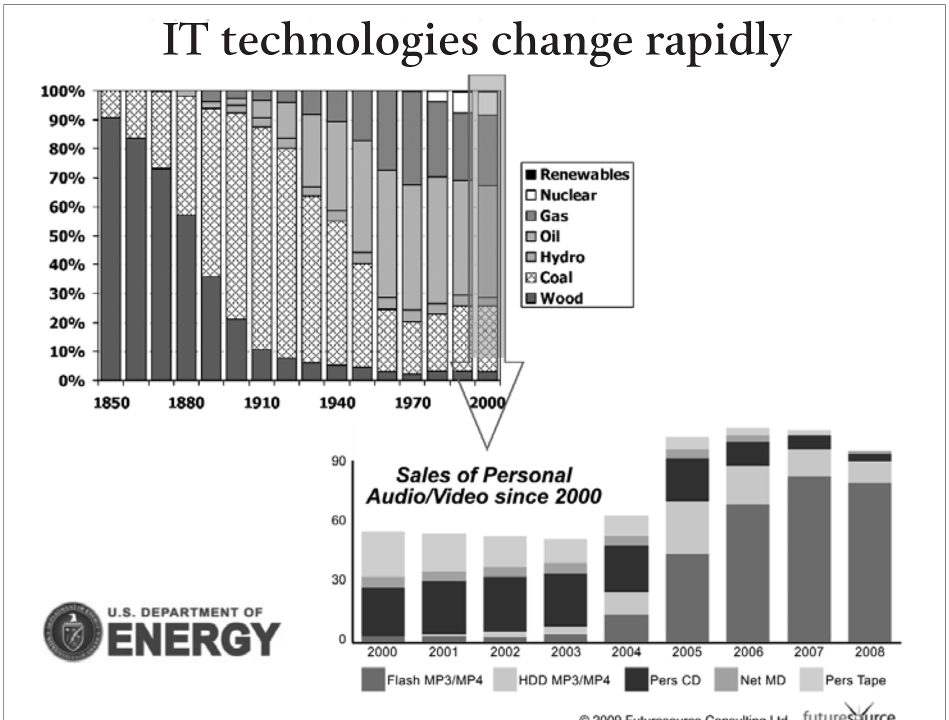

Figure 2

tion projects makes it difficult for any one player to move along the learning curve.

All of the players we need to get together have conceptions of their roles that are hard to change but indeed have to change if energy innovation is to proceed at the pace we need it to. We in the Department of Energy are pursuing a variety of programs to stimulate energy innovation. Among these are the Energy Frontier Research Centers that are focused on basic science and technology; the Advanced Research Projects Agency-Energy (ARPA-E), which will nimbly fund high risk, high payoff concepts; and the energy innovation Hubs that would bring together diverse players across multiyear, directed research programs from basic research to demonstration. Significant amounts of stimulus and base program funding are going into innovation in diverse areas, including vehicle technologies, manufacturing, carbon capture and storage, renewables, and modernization of the electric grid. We are making tangible progress in energy innovation.

Technical innovation alone is not going to lead to the jobs that are the other dimension we need to be addressing. Many energy technologies developed in the United States in past decades, including photovoltaics, automobile efficiency, batteries, electricity transmission, power electronics, and nuclear, are now dominated by other countries. To capture all of the jobs that will stem from energy innovation, we have to reverse the U.S. decline in manufacturing and again make this country a favored venue for production. Since 2000, about six million jobs have been lost in the manufacturing sector, a 30 percent decrease. If we are going to reverse that trend, many nontechnical issues need to be addressed, such as labor costs, health care costs, and regulatory and tax regimes. If we do not address those issues, the United States will not realize the full benefits of whatever technical innovation we can achieve in the next many years.

Fission has to be a significant part of the country's energy future if we are going to address greenhouse gases with reasonable economics and at scale.

John W. Rowe

John W. Rowe is Chairman and Chief Executive Officer of Exelon Corporation. He was elected a Fellow of the American Academy of Arts and Sciences in 2009 and serves on the advisory committee of the Academy's Global Nuclear Future Initiative. He was recently appointed to the U.S. Department of Energy's Blue Ribbon Commission on America's Nuclear Future.

What do we really know about energy in the future, and what do we not know? I suppose the most important single thing we know is that the amount of energy around will be about the same as it has always been. The laws of conservation of energy and the doxology we used to sing in the Methodist church where I grew up are about the same. We know that certain policy parameters are pretty well determined. It is important that we become less dependent for our energy needs in the United States on certain portions of the world, and in parallel it is important that our remaining dependence be organized in ways that are safer than they are today.

We know that it is important that we address the climate challenge but also and increasingly that we plan to cope with our failures in addressing it. We know that the economics of energy remain vital to all of our other social and economic objectives. We also know quite a bit about the sources of energy that give us opportunities to meet these policy objectives. We know the opportunities for greater efficiency are vast. We know that natural gas will dominate the economic supply of low-carbon energy for at least a decade, perhaps several. We know that just over the horizon of a century or so the direct uses of solar energy must become a better, even larger portion of our energy supply.

We actually know quite a lot.

But we also don't know a vast number of important things. We don't know what will go along with all of that natural gas and that ultimate solar hope or expectation. We don't know what bridges will follow the natural gas bridge to a lower carbon future. These are things about which we have opinions, and the opinions vary greatly. What we do know is that in the past when we have picked choices within these areas we have often been wrong. My company runs the nation's largest fleet of nuclear reactors, and I can say with an almost straight face that I have never met a nuclear plant I didn't like. I grew up on a farm in Wisconsin and had to tend the windmill; so I've almost never met a windmill I did like either. But I wouldn't submit that that's much of a guide for energy policy.

It is important that we become less dependent for our energy needs in the United States on certain portions of the world, and that our remaining dependence be organized in ways that are safer than they are today.

We know that new nuclear plants today are a difficult economic bet because foreseeable prices for natural gas will trump nuclear again and again and again. We know that wind needs a sibling, nuclear or coal or natural gas, to back it up. We know we have often been wrong. Resources for the Future conducted a poll about a year-and-a-half ago, slightly before the recession traumatized American opinions on nearly everything. In that poll the majority of Americans appeared to believe that the climate challenge was real and that the United States should do something about it. However, the majority of Americans don't like to think

Natural gas will dominate the economic supply of low-carbon energy for at least a decade, perhaps several.

of a carbon tax, because they know that costs them money, and they don't really like the idea of cap-and-trade, because they rightly think that will cost them money. But they were quite fond of renewable portfolio standards, because they assume these will cost only me money.

We at Exelon have done a great deal of work on the climate issue. We have something we call Exelon 2020, a plan to reduce, offset, or otherwise neutralize our entire carbon footprint by 2020 (details are available on our corporate website). We actually can do it, largely because of our seventeen nuclear reactors. And we can do it without building a new nuclear plant. Instead we will do it with a mix of energy efficiency, natural gas, wind, and offsets and by upgrading our existing nuclear fleet. In developing Exelon 2020, we looked at the relative cost of all sorts of measures in terms of dollars per ton of avoided carbon dioxide. Not surprisingly, we found that some forms of conservation are nearly free. What we don't know is why people aren't doing them anyway.

We were able to cut energy consumption in our home office by 50 percent, more or less economically, but we know we can't do that in most of our buildings. We know that natural gas trumps most other choices for a long time. We just don't know how long. We know that upgrades in our nuclear plants are relatively cheap. For the first time this year in our analyses wind became cheaper than new nuclear – not because the new nuclear became more expensive but because the gas we assume backs up the wind became so much cheaper. But the real issue is that wind now costs $50 – $90 per ton of offset CO_2, depending on where the wind is. New nuclear is somewhere around $70 a ton, coal with carbon sequestration is in the hundreds for a new plant, and solar is even higher. This makes a big difference.

California is relying heavily on renewable portfolio standards. I have heard estimates of $150 – $180 per ton as the price of these standards. In electricity terms that amounts to an increase of $0.15 – $0.18 per kilowatt-hour. California can't afford it, and no other state would contemplate affording it.

Congress is grappling with the American Clean Energy and Security Act of 2009 (commonly known as Waxman-Markey), a bill that will probably cost $15 – $20 per ton; yet it passed in the House by only seven votes after John Holdren, Rahm Emanuel, and the President of the United States himself applied all the muscle they could put behind it. But we simply must have cap-and-trade or a carbon tax. We simply must put the costs of CO_2 and other greenhouse gases into the marketplace precisely because none of us is smart enough to build that bridge between our natural gas- and coal- and nuclear-driven present and our solar-driven hope. Not a one of us can get it right. To those who argue that "we have one chance and we must get it right," I respond with deep respect that I hope they are wrong, because we are unlikely to get it right. We have a number of self-correcting chances, and we must build a framework of policy and markets that allows us to adapt, that forces us to adapt, that demands that we innovate, that rewards the innovation, and that makes possible structures we can't fully see today.

This is why Exelon has been working on cap-and-trade systems for most of the past decade. This is why I spend too much of my time in Washington on my knees lobbying. This is why we pulled out of the U.S. Chamber of Commerce, a relatively trivial act that got more attention than anything constructive we have done. We simply must build a system that allows us to react on a rational basis, that incents us to deal with the climate issue in the lowest-cost way, and that recognizes the great imperfections in our knowledge of the gaps between today's economic and political realities and the enduring musts of physics and geology.

Paul L. Joskow

Paul L. Joskow is President of the Alfred P. Sloan Foundation and Elizabeth and James Killian Professor of Economics and Management at the Massachusetts Institute of Technology (on leave). He was elected a Fellow of the American Academy of Arts and Sciences in 1991.

Many of our energy policies were formed during the first and second oil shocks of the 1970s. But a lot has changed since then, and our energy policies need to change, too. The energy intensity of the U.S. economy has declined dramatically since 1970, and economic performance, whether measured by gross domestic product (GDP) growth or productivity growth or inflation, is much less susceptible to oil price shocks than was the case during the oil price shocks of the 1970s. The utilization of energy per real dollar of GDP had declined by over 50 percent through 2007 and is likely to continue to decline in the future even if no new policies are adopted.

Many factors have led to this significant increase in the energy efficiency of the U.S. economy. The structure of the U.S. economy has changed dramatically, and technological changes in the production and use of energy have played an important role. Regulatory initiatives aimed at increasing end-use energy efficiency have also played a role, as have higher energy prices. The relationship between GDP growth and growth in energy use has also changed. The elasticity of energy consumption with respect to GDP (that is, how much energy use increases if GDP growth increases 10 percent) has declined significantly in the past fifty years. In the 1960s it was 0.9 (meaning that if the GDP grew 10 percent, energy use grew 9 percent). During the 1970s elasticity declined to 0.45. During the 1980s when energy prices were really high, it declined to 0.25. During the 1990s when energy prices fell, it climbed back to 0.4, but between 2000 and 2007 it fell to 0.15. That means a 10 percent increase in GDP growth now leads to only a 1.5 percent increase in energy use.

So the relationship between changes in economic activity measured in a number of different ways and changes in energy use, while still important, has declined significantly in the last thirty-five years. Energy still plays an important role in the economy, but that role has declined and will continue to decline in the future. Numerous studies by economists have tried to relate various measures of economic performance to energy price shocks subsequent to the two oil price shocks of the 1970s, and the measured impacts have repeatedly been shown to be relatively small. This has implications for energy security policies and our views about the economic significance of imports of oil from other countries.

Global oil demand will continue to rise over the next twenty-five years, a rise that is primarily attributable to growth in developing countries.

If you have been in the energy business for a while, you know that predicting the future is a prescription for going broke. But the best estimates that I rely on suggest that with the energy policies currently on the books – including the new energy policies introduced in the last few years – U.S. energy consumption will increase slowly over the next twenty years, perhaps by 0.5 percent per year (using the Obama administration's forecast for economic growth). U.S. petroleum consumption probably peaked in 2006. Indeed, petroleum consumption in the aggregate for the member countries of the Organisation for Economic Co-operation and Development probably peaked in 2006. My expectations for little growth in annual U.S. petroleum consumption for the next couple of decades can be explained by mandated improvements in the energy efficiency of passenger cars and light and heavy trucks, which will gradually increase the energy efficiency of the stock of vehicles on the road, the growth in the use of biofuels, and the stabilization in miles driven per passenger vehicle. U.S. petroleum imports from countries outside of North America have almost certainly peaked as well under best-case oil price assumptions. U.S. CO_2 emissions will be roughly flat over the next twenty-five years absent new greenhouse gas emissions mitigation policies. That is the good news.

Much of the thinking about energy security has not adapted to changes in the relationships between energy use (and energy imports) and the performance of the U.S. economy and those of other oil-importing countries.

The bad news is that the situation is different in many of the other developed countries, which import much more of their energy, and in most of the developing countries. *Global* oil demand will continue to rise over the next twenty-five years, a rise that is primarily attributable to growth in developing countries. Oil prices are likely to continue to rise, possibly doubling over the next twenty years in real terms, although technological developments in extraction from existing fields and in the identification and extraction of oil from deep water deposits may reduce that price trend. Global oil exports will become increasingly concentrated from countries in unstable areas of the world, the Persian Gulf and Africa in particular, as production in other producing regions such as Mexico, the North Sea, Latin America, or at least net exports from these areas, decline as well. This suggests that while the impact of oil price shocks on the U.S. economy may have declined significantly, the *probability* that supply disruptions and price shocks will occur may have increased significantly. Finally, flat CO_2 emissions are not nearly good enough for the United States if widely accepted global targets for containing the rise in average global temperatures are to be met. To meet these goals and the balance between the distributional and political issues that arise in negotiations between developed and developing countries, we are looking for reductions of 80 percent by 2050 for the United States and countries like Canada, Australia, Japan, and the EU, something nowhere close to being flat.

Much of the thinking about energy security was also formed during the 1970s and has not adapted to changes in the relationships between energy use (and energy imports) and the performance of the U.S. economy and those of other oil-importing countries. Every president since Richard Nixon has articulated some form of a U.S. "energy independence" goal. "Energy independence" should be read as something like "ending oil imports" or "ending oil imports from unstable areas of the world." The goal has never been achieved, and it never will be, and it is not really a good idea from an economic or an environmental perspective to try to make it happen. Conceptualizing energy security issues with a metaphor built around "U.S. dependence on imported oil" that is produced in insecure areas of the world – read the Persian Gulf – is misleading. Yet this metaphor continues to play a big role in U.S. energy policy. The United States itself actually imports relatively little oil from the Persian Gulf. The United States is the largest producer as well as the largest consumer of energy in the world, but our largest trading partner, accounting for 60 percent of the oil we import, is Canada. Mexico is also a big oil trading partner. And Canada accounts for essentially all of the natural gas we import. Persian Gulf countries account for only about 3.5 percent of U.S. energy consumption and 10 percent of U.S. oil consumption. Our allies in Europe and Asia import much more of their energy from that region of the world than does the United States.

Energy security issues are global issues . . . other countries need to and must bear more of the burden of securing oil supplies in the future than they have in the past.

But these facts are irrelevant. They reflect 1970s thinking. The oil market is one big integrated international pool where prices are typically quite well arbitraged across delivery locations. The trading patterns that we see reflect differences in transportation costs. It is not a shock that we import oil from Canada, Mexico, Venezuela, and from western Africa and that Japan and China and countries in Europe import oil from Russia, North Africa, and the Middle East. These are the trading patterns that minimize transportation costs. The effects of an oil supply disruption, whether it is from a disaster in some country or from cartel behavior, adversely impact *all* oil-importing countries regardless of where each specific barrel of oil they import happens to come from because *global* oil prices will rise in response to an oil supply disruption wherever it happens to occur. All oil-importing countries are affected by reduced supplies and higher prices, though the *effects* on economic activity will vary from one country to the next depending on the importance of imported oil in their economies. The picture of the United States being targeted by one or more oil-producing countries and having to absorb the entire supply hit reflects a deep misunderstanding about how oil markets work today and, one hopes, will continue to work in the future.

This suggests that energy security issues are global issues. A global problem requires global solutions, and other countries need to and must bear more of the burden of securing oil supplies in the future than they have in the past.

The recent presidential campaign featured debates about the desirability of promoting renewable technologies like windmills and/or "domestic" nuclear power (most uranium used in the U.S. nuclear power industry in now imported by the way). These technologies produce electricity. However, the United States consumes essentially no oil to produce electricity. That wasn't true in the 1970s, when nearly 20 percent of the electricity was produced with oil. This suggests that promoting wind, nuclear, and other technologies that produce electricity provides no direct energy security benefits because they would displace coal and natural gas produced in North America. They don't directly displace imports of foreign oil. The primary short-run argument for promoting renewable energy and nuclear power is to reduce carbon dioxide emissions – not to promote energy security goals. In the longer run the role of these technologies in the energy security story must work through the transportation sector, where 70 percent of the oil is consumed in the United States. The future of transportation will have to include electric vehicles, including hybrids, the expansion of environmentally acceptable biofuels, increases in vehicle energy efficiency, and perhaps even increased use of compressed natural gas if natural gas prices stay low and if we want to reduce oil imports.

Technological change has had important effects on energy production and use and must continue to do so if we are even to come close to achieving greenhouse gas reduction goals consistent with our economic performance goals. The revolution going on in the natural gas supply business in the United States, a revolution that is likely to spread to Europe and Asia, is a good example of how technological innovation is making large, new domestic (and Canadian) supplies of natural gas, the least carbon-intensive fossil fuel, available at relatively low prices. A combination of technological developments in horizontal drilling and hydraulic fracturing is making gas trapped in deep shale deposits, gas that we always knew was there but thought was too costly to extract, available at relatively low prices. Developments like these promote all of our economic and environmental goals. They make energy less expensive, they keep energy prices low, they use domestic and Canadian resources, they promote economic growth, they are partially the result of a more competitive natural gas sector, they reflect the benefits of decentralized technological innovations developed and deployed by the private sector, and they reduce environmental damage from energy use.

Many commentators argue that we need the equivalent of the Apollo program to develop new energy technologies that meet economic and environmental goals. I think that the Apollo program, which calls to mind government spending on selected large-scale technological innovation programs focused on specific technologies chosen by the federal government, is the wrong metaphor for technological change that will promote the widely accepted economic, energy security, and environmental

Technological change has had important effects on energy production and use and must continue to do so if we are even to come close to achieving greenhouse gas reduction goals consistent with our economic performance goals.

goals that I have discussed. There is enormous uncertainty about future energy demand, the attributes of future energy supply technologies, prices, the rate and direction of technological change, and other attributes of the energy system and its role in the economy. Getting locked into what appears to be "the solution" to mitigate CO_2 emissions or reduce imports of foreign oil would be a big mistake. Creating an incentive structure that aligns policy goals with the incentives of consumers, producers, equipment suppliers, and those who finance them is critical for good policy outcomes. The most important incentive-compatible policy to put in place is the implementation of appropriate prices on greenhouse gas emissions. The prices placed on greenhouse gas emissions will end up being much higher than what is anticipated by the American Clean Energy and Security Act of 2009 (Waxman-Markey) that is currently moving through Congress if its ambitious 2050 GHG emissions reduction goals are to be met. We want those charges to flow through naturally into energy prices and to allow producers of energy and consumers of energy to respond in ways that make them better off when they face these prices. Whether the mechanism used to place appropriate prices on greenhouse gas emissions is emissions taxes or a cap-and-trade really doesn't matter much in the grander scheme of things, though it is a lively focus of debate among some economists. In my view, for those of us interested in policies that place appropriate prices on greenhouse gas emissions, the debate among economists about whether it should be a tax or a cap-and-trade system or some hybrid mechanism is not very important (it is like arguing about how many angels are on the head of a pin), and the apparent disagreements among economists is being used by some interest groups as a rationale for opposing any policies that place prices on greenhouse gas emissions. What matters is getting a price on greenhouse gas emissions to stimulate the decentralized incentives that on the demand, supply, and innovation side will lead to the identification of a portfolio of competing technological options to reduce our reliance on fossil fuels and to reduce the emission of greenhouse gases into the atmosphere.

The government's record on picking winners in energy technology is pretty bad. Coal gasification: not too good. The Clinch River Breeder Reactor Project: not too good. Nuclear waste storage: $20 billion down the drain. And the government played almost no role in the identification or deployment of the two technologies that have been most fundamental in spurring development of North American natural gas resources. If we are going to bet on the future, let's not have the Apollo program on our mind. Instead, let's focus on getting the incentives right. That means making it much more costly to emit greenhouse gases and to allow the decentralized entrepreneurial spirit and the decentralized interest of consumers in saving money to motivate efforts to find the best, the most innovative, and the most economical solutions to these problems.

John Doerr

John Doerr is a Partner at Kleiner Perkins Caufield & Byers. He was elected a Fellow of the American Academy of Arts and Sciences in 2009.

We have heard many times that America confronts three interrelated crises: an economic crisis, a climate crisis, and an energy security crisis. My message is that we face a fourth, a competitiveness crisis. At stake is our worldwide standing in the next great global industry: green technology. Fifty years ago America won the space race with the Soviet Union. Today we are in an "Earth race" for the future of the planet and an energy race for the future of America's standing in the world.

I was inducted into the Academy yesterday. When I received word of this honor, I was quite sure they had made a mistake because I am not a distinguished thinker or a scientist or an artist or performer. In fact, I am an engineer and a partner at the venture capital firm Kleiner Perkins Caufield & Byers. We work for the country's great colleges and universities. We get funds from their endowments, and we invest those monies in the risky plans of unproven entrepreneurs who would never qualify for a bank loan. We are not financial engineers. Some would say we are investing in sub-sub-prime opportunities. But it turns out these entrepreneurs end up building real businesses with lots of jobs – in the case of my partnership since the mid-1970s, over 500 companies and 400,000 U.S. jobs. The companies include the likes of Genentech, which pioneered an entirely new industry, and Google, which changed the way we search. So my perspective is that of the entrepreneur and the innovator.

How far behind are we in this energy race? Did you know that the United States is home to only two of the top ten solar photovoltaic producers worldwide, only one of the top ten wind providers worldwide, and only one of the top ten advanced battery makers worldwide? Only four of the top thirty companies worldwide in these green technologies are headquartered in the United States. Yet we use a lot of these products, and we use a lot of energy. At this point in the race for the next great global industry, we are not winning. That fact should worry all of us a lot. If we lose our advantage in technologies that were invented and pioneered here, it will cost us dearly.

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So who is on track to win this race? China. China's commitment to green technologies is staggering. China is on track to deploy 120 gigawatts of wind by 2020. That is more than four times the cumulative U.S. wind deployment over the past thirty years. It is the equivalent of 250 coal-fired power plants. China is investing in energy stimulus on a scale that is six times the U.S. investment from our stimulus package. And China is deploying high-speed rail at a pace and scale that are almost hard to imagine.

Can we possibly catch up? I think we can, but only through the power of good old homegrown American entrepreneurs and innovations and the right policies and the power of private capital markets. More money flows through private markets in a day than through all the governments of the world in a year. Never underestimate the power of entrepreneurs. They do more than anyone thinks possible with less than anyone thinks possible.

All the work that these entrepreneurs are doing will fail unless we get one thing really right. I have recently spent time in Washington, D.C., to advocate for comprehensive forward-looking energy and climate-change legislation. This legislation must have four key components. First, it must put a price on carbon. By putting a price on carbon we will unleash the investment of worldwide capital markets. We need that capital. The market needs a long-term price signal. We need the equivalent of what the Netscape initial public offering was for the world's Internet entrepreneurs. Putting a price on carbon will rally entrepreneurs, innovators, investors, policy-makers, and business leaders to get about this important business.

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Second, we need to get the rules and regulations for our utilities right to drive efficiency, to drive renewable portfolio investments, and to get a national unified smart grid. Third, we need efficiency standards. America should have the most fuel-efficient cars and the most energy-efficient buildings in the world. The only way to get there is through standards and incentives. Fourth, we must get serious about funding R&D&D (the second *D* is deployment) at scale. Energy is a $1 trillion component of our economy; yet, in 2008 the federal investment in energy research was about $1.8 billion. This is shameful.

We know these kinds of policies can work. We know innovation can work. It is already working in other countries around the world. Denmark has a smaller population than Missouri, Tennessee, or Michigan. In 1970 they put in place policies to encourage a low-carbon, independent energy future. These policies led to the start of their wind industry, which today supplies a third of all windmills in the world. In 2008, Denmark's technology exports were $10 billion, and their unemployment rate was under 3 percent.

Fifteen years ago Web browsers did not exist. The very idea of Internet point and click that we now take for granted hadn't been invented. We had no Internet at our fingertips, no e-commerce, no search engines. Today these things have transformed our lives. Now, imagine a world in which Microsoft was a German company; Apple was Japanese; Google, eBay, and Yahoo were all Chinese-headquartered companies; and only Amazon was American. That is the path today with respect to our nation's prosperity and worldwide leadership if we don't address the looming clean energy competitiveness crisis. Today's Internet was created in about fifteen years and is a $1 trillion economy that 1.2 billion people around the world access. Energy is a $6 trillion economy with 4 billion users of electricity around the world, and usage is doubling every twenty years or so. It is the "mother" of all markets, the largest economic opportunity of the twenty-first century. For the United States to lead in this future we need the right policies, we need the right incentives, and we need the right kind of innovation. Our competitors around the world have woken up. We need to do the same with forward-looking comprehensive climate and energy legislation, or we will be buying our future from them.

Discussion

Richard Meserve:

Steve, Paul Joskow pointed out that the government does not have a good track record when it tries to select winning technologies, and John Doerr questioned whether we have the right policies in place to move forward appropriately in the area of energy technology. How is the Department of Energy confronting these issues?

Steven Koonin:

First, as the representative of the government, I'll just note that about eight months ago the government changed, so I'm not sure I have to defend what the government did over the last decade or so!

I find myself much in agreement with Paul Joskow and John Rowe, and I'm disappointed if I gave a different impression. I certainly didn't mean to imply that the government is good at or should be picking winners and losers. A level playing field, a universal price on carbon, and low-carbon portfolio standards are probably the best way to go about tackling the greenhouse gas problem. That said, the slightly different points of view held by an economist and a technologist are worth highlighting.

Paul argues that if we just set a price on carbon the market will take care of everything else. Perhaps. As a technologist I have some appreciation for the state of play of various technologies and the potential for their evolution and deployment. I think we can make reasonable projections, at least on a ten- or twenty-year time scale, of what is going to happen, particularly given the long time scales for energy. Roughly six years is needed to put a major power plant or refinery into the ground from the time you say go, whereas you can probably deploy a software build in six days. So the time scales are very different.

Paul Joskow:

Putting an appropriate price on CO_2 emissions and emissions of other greenhouse gases is not the only policy we need, but it is the most important policy. We will need supplementary policies, too, but the guiding principle, if the focus is on greenhouse gas mitigation, is to find the most economical options for reducing greenhouse gases. We will have to make some guesses as to what those options will be. But by putting a price on CO_2 emissions we will inevitably lead both consumers and producers, as well as companies that finance innovation, to look for the most profitable and least costly solutions.

We ought to be focusing on the low-cost options first, moving our way up the curve, doing more R&D on some of the higher-cost options to bring their costs down, and providing flexibility for new ideas from both the demand and supply sides to enter the market and make contributions to mitigation rather than trying to constrain them by deciding what is and what isn't in a renewable energy portfolio standard. If nuclear power is as carbon free as wind energy, then why shouldn't it be part of the renewable energy portfolio standard? Why shouldn't it get the same treatment as other renewables? I know the answer is politics, but from an economic perspective it makes no sense.

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John Doerr:

I do think there is good reason to treat nuclear separate from other renewables. Enormous capital is required to build these plants, and much legislative underbrush needs to be cleared so we can streamline their siting. To have nuclear competing against all the other renewables for those incentives could sop up all the incentives we have to offer.

John Rowe:

Ideally we would have a legal structure that provides a framework of property rights and trading rules that make an efficient marketplace respond to a set of social needs. The challenge in energy is that the patchwork of legal interventions in the marketplace really doesn't constitute a framework. The effect is more like a group of rifle shots going off throughout the market. One major correction to this would be a cap-and-trade or carbon tax or other carbon-pricing measure.

Nuclear is challenging because it doesn't take three or four years to make a nuclear plant; it takes eight. They come in about $6 billion clumps. They're all pigs in the python.

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Devising a market structure to deal with the interplay between different kinds of renewable technologies and nuclear is difficult because the more you do of one in the short run the less economical the other is in the longer run. And in the case of nuclear, anything you get correct now won't come into play for a decade. Unfortunately, we are not good yet at finding a way to use policies to frame a market that is informative and has healthy feedback mechanisms instead of a relatively self-destructive feedback mechanism.

John Doerr:

We have just gone through what I hope is the worst economic crisis of our lives and what is perhaps the second worst in our nation's history. The energy choices we are going to make will be made in light of our Great Recession, which means that preference will be given to generating a lot of jobs really fast. Some observers have argued that a jobless recovery and another year of high unemployment would pose the gravest threat to the nation's and administration's agenda. Why not, as some really smart people have observed, put the million-and-a-half out-of-work construction workers to work retrofitting America's homes, which emit twice as much greenhouse gas as the entire light-vehicle transportation fleet? The energy savings would be abundant, and we would create a new American industry, an offshoot of the home-building industry. Over the course of a decade or two we should assess and, as needed, retrofit 100 million American homes. In fact, we probably can't get to our climate goals if we don't do this.

Paul Joskow:

The American public has not been adequately prepared for the sudden onslaught of carbon legislation. The level of discussion, even among well-educated people in the United States, over the last five years has been quite different than in Europe and Japan, where these issues are still being discussed. This is creating a challenge for politicians. To meet the goal of 80 percent reduction by 2050, energy prices will have to go up, and nobody wants to tell the truth about that. Waxman-Markey and some of the other bills are designed to hide the ball or to delay the rise in energy prices. This is unfortunate because it will lead to much more inefficient programs. Energy prices need to rise for two reasons. First, we want to give consumers incentives to adopt energy-efficient technologies. Second, the technologies for reducing greenhouse gas emissions are going to cost some money, and eventually someone has to pay. The government can't pay for all of it forever. Until we bite the bullet and educate the public about the costs as well as the long-term benefits of controlling greenhouse gas emissions, we are going to have difficulty passing the legislation that will get us on a path toward a least-cost solution to these problems. ■

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