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ON SCIENCE & PUBLIC POLICY

From Oil Sands & Cornfields to Server Farms: Principles to Consider When Formulating Energy Policy

By Mark Mills

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Jeff Kueter: Ladies and gentlemen, welcome. I am Jeff Kueter, the President of the George Marshall Institute, and it is my pleasure to welcome you to the latest installment of the Washington Roundtable on Science and Public Policy. This speaker series is designed to bring scientists and engineers together with the public policy community here in Washington to discuss issues of the day. Of course, energy and the quest for energy independence is of critical national importance. Kicked off, perhaps symbolically, by the President's State of the Union address earlier this year, the quest for energy independence is not a new one in the United States; presidents since Nixon have been articulating strategies and paths forward to try to build the energy security of the United States or to stabilize it. Energy is critical to our economic prosperity and to our individual wellbeing (as anyone who steps outside this building today is going to realize right away), to our personal prosperity and to our nation's security. But with all of the policies and proposals that you as policymakers have before you to try to strengthen the nation's energy system and to improve our energy security, whether it is reflected in the quest for independence or whether it is modifications of the existing infrastructure, there are still other aspects of energy that we may not fully understand.

So it is our pleasure to welcome our speaker today, Mark Mills, the author of what I think is a very compelling book on the subject titled *The Bottomless Well: The Twilight of Fuel, the Virtue of Waste, and Why We'll Never Run Out of Energy.* I think he will provide you with some interesting perspectives and hopefully some provocative comments that will influence or at least inform the policy debates going forward. Mark is a physicist, the Chairman and Chief Technology Officer of ICx Technologies and a co-founding partner in the venture fund Digital Power Capital. He is also a founding member of the research firm Digital Power Group and a longtime Washington player who served in the Reagan White House and on the Hill, but now is in the private sector, though still dabbling in public policy every now and again. We welcome him here and thank him for coming.

Mark Mills: Thank you Jeff, and thank you all for coming. Talking about energy, especially these last few weeks, is perhaps an obviously timely subject; on the other

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hand it may seem less compelling because there is so much news and attention focused on non-energy issues in the Middle East, the obvious crises that are bubbling up and reaching the boiling point. But as you all know, especially those of you who have been around a while or are students of energy history, there is a cycle, there is a pattern. For quite a few decades now, turmoil has continued in the Middle East, and because there is a lot of oil there, we talk about energy policy and so forth. Energy policy seems to be driven by events in the Middle East. What I want to do instead is talk about the fundamental principles that, I think, should inform energy policy, principles that are anchored in economics and physics and that, without regard to energy policy, probably will drive what the energy future looks like. It is going to be a very high-level picture and it will be necessarily reductionist, as opposed to detailed about a lot of facts. If we have time afterwards, you are welcome to challenge me on some of things I say that you might find difficult to give credence.

It is impossible not to start talks about energy without talking about oil first. So let's look at the occasion of the last oil shock in 1979. In August of that year at the National Press Club, in the midst of an oil price-induced recession, a deep national recession, our nation's first Secretary of Energy James Schlesinger said,

> *"The energy future is bleak and is likely to grow bleaker in the decade ahead. We must rapidly adjust our economies to a condition of chronic stringency in traditional energy supplies."*

So in a couple of years of Secretary Schlesinger's dire warnings, oil prices did rise further; they went to the still record high of $84 a barrel, in inflation-adjusted dollars. But in the decades that followed, rather than stringency, oil prices relaxed and traditional energy supplies increased enough to support the equivalent of an increase in annual U.S. energy consumption of three billion barrels of oil-equivalent a year. The U.S. GDP doubled over that time period. So now oil prices once more are rising into that same peak; we are close to what we experienced in 1979. But this time, if you look at the last few years, as oil prices have been rising, the economy did not go into recession; the economy has been growing right alongside rising oil prices. It is a very different phenomenon from twenty-seven years ago. What happened?

Technology happened. I don't mean oil exploration and production technology, which is important, of course; I am talking about a deep, fundamental technological transformation of our economy. In simple terms, the dot.com-era techno-dweebs were right, even if a little early and hyperbolic: this *is* a new economy. The whole idea of a new economy, which became discredited, indeed is true; we are entering a new economic era. Our GDP is increasingly tech- and information-centric. Everyone knows that and writes about it, but that phenomenon, that reality is rarely connected to energy discussions – our economy is ever more economically distant from the price of oil and raw fuels.

Obviously, high-priced oil matters to people. The price of everything matters at some level. High-priced oil takes money out of people's pockets and it is particularly painful for those with lower incomes. High commodity prices do ripple through an economy, but it is a *ripple*; typically it is not a tsunami. Let me give you a historic analogy before going on to these basic energy principles.

In bygone eras, and today in undeveloped countries, the price of food and the health of the agriculture sector completely dominated national economies. In an industrial economy, while self-evidently food still matters – no one stopped eating after the industrial revolution – food prices and the agriculture markets lost their ability to undermine national economies. Now we are in a post-industrial, increasingly tech-based economy, so rising oil prices remain important, but they don't have the same capacity to whipsaw the economy. They are being eclipsed by larger forces. We still eat, agriculture still matters, and we still drive lots of oil-dependent vehicles. But they don't have the same power to affect our economy as fundamentally as they did in decades past. This is a pivotal economic milestone and it is one where electricity has become our nation's primary energy commodity. Put simplistically, electrons trump barrels, which is the first of seven Principles of Energy Reality.

Principle #1: Electrons trump barrels

Look at our economy from the perspective of where energy is used, rather than the point of where it is produced. Nearly all of the machines, tools and businesses that make up our economy use only two forms of energy. They consume electricity or oil, or oil's hydrocarbon cousin, natural gas.

When the first oil-shocks hit in 1973 and 1979, 60 percent of the industries and economic activity in America were directly dependent on barrels of oil (or the equivalent) and the remaining 40 percent were directly dependent on electricity. Today, the ratio has completed reversed; 60 percent of our GDP depends on electricity. Our economy has become much more electrified and we have a profoundly different ratio of dependence on energy in our economy.

This single fact explains the unanticipated resilience of the economy to oil hovering north of $70 per barrel. The oil-based engine and boiler parts of our energy economy are receding in the economic distance. Adjusted for both inflation and the smaller share that oil has in our economy, oil would need to hit over $120 a barrel to have the same economic impact as the recession-inducing price spike of 1981. The bad news in this fact, I suppose, is that there is a lot of headroom yet for short-term oil price hikes. But the long-term reality is that price spikes tend to be temporary and they rarely sustain at those spike levels and our economy is phenomenally more resilient.

This electrification trend, which is what has created the resilience, has been going on for decades and it will continue. Our venerable Energy Information Administration's forecasts, put in barrel-of-oil terms, call for additional resources equivalent to 80 *billion* barrels of oil to fuel just the *additional* power plants needed to meet new electric demand over the next couple of decades. This rising electric dependence of our economy is the single most important public policy feature of the U.S. energy economy, which leads to the Second Principle:

Principle #2: Silicon increases energy demand

By silicon, I mean the digital economy. People talk a lot about how the digital era might lead to a less energy-intensive economy. Think about the rise in electric consumption over the last decades. It cannot be attributed to the use of lots more lights, air conditioners, motors and pool pumps, as it was during the post WW-II industrial boom. In fact, engineers have made that class of mid-20th century appliances astoundingly more efficient, so much so that if they were the only things we were using that consumed electricity, the overall electric demand in the United States would have declined or at most stayed flat.

There is today a vast new constellation of electricity-consuming silicon-based technologies that didn't exist two decades ago. There are hundreds of millions of digital devices from desktops to palmtops, used in homes and offices, on factory floors and shipping docks, and there are thousands of million watt industrial-scale digital technology enterprises from chip fabs to server farms, all plugged in to the electric gird, all part of the silicon revolution.

A reductionist, but roughly indicative, way to think about the digital economy's electric impact is to count the production of semiconductor silicon itself. Every square inch of semiconductor silicon shipped costs about one-kilowatt-hour just to manufacture. And then that same square inch of silicon, once wired inside some device, ends up consuming, on average, another kilowatt-hour a year. Annually, we ship semiconductor-grade silicon measured not in square inches but in square miles.

Silicon's energy impact is evident, if buried, in the EIA data, which forecasts the commercial sector accounting for the majority of new electric demand. And over half of all that demand comes from a catchall category simply, mysteriously labeled, "other." The "other" category includes equipment like gasoline pumps in service stations, medical imaging equipment and "new telecommunications" equipment. Since one doesn't expect an MRI on every desktop, there's no mystery as to what would account for the new electric uses.

The demand for silicon-based digital devices is ubiquitous and far from sated in every niche of today's $12 trillion U.S. economy and tomorrow's $20 trillion economy. Which brings us to the Third Principle, one that runs counter to an entire subindustry devoted to the proposition that efficiency can reduce energy demand:

Principle #3: Improving efficiency *increases* energy demand

Policies promoting energy efficiency have a remarkable feature: they are deeply, enduringly bipartisan. They are in every energy proposal I can remember seeing; everyone genuflects to energy efficiency. But unfortunately for the disciples of energy-efficiency-as-savior, it is demonstrably fallacious that the nation's energy demand will decrease as overall efficiency rises. At the highest level of abstraction, the U.S. economy is twice as energy efficient today as it was fifty years ago and we use three times more energy. Fifty years from now, likely we'll be three times more efficient and we will probably use twice as much energy.

It is apparently seductive, but obvious, to note that replacing a specific device or appliance with a more efficient one will decrease that specific device's energy use in that one application. The problem is that in the real world, we find many more new uses for that same or similar devices, and like magic new devices and technologies appear with the passage of time and they too consume energy, typically electric energy.

From a basic economics perspective, improving efficiency is synonymous with reducing the cost of operation. In economics, it is a tautology. Absent punitive regulations and sumptuary laws, the overall effect of reducing costs is to increase consumption. Put another way, if you want to decrease demand, you should increase prices and decrease efficiency.

In the energy efficiency game, there is a statistical scoundrel's fallback which goes like this: while energy use has gone up, not just for decades but for centuries, it would have gone up even more if we didn't promote energy efficiency. The problem with that observation is that it is not only simplistic, but backwards. Demand grows in large measure because efficiency improves.

The steel mills of Dickens' London were horribly inefficient. Our steel mills today are more than ten times more efficient. The industrial revolution followed because that technology got better, more efficient, and cheaper. So too with the automobiles at the dawn of the 20th century: today's SUV gets 50 percent better gas mileage than a 1952 Buick of the same weight and horsepower. Post WWII aircraft inhaled aviation fuel at three times the rate of today's Boeings and Airbuses. The first computers burned one million times more electrons per logic operation than today's computers. ENIAC, the first computer, was a frightening 170 kW beast, the first and planet's only data center at the time. Today's super-efficient logic processors have led to thousands of data centers across the world, often clocking in at the 10,000 kW range per building. Total electricity fueling data centers three decades ago was irrelevant and it is now one of the largest single industrial-class of demand. These are steel-mill-class electric consumers. This brings us to the Fourth Principle, which arises from a strange aspect of the physics of the energy we consume:

Principle #4: All BTUs are not equal

Much about energy policy is distorted by the metrics used to count energy supply and consumption. The unit of choice is the (archaic) BTU, the British Thermal Unit. It is a perfectly respectable unit to measure energy. America consumes about 100 quadrillion BTUs, or 100 Quads. One source, or use, of quads looks like another when toted up in the government's national energy accounts. So we trot off looking for ways to find or save BTUs here and there, seemingly without logic. This is roughly as useful as comparing tons of gold to tons of wheat; obviously a ton is a ton, but is a near meaningless measure of the value and utility. So too with BTUs.

The BTUs in photons from the sunlight landing on pastures can appear as BTUs of carbohydrates in wood burned in a fireplace or transmuted into BTUs of alcohol. Similarly the BTUs in coal piles at power plants can appear as BTUs of electrons to power microprocessors or BTUs of photons from a laser. We pay $2 for a barrel's worth of the BTUs from wood burning in a campfire and about $60 a barrel for the heat from wood alcohol. We pay about $10,000 for a barrel's worth of electrons consumed by Pentiums and $200,000 for a barrel's worth of photons from a laser. The market, needless to say, recognizes and willingly pays for – indeed prefers – the latter BTUs, because they are higher quality, they can do more, and more valuable, things.

The problem with this characteristic of energy is that there actually is no metric, no number you can use to measure it. To spend just a moment in physics, we're talking about entropy. Entropy is a strange concept that the Victorians loved and wrote novels about. It is entropy that defines the difference between photons from a fireplace and a laser. There is a lot of entropy – disorder – in cow pasture and fireplace photons. The Pentium's electrons and the laser's photons dance in exquisite synchronicity with nearly all the entropy stripped away. That is why they are so valuable. There is nothing in the BTU numbers that reveals the difference between these different manifestations of energy. We only see the difference in the price and what they can do.

To strip entropy – to have more ordered energy – takes two things, technology and energy. You consume energy to strip entropy. This is one of the basic laws of physics, a law with respect to the conservation of energy. Einstein (and I paraphrase) considered this one of the most enduring principles of nature. We will never get enough of the higher-value, lower entropy BTUs. So policies that treat all BTUs as equal are doomed to failure. This brings us to the Fifth Principle, arising from today's obsession to reverse two centuries of progress towards higher value forms of energy:

Principle #5: Hydrocarbons trump carbohydrates and uranium trumps all.

We have bipartisan enthusiasm right now in Washington to pursue the use of carbohydrate-based fuels, largely derived from such foodstuffs as corn and soy, and perhaps types of grass. America certainly does have a lot of land and we grow a lot of carbohydrates. But as magical as nature's photosynthesis is, it is remarkably inefficient, converting under 0.5% of cow pasture photons to stored carbohydrates. It thus takes a lot of land to make serious quantities of carbohydrate-based fuel. If all current corn and soy production were converted into alcohol and biodiesel, it could displace 10 percent of our transportation fuel. We could use more land. But the use of land is arguably the single most important and accurate measure of civilization's impact on the environment. It is our consumption of land which fundamentally determines how much impact we have on the environment.

Overall, counting all the land required, from mines and roads to refineries and storage depots, hydrocarbon fuels (whether oil, coal or natural gas) require roughly 1,000 times less land per quad of energy produced compared to any carbohydrate-based fuel scheme. Land use per quad drops another 1,000-fold if uranium is the raw energy resource of choice. All of the annual energy needs of Manhattan, all the buildings, computers, cars and buses, could be fueled by uranium fuel rods that would not fill up a single New York apartment. Such fundamental advantageous disparities can be ignored by policymakers, but they cannot be ignored forever.

To reduce environmental impacts, you would fuel cars from the electric grid, not from cornfields. Barely noted outside of techno-circles five years ago, we now hear increasingly not just about hybrid cars, but plug-in hybrids. A plug-in hybrid provides the option to choose the electric grid, when convenient, over the fuel in the tank, which is a realistic option for urban driving distances even with today's battery technology. Every kilowatt-hour taken from the grid displaces one pint of gasoline. That is pretty significant, considering that short-distance urban trips account for a very large share of transportation fuel use in the United States. The rap on hybrids is that they're more hype than hope. But most of what makes today's hybrids expensive strongly resembles what made computers expensive a few decades ago: silicon and digital technologies, in this case high-power versions of the same. But the trend is towards cheaper, perhaps more rapidly than many realize. This leads us to the Sixth Principle:

Principle #6: Cheaper is better

In Washington, like most places, money matters. When it comes to price, our energy policies are at odds. One on hand, the alternative energy advocates revel in, even blatantly praise, high-priced oil as the long-needed stimulus for favored non-oil sources. On the other hand, most economists, and I would say most consumers and politicians, chafe if not rebel at higher priced energy. Over the long run, governments (at least free governments) prefer, and technology enables, ever-cheaper energy for society. Even if in the short-run, geopolitics, regulations, speculation, and just bad luck can whipsaw energy prices, lower prices are a good thing, not just for American consumers, but for poor nations, for technology progress, perhaps surprisingly, and for our national security. Let me tell you briefly about why low prices matter to each.

Obviously high energy prices retard economic growth and human development. That is easy to figure out. They punish poor nations and poorer parts of our economy. High energy prices can also distort technology progress. Over time, for those who are students of technology history, new technologies displace old technologies almost invariably because of inherent economic advantages. They become sustainable because they can survive, even prosper, regardless of relatively short-cycle price gyrations in what they're competing against.

Perhaps most importantly, high oil prices exacerbate our national security problems. The reason is simple. We talk a lot about energy independence and national security, especially now with what is going on in the Middle East. On the planet we happen to live on, a large quantity of cheap oil is located in the Middle East. That is not going to change. Even if America purchases not one barrel of oil from that inconvenient location, all of the rest of the world will continue to buy that oil for the foreseeable and relevant future. Since the U.S. economy – not to mention many of our geopolitical interests – is linked to the worlds' economies, nothing changes regarding our geopolitical security. Worse yet, since the U.S. is the world's largest oil consumer, our policies can artificially prop up high prices for longer than they ought to stay up there. The implications are serious.

A world with a sustained price of around $70 a barrel price instead of, say, $30 will transfer to Middle East nations a cumulative increased cash windfall of over $15 trillion. Even in America, $15 trillion is a lot of money. It is the money, and the trouble it can buy, that we should worry about, and about which we can do something. Preventing a $15 trillion surplus wealth transfer to the Middle East is only possible if the free world's energy policies are single-mindedly focused on ensuring low energy prices. It is about the money and the bad things that can be done with that much money.

The demand for oil will not shrink, any more than demand for energy will, for decades to come, certainly for periods longer than any policies can address. Which brings us to the Seventh (and last) Principle:

Principle #7: Energy demand always rises, which is a good thing

There has been no period in human history, outside of pandemics and total wars, or the equivalent of both in totalitarian societies, when energy demand has not risen. Technology progress brings economic and social progress. And rising energy consumption is a surrogate measure of the rising use of new technologies, new tools and new machines, of rising affluence and well-being. It is also a collateral measure of societies' rising ability to afford to devote resources to protecting the environment. Affluence permits us to do things to protect the environment, and affluence is linked to rising energy consumption.

Oil and its hydrocarbon cousins are the fuels of nearly all transportation and will be for some time. Electricity will continue to be the primary fuel for economic growth for the developed world and will shortly become the primary fuel in the developing world. Conventional or what I call "near conventional" resources that we know about today are available in such staggering quantities that the idea of energy resource shortages has no meaning. We need no magic new technologies, no Manhattan or Apollo programs to unlock access to these resources. At a fraction of today's oil prices, the long-term availability of both liquid fuels and fuels for electricity is hardly bleak. The total known resources of conventional oil, deep-water oil, heavy oils, oil sands, shales and coal are measured in tens of thousands of billions of barrels of oil-equivalent. North America alone has over 3,000 billion barrels of oil-equivalent in heavy oils and tar sands and shale oils and oils we are not allowed to look for or extract. Uranium takes the numbers in to the stratosphere.

Eventually, energy policies will succumb to reality. In the meantime, we might chose policies that permit and encourage industry to tap in to the gargantuan "traditional" energy resources around us. As supplies continue to expand, prices will inevitably soften, and the economy will grow apace. It is not conceivable that the pundits in 2033 will look back at 2006 as some pivotal point of energy and economic collapse, any more than it was the over the same period looking back to Secretary Schlesinger's 1979. While we likely will continue to face the same Middle East political quagmire for decades to come, there is no reason for our energy policies to be stuck in a quagmire of mythology. We can, in fact, anchor some policies in reality. Frankly though, I don't expect we will. I understand political reality and why Iowa corn farmers are happy about corn alcohol. I understand why people oppose nuclear power, though I confess I fail to understand the anathema to the marvels of oil as a fuel. But in the end the facts, the reality of our economy will dictate what we do in the future. The real question is how painful we make the transition. As you can probably guess, I am a fundamental optimist about a very exciting and economically interesting and affluent future. We will use a lot more energy getting from here to there. Thank you.

Questions and answers.

Question: You were saying that electricity is going to be a more important fuel for transportation, but at the same time you say that there is a lot of fossil fuel which is available and going to become available. What do you think are the prospects for transportation and the energy that we are going to use for transportation thirty years from now?

Mills: The question was about the prospects for energy for transportation. As I said, most of it is going to be oil and I was talking about the ascendance of electricity. I was pretty careful to try to stress that most transportation fuel will stay oil. Airplanes are going to be oil-fueled for a long time. Big trucks can use oil and compressed natural gas. But cars can switch over and cars can do remarkable things because of the short distances and the light weight that cars have, compared to aircraft. Fundamentally if you had to pick a number, transportation is not going to be less than 70 percent oil-fired, it might be 80 percent, instead of 99 percent oil-fired. While there are lots of liquid fuels that can be used for cars, we have many more good options to make electricity with to power electric-assisted cars. But fundamentally we need oil to run the transportation sector. That is the reality. As I said, the economy is really split in two pieces: we have the oil economy, which is almost entirely transportation (aside from feedstocks) and we have the electric economy. It will change in time, in decades and decades, but it will be tough.

Question: You mentioned a percentage of 5 percent to be the energy supplied from carbohydrates. Where did you get that figure from?

Mills: There are several studies; making alcohol fuels from corn is an old subject. There was actually a report in *Nature* magazine two issues ago on this subject exactly.

Question: This is inconsistent with the President's figures in his State of the Union address and that is why I am asking.

Mills: Well, the problem is that the arithmetic is hard to deny. I understand that people want to promote it and I understand how these statistical errors creep into speeches, having been an architect of such speeches twenty-five years ago. Let's say alcohol fuels could be twice as big and the guys who came up the 5 percent and we get twice as efficient as –

Question: They were talking about six times.

Mills: Now the President's statement, if I recall, and I can do the forensics here, related to the use of alcohol fuels to displace the oil from the Middle East, not –

Question: What about cellulose?

Mills: If you add switch grass, that carbohydrate, you can use prairie grass and you can go another five points.

Question: It seems to me you could increase that number.

Mills: Well, statistically if you put under irrigation six times as much land as we have today in the United States of America -- we can do it, we certainly have that much unirrigated land -- you could do the arithmetic and get to 30 percent. We would thus have to put under plow six times as much land as we now have under plow for all corn and all soy.

Question: To follow up on that point, it seems to me that what is left out is alternative technology, such as gasification, for example, or using forest waste or using solid waste. I think the President's speech referred to that technology and it is the basis for his 30 percent displacement.

Mills: You can take wood waste. In fact, the forest industry in the last thirty years has been very good at channeling a lot of its wood waste into its own processed steam and there is not much left to tap into. Trash can be made into fuel; anything organic can be made into fuel. Chemists are pretty good. You can take anything organic that has hydrogen and carbon in it and make a fuel out of it. But you can't get from here to there on the arithmetic. There is no possibility that we could substantially or realistically replace oil even if we used all of our waste and corn and made it into fuel; we just don't get from here to there. You could do numbers that would get you altogether to a third of our oil use, but it is not meaningful. Then you have to ask two questions: what is the cost of doing it and, frankly, what is the environmental impact, because it is an enormous consumer of land. It would mean you need a lot of transportation just moving low-energy-density stuff around in trucks, basically. There are those who think alcohol fuel is an energy loser, and it may be.

Question: What about coal liquids?

Mills: I included coal in my large hydrocarbon numbers. Coal liquids have been feasible for a long time. Patton's Third Army rolled into Berlin on coal liquids that the German government developed after we bombed the oil fields in Central Asia, as you may recall. They had a process that we can still use today to turn coal into oil; that is what Patton used. It is more expensive than tar sands oil and it is more expensive than Middle East oil and it is more expensive than North Sea oil, but it is doable. It is just chemistry. But it depends on what price you want to pay and is also depends on the march of technology, which tends to drive those prices down. We first began extracting oil from the tar sands thirty years ago. The best I could determine at the time from some of the Parliamentary audits from Canada was it was costing between $30 and $60 a barrel (we couldn't tell really what) to make oil from tar sands. It appears that the clearing price to get oil out of tar sands now is around $12 to $15. When we first started drilling in the North Sea, just finding and lifting a barrel of oil, never mind transporting it from the North Sea, was $30 a barrel. That's why there weren't many North Sea platforms. The technology got better and the finding, lifting and platform costs all are now about $7 a barrel. The technology got better. Tar sands, coal liquids and even oil shales will probably follow the same trajectory in time. That is why you are talking about thousands of billions of barrels-equivalent of oil in coal and similar hydrocarbons.

Question: We are on a trajectory to more nuclear energy. How long will uranium last, and what's beyond that using other technologies and fuels, like thorium?

Mills: Essentially the question is about the fuel supply for nuclear power, if we start expanding it, how much uranium is available and thorium. First, to get the amount of uranium, measured in barrels of oil equivalent, add another zero to the hydrocarbon numbers, just on conventional uranium that we know of in easy-to-find fields. So we are in centuries. And I would contend that since we can't make policy for decades, centuries are not relevant.

A long time ago I had colleagues who were exploration geologists in northern Canada looking for uranium. They typically would come home after two weeks. This is the case with most resource companies; you tend not to spend money proving your reserve once you get to a proven ten or fifteen year forecast. They would find another five or ten years' worth in two weeks and come home. Most of northern Canada is radioactive; it's pretty hot. Do you remember the big Soviet nuclear satellite Kosmos 954, when it crashed and splattered in northern Canada? It was the biggest nuclear reactor that we know of, at least that is not classified, that was ever put up in orbit. It splattered itself all across northern Canada. The first problem they had finding all the debris, seen from overflights, was that the background was so radioactive that picking up pieces required better spectrometers to see fission products instead of the radium and uranium. Uranium supply is a non-issue. If we get to fusion, and that is science fiction still, that puts the energy resource number into infinite domains that have no meaning. The tar sands of Canada have over two thousand billion barrels of oil. I don't know who you want to buy from, but I know who I would pick, just in terms of geopolitical stability. But the fact is the Middle East has a lot of pricing power. Their lifting and finding costs are between fifty cents and two bucks, depending on whose numbers you believe. That is a lot of pricing power. All you have to do is drive the prices back down to ten or eleven dollars where they were in 1999 and you could be writing negative numbers against hundred billion dollar operational investments in Canada in a few years.

Question: Do you think there is enough capacity in the Middle East to drive the prices back down?

Mills: That's a good question. The price of oil today – and this is just my opinion – is being heavily driven by traders. All inventories worldwide are higher right now than they were a year ago, the real inventories are higher everywhere, production is higher, so there is more oil moving around the world today. There is more production, there is more absolute refining capacity on the planet, and there are more finds. The prices are spiking because of traders, nervous markets, and of course geopolitics. One could spook the traders in the other direction. That is what you do, both legally and illegally on Wall Street, and in the international markets. One can spook the traders, if they think prices are going to hit a crater again. I still have my copy of *National Geographic* from 1980; the "Special Issue" on energy. They did another Special Issue just last year about energy again. I put them together to compare and contrast – they read like virtually the same issue. The 1980 forecast in National Geographic was that the price of oil would be $200 a barrel in the year 2000, in today's dollars. But in 1999 it became $11 and the traders really got spooked. That said, I doubt there's enough near-term production to drive prices back to $11. I think we are moving into a near-term era of slightly higher sustained prices. My guess is that a real sustainable price of oil is probably in the high twenties or low thirties now, rather than what it used to be for years, in the mid-teens. It is not material in a $12 trillion economy; it is material when people trade it up to $80 or $90. When I did a calculation of $120 a barrel, last year the Goldman Sachs analysts who work in this domain came up with their own analysis. I think they may have been stimulated to do their own calculations after hearing me put forward the $120 number on the Lou Dobbs show. They are much smarter economists than I am and they came up with $140 per barrel as the economic-impact equivalence to the last price peak in 1981, because the inherent resilience of the economy is just different. There was an article today in the *Washington Post* saying that oil has to be $100 to get everybody's attention. Maybe it does, but it won't stay there long. I would be short on oil, if I were a trader. But not short in a month.

Question: There are a number of conservatives who are critical of nuclear energy and say that it can't work without government subsidies. "Windmills for conservatives" is what they call nuclear power. I am curious about what your thoughts are.

Mills: Windmills for conservatives – I like that! The adage that politics makes strange bedfellows is nowhere truer than in the energy domain and energy politics. They are right. Nuclear power has a problem now because it is in a very difficult Wall Street dynamic because of the history. The history is recent enough and painful enough that it is hard to conceive in the United States of America, in the near future, that we will have much nuclear expansion viable without government support or intervention or something to stabilize what essentially amounts to regulatory risk, because of the experience post 1979.

I like windmills; I actually like how they look. I like big things and rotating stuff – maybe because I worked as a mechanic and raced motorcycles in my youth. Many people I know hate seeing a ridgeline filled with windmills. More importantly, fundamentally on a proper equivalent basis, windmills are expensive. They are inherently more expensive than nuclear power, if you compare apples and apples. But people like them so it will be easier to build them. You could build them in small increments. But to give you a scaling idea of windmills, because it is a very low-energy-density source, if we build windmills the size of the Washington Monument, which is the favored size of industrial scale windmills, 500 feet high with blades that are about 350 feet across, and we place them in a one-mile wide swath and put them every quarter mile (you can't put them too close together) and we went from here to Los Angeles and back, we still wouldn't replace *existing* nuclear power plants. An incredible number of windmills have to be built to be material and it is not going to happen. So build all you want.

Here is the deal with alternatives, whether it is wind, solar, cellulosic ethanol, anything. Do it all, throw money at it. I don't object to throwing money at alternatives so long as we target cheaper energy – energy equivalent to perhaps a price no higher than $50 oil. But still twenty or thirty years from now, there is no possibility that these alternatives will be 30 percent of America's energy. But let's say it is 50 percent – pick your number. The remaining question is still; where is the other half going to come from? We are going to have to drill for oil, drill for gas, build nuclear power plants, burn more coal. At some level, that reality hasn't sunk in that no matter what the growth rate of all this other stuff is, there is no arithmetic that can get you to be the primary source of America's energy. These alternatives just don't have high inherent energy density. You couldn't live on the earth if the wind were high enough to matter or the sun were intense enough. Just as a benchmark, the square inch of silicon that makes a Pentium consumes about 5000 times more electricity in a year than a square inch of silicon can generate if made instead in to a solar cell. It takes a lot of silicon as a solar cell to fuel one Pentium. That is because the sun is not too intense, fortunately, not that solar cells aren't efficient enough. These numbers, by the way, are not significantly different today than twenty-five years ago. You can "google" this; look at 1975 or 1979; nothing has changed on that front. Windmills are basically the same today as then, just a little cheaper.

Question: I am intrigued about the use of enzymes for ethanol production. Could you talk about that?

Mills: The biggest single wild card in biological carbohydrate fuel production is genetic engineering of enzymes, no question about it. Theoretically it is possible to produce an enzyme that would create alcohols that look more like gasoline than alcohol. I thoroughly believe that that will happen and I think that will unlock a lot of access to less fruitful land, such as switch grass and prairie grass. The problem is that even with that, you can't change the fact that of the photons coming into a pasture, only 0.3 percent of the photons are converted into carbohydrates. What we are looking for is some way to get those carbohydrates unlocked. If I can come up with a clever enzyme that can unlock them, and assume I can get it 30 percent efficient at unlocking them, which would be phenomenal, you are still left with the fact that you need a lot of land. That doesn't change. So my land numbers just assume it doesn't matter whether you are growing trees or switch grass. You use a little less land if you grow sugarcane in Brazil: so we'd require 500 times more land instead of 1,000 times more land compared to a hydrocarbon economy. Genetic engineering could help our ability to compete with Brazilian sugarcane. But their location on the planet will leave them an inherent advantage with carbohydrates and ethanol-based fuels cheaper compared to us. Still I am sure that will happen. If we can get 5 percent of our fuel from alcohol, 5 percent is five points. For me, that is fine, as long as it is cheaper. I want it to be cheaper than the oil, not more expensive. That is just my bias. Provided we keep the quantities small, I think we will get there.

Question: There is a technology today that is commercial. It is a concentrated acid hydrolysis technology and its economic cost is about seventy cents per gallon to produce ethanol. It doesn't require futuristic technology or dramatic development and it has been demonstrated in Japan by the equivalent of their Department of Energy. It is actually in the process of trying to come back to the United States. Its development here was prevented by the government.

Mills: A similar problem is the imported Brazilian ethanol. The seventy cents a gallon for production of ethanol has to be compared, not against what we pay for gasoline, but the production cost of oil. Seventy cents a gallon is about $30 per barrel. It barely meets the $30 per barrel hurdle. But in the real world, since tar sands are $12, if I am an investor, I am investing in the $12 production from the tar sands, not in the $30.

Question: But you are putting ethanol into your gas tank, not tar sands.

Mills: That is not my point; the point is that you are producing a raw fuel. The fact that gasoline has taxes on it and is whipsawed by traders is a result of the fact that we use lots of it. If we use lots of ethanol, I promise you that it will be whipsawed by traders and it will have taxes on it. It is when it is a trivial amount of fuel that we have the luxury of pretending its price is seventy cents a gallon and gasoline is three bucks a gallon. Gasoline is not three bucks a gallon; the inherent resource cost of gasoline is about twenty cents a gallon or less than that actually. The fact that we are willing to let markets do what they are doing is normal; it is a big commodity and a lot of it is in trade. You can't compare – though people do all the time – the isolated raw-production cost of fuel A to the delivered gasoline cost in your gas tank. You have to compare apples and apples and at the same scales.

Question: Do you think it would change if you have environmental offsets, like you have environmental offsets like so-called greenhouse gas offsets?

Mills: Without getting into my opinion about greenhouse gas offsets, or any offsets for that matter, let me just state again that those are known in traditional economic theory as intrusive regulations or sumptuary laws. Congress is allowed to do that; it does it all the time. It doesn't change, though, the economic fact that there is three dollar a barrel alcohol and ten dollar a barrel oil in the correct apples-to-apples comparison. If you say you happen to like the alcohol from farmers and not the oil from the Arabs, that is okay and you can artificially pump one up. But it doesn't change the fact that it is inherently more expensive; it doesn't change the fact that it uses a thousand times more land. It doesn't change that fact.

Question: But you're arguing against yourself because the GHG benefit of alcohol is different. You have racecars that run on alcohol that have an entirely different combustion mechanism than hydrocarbons.

Mills: The absolute difference between alcohol and gasoline in the scheme I am talking about is nominal; it is not huge.

Question: I know the emission benefits for greenhouse gases; there are differences.

Mills: Once you move into the externality domain and you start to find external benefits, you move from science into policy and into some gray territory, which I stipulate again is Congress' purview. But it is a much more fuzzy science, I promise you. That is why we have more debates about the putative benefits.

Question: The challenge is to find enough arable land that can be used without irrigation.

Mills: Arable land is sort of a code word for lots of water and lots of fuel because you have to get lots of fertilizer. Water is a factor, absolutely. If you happen to be in Brazil you can get it free, but if you are here, you have to irrigate it. To use your externality argument, food-based alcohol fuels are net bad for the environment. All the metrics coming in are just ugly. And you have far less control over them than you do with drilling oil wells, poking a hole in the ground and extracting oil. It is just unavoidable reality. Nothing is perfect, but using lots of land to make fuel is an ugly thing environmentally. There are lots of negative eventualities that we don't regulate or care about because it is a minor industry; when it becomes a major industry, and I think we will make it a major industry, we then will regulate it similarly, and properly so.

Question: Where is nuclear power on the cost schedule? Where could it be if we had cookie-cutter plants, no unique, handcrafted plants and ones that have the technology to shut down instead of melt down if something goes wrong?

Mills: Nuclear power has such inherent advantages that with all the stipulations, if you standardize new construction, it is one of the lowest-cost forms of electricity we can conceive of, just on those metrics. All the costs are in what are called the soft regulatory and social areas and the variables. Most nuclear plants that operate today that have been nearly fully amortized – I am sure you know this – are operating anywhere from half a cent to one and a half cent a kilowatt-hour. The only things that are cheaper are fifty-year-old hydro-dams. Hydro-dams are now more expensive than nuclear plants, probably because of what is available to dam up in America, but also partly because of regulations on what we permit to be built. In the grand scheme of things, the higher-density fuels are always cheaper. In the reality of things, we can create incredible distortions to make things more expensive. The criticism that conservatives have that nuclear power requires government support is probably true. I think it is going to be very tough for America to expand its nuclear capacity without government support. I was a Reagan White House guy and I am not for government intervention, but I think if you recall, while Reagan policy did oppose government intervention, there were exceptions. You just have to look at reality. It shouldn't always be the first reflex, but I have to say, knowing what Wall Street thinks about this, its going to be very, very tough to get standardized nukes going in America for some time.

I think nuclear is inevitable, but the U.S. has an advantage over many countries. I did an analysis and a brief for the nuclear industry some fifteen years ago and presented an engineering analysis comparing a zero-emission coal plant to a nuke. One can build a zero-emission coal plant; the chemistry is not magic, like cellulosic ethanol. My contention was simple: if we could do that cheaper than a nuke, then we will build a coal plant, because we have lots of coal. And in fact it has happened; we have increased our coal burn since Three Mile Island by four hundred million tons a year. We cancelled nuclear plants equal to four hundred million tons of coal burn, a one-to-one swap. For twenty years prior to that we did the reverse; we were building nukes to not burn coal. Our energy policy fundamentally was to reverse that for two and a half decades. I think that is what we will do, by the way, for the next decade or two: we will burn more coal because we will need the electricity. We will not pursue natural gas primarily for the next cycle of power plant construction – that I am very confident about.

Question: Aside from public opinion, which is a big factor, and costs, what are the other impediments to nuclear power?

Mills: Well, everyone says nuclear waste. That is a barrier, because it is a public perception, but it is not a technical barrier. I don't want to get on a tangent on that issue. There are no barriers to building more nuclear plants except the regulatory public environment we are sitting in. It is not difficult to conceive of building small nuclear plants, big ones, small ones, modular ones; there are lots of options. Andy Kaydak, who was the president of Vermont Yankee and is now a professor at MIT, has been working with the Chinese on next-generation high temperature gas reactors. There are no barriers technically.

Question: Are you following the IGCC technology? What do you think about the concept?

Mills: IGCC, for those of you who don't know, is Integrated Gas Combined Cycle, which is a clean way to burn coal. If you look at companies that have built IGCC plants, what they will tell you is that it raises the cost of electricity by 20 percent or some modest number. I think our economy will be very tolerant to paying 20 percent more for electricity to have coal burned more cleanly in new plants. It is certainly a viable technology. I don't think anybody wants to burn coal dirty today. (I don't know about fifty years ago.) It is not prohibitively expensive and I think that is going to be a lot of the new coal construction. It may be cheaper than further scrubbing.

Question: You identified a trend of relying more on electricity than on oil. Does that indicate we are moving toward a climate where our energy policy can be decoupled from our foreign policy?

Mills: The answer is yes, if the policies are dictated by the perception that our strategic interests are tied to where we buy our fuel, not to where other people buy their fuel. We get essentially all of our electric fuel domestically in North America. The electric grid is fueled by domestic fuel sources, 95 or 98 percent. If we keep electrifying, we can produce our energy domestically. But if we 100 percent electrify everything and make hydrogen from nuclear power plants electrically and fly our aircraft on hydrogen, if the United States buys and uses not one drop of oil, I don't think that changes the geopolitics and our interests in world events, because no one else will be able to afford that. In the timeframes you are talking about, the next several decades, that will be a very expensive policy. With our $12 trillion economy, we have the money; we can afford to devote more of our money to raw energy and fuel purchases. We could do it in principal, but that doesn't change the Middle East oil or change the fact that China, India, all the Stans, Indonesia are going to be buying oil, because oil is an incredibly useful fuel, especially for developing nations. Yes, it disconnects us and puts us one step further from oil. The more important part is that it means that the economy is more resilient to the nature of our primary fuel sources, since you can make electricity any way, from windmills to burning trash. It means that if buildings are electrically powered, you don't care how the electricity is made, except in terms of price. You are using the same equipment. Nothing is required for you to fuel-switch the economy. That adds a lot of resilience to the economy. We fuel-switched, by the way, during the price spike from 1979 to 1983. Electric utilities dramatically decreased their consumption of heavy oils and increased their burn of coal during that several year period because they could very quickly fuel-switch and crank up the coal burners. It didn't change the supply of electricity and it took some pressure off short-term high prices at the time.

Kueter: Thank you very much.

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