Energy Policy for American Leadership in the 21st Century

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THERE ARE THREE BROAD and immutable trends that should anchor American energy policies in the realities of our 21st-century circumstances. First, the world's populations and economies are getting bigger and more interdependent. Increasing world trade increases petroleum's geopolitical importance because oil supplies 95% of the energy used to move goods and people. Second, urbanization and ever-deepening societal dependence on digital systems are accelerating. These two trends increase the importance of electric-grid reliability and security in the face of natural disruptions and rising threats of both physical and especially cyber-attacks. Third, the astronomical scale of prospective global demand for all kinds of goods and services will create unprecedented stresses on land use and environmental conditions, calling for radical advances in basic sciences and not just incremental improvements in existing technologies.

Even the energy forecasts with the most aggressive expectations for rapid alternative energy growth see hydrocarbon use rising substantially and continuing to dominate overall supply. Thus, over-arching policy frameworks to meaningfully address these core future realities should do three things.

First, they should re-orient oil and natural-gas policies to capitalize on the economic and geopolitical opportunities from facilitating an American shale 2.0 revolution. The U.S. should develop policies — and mount dedicated trade missions — to support and accelerate the export infrastructures and abilities for our thousands of small and mid-sized oil and gas companies to compete in a low-price world. Niall Ferguson, Harvard professor and historian, has observed: "There are deleterious consequences if the leading power in the world abdicates its leadership role."[1] America now has a generational opportunity to take a leadership rather than subservient role in a key aspect of global geopolitical stability.

Second, they ought to re-focus electricity policy around the primacy of security and reliability to reduce exposure to physical and cyber threats. Cyber-attacks across all sectors have been growing at a 60%-per-year rate; there has been a similarly rapid rise in attacks targeting America's electrical and physical infrastructures. A physical cyber-security framework is needed, which moves at the speed of innovators and not of bureaucrats. Vinton Cerf, Google's VP and Chief Internet Evangelist, recently and correctly noted: "[A]s dependent as we are on communication technology, we're even more dependent on electricity."[2] Information technology can be used to help secure the grid; it should not be (even if advertently) used to make the grid more vulnerable.

Third, they should restructure federal research funding towards a focus on basic science — new "miraculous" technologies won't emerge from subsidies or corporate welfare where the Department of Energy spends money on industrial-class projects best left to industry. Federal support for basic science is waning not growing; that should be reversed. Bill Gates recently called for a tripling of basic research at DOE to pursue the long-term breakthroughs needed: "[W]e need innovation that gives us energy that's cheaper than today's hydrocarbon energy, that has zero CO2 emissions, and that's as reliable as today's overall energy system. And when you put all those requirements together, we need an energy miracle."[3] Radical transformations in technology are hard to predict and impossible to order-up, but they inexorably emerge from a healthy curiosity-driven basic science enterprise.

THE MORE THINGS CHANGE . . .

With an energy-costly war behind us, a reevaluation of the world's and the nation's energy resources was timely . . . with the probability of long-continued international strain — or worse — and fiercer international competition for energy.

— From the April 12, 1948 meeting of the American Petroleum Institute[4]

Energy is fundamental to the operation of everything in society from propelling vehicles to powering the internet, from growing grain to growing silicon ingots, to illuminating TV screens and rooms. While energy policies over the stretch of modern history have been driven by geopolitical, economic, and social interests, all possibilities are ultimately bounded by the physics and, derivatively, engineering realities of energy.

The fundamental energy sources available to power society have remained essentially unchanged for 75 years. The idea, often articulated now, that there are "a multitude" of new energy options to satisfy society's needs is rhetorical hyperbole. There is no new physics in energy. And there are no new energy sources, just better ways to use those that exist.

The newest addition to the phenomenology of energy production dates to the 1954 invention of the solar-electric cell at Bell Labs, followed by the first megawatt-scale PV station built in 1982 in Hisperia, California. Nuclear fission was demonstrated in 1939 and the first power plant completed in 1957 at Shippingport, Pennsylvania. Oil and natural gas reach back a century and a half, coal's history is storied, and water and windmills as sources of energy date back to the Middle Ages (indeed in some respects to pre-history), with the first megawatt-scale wind turbine built in 1941 in Vermont.

The most remarkable new, and unpredicted, change in the energy landscape has been the rise of shale technology. Oil and gas production from shale fields has added 400% more to the U.S. energy supply in the past decade than solar and wind combined.[5] And that rapid and unsubsidized growth in shale hydrocarbon production contributed more than $1 trillion to the U.S. GDP since the end of the Great Recession and thus played a disproportionate role in keeping America from sliding back into negative GDP territory during the long recovery.[6]

In economists' terms, shale technology has been a beacon of success by achieving astonishing productivity growth in an economy where that key growth metric has been otherwise lagging for years. Federal policy played only a minor role in the shale revolution by providing some valuable (though relatively modest) R&D funding to shale pioneer George Mitchell's company in the late 1990s. But it was a role that nonetheless offers lessons relevant to framing future energy policy.

Presidents are remembered for many things, and energy-related policies, while frequently important, rarely dominant presidential histories, except at pivots in history that are usually driven by geopolitical events. In that regard, the two iconic energy-related historical pivots thus far were President Eisenhower's "beating swords into plowshares" with his "atoms for peace" following World War II and the discovery of nuclear fission, and President Nixon's emergency measures (amongst them the ignominious national imposition of the wildly unpopular 55 mph speed limit) in reaction to the epoch-setting 1973-74 Arab oil embargo that created gas lines and shot petroleum prices up 300% nearly overnight. No other events or policies of similar moment have occurred in modern history.

It is possible that another energy-related pivot in history could take place during the term of the next president if, for example, policies were enacted to facilitate the return of America as a geopolitical petroleum power. Or, on the other side of the equation, we could see an historical pivot if polices are enacted that increase the prospect for and result in a bad actor's successful cyber-attack on an American city's power grid. Either of these potential events entail significant geopolitical fallout.

But if the next president wants to shape events more than be shaped by them, a few key facets of energy innovation policy must be kept in mind.

THE WORLD AS IT IS

It is nearly impossible today to discuss energy policy without confronting the global-warming issue. Consequently, essentially all energy-policy proposals and debates can now be divided into a basic philosophical difference between two camps. On the one hand there are the ideas that seek to deal with the energy world as it is. On the other, there are those aspirational ideas and proposals that seek to reshape the energy world into what it should be to conform to a certain vision.

The energy world, as it is today, can be distilled into these essential facts: 85% of global energy needs are met with hydrocarbons.[7] Technology has steadily, even radically expanded access to hydrocarbons at ever-lower costs. Over the past two decades 80% of the net additions to global energy supply came from hydrocarbons.[8] The emergence of American shale oil and gas has been the single biggest change on the global energy landscape in decades.

Then there is the aspirational energy world — a world as it "should be" rather than as it is today — one that needs to become utterly free of hydrocarbon use. The "aspirational" worldview is animated by an expectation that adding more carbon dioxide to the atmosphere from burning hydrocarbons will cause not just somewhat undesirable but potentially catastrophic changes to the planet's climate.[9] An energy future devoid of hydrocarbons must overcome the following: All renewable energy sources collectively comprised just over 10% of net additions to global energy supply in the past two decades.[10] And this comes after two decades and roughly $1 trillion dollars of global subsidies so far.[11] Serious analysts, as opposed to aspirational advocates, have universally concluded that there are as yet no viable means to completely replace hydrocarbons at the cost and scale society needs.[12]

The two worldviews are not incompatible in theory. The first is the reality of today, where the second is aspirational. The key issue is the timeline. Energy policies potentially compatible with both worldviews are thus at odds regarding priorities. Conflicts and costs arise when policies seek to radically expand or accelerate our pursuit of the hydrocarbon-free aspirational worldview and ignore economic and derivatively social and geopolitical realities. In essence, the disputes distill into to whether policies establish as a priority the economic, employment, and social benefits from cheap energy, or force on society far higher *known* energy costs *today* in order to minimize putative *theoretical* costs that may arise in the *future* from carbon-dioxide-induced climate changes.

Reconciling the two worldviews is made difficult, if not impossible, by hyperbolic rhetoric and claims of an imminent or inevitable global apocalypse. The framing of energy policy is thus reduced to trading the actual welfare of people today (eliminating cheap energy) for the theoretical welfare of people in the far future. The only way this conflict could be mooted would be if non-hydrocarbon energy were in fact cheap, which it most certainly is not.

In a framing typical of the energy aspirational worldview, leading environmentalist Bill McKibben writes that companies and policies that support hydrocarbons are "helping push the planet over the edge and into the biggest crisis in the entire span of the human story."[13] Accepting such a proposition doesn't leave much room for debate never mind compromise with regard to taking actions that could avoid such a calamity.

McKibben is far from alone in using such apocalyptic rhetoric, though he is one of the more articulate and effective campaigners for the proposition of completely abandoning hydrocarbons. News stories, studies, and proposals commonly use language invoking the "health of the planet and the survival of its natural systems."[14] One campaign pursuing oil companies as "climate culprits" claims policies and businesses that support hydrocarbons have "pushed humanity (and all creation) toward climate chaos and grave harm."[15]

The apocalyptic thesis has been gaining far more visibility in recent years, though it has been around for decades. Twenty-five years ago, the then-secretary of state of Brazil said: "The specter of global warming unites humanity in a common task."[16] In the same vein, U.N. Secretary General Ban Ki-moon called the 2015 Paris climate agreement "a monumental success for the planet and its people."[17] A poll of global business and political leaders attending the 2016 Davos confab found climate change ranked as the number one concern for the first time, ahead of regional wars, weapons of mass destruction, pandemics, and water shortages.[18] It's notable that this ranking stands in stark contrast to general public opinion, which ranks climate at the bottom of a long list of concerns.[19]

For a significant proportion of both U.S. and foreign policymakers and policy influencers, global warming does in fact take precedence over nearly any other consideration. Consequently, we are told that climate solutions will require "new supra- and transnational institutions," that there is an urgent need to "transform world economies,"[20] for mandates "for global governance of energy," and for policies "limiting final energy demand."[21] Indeed, for some, a climate-centric energy policy requires challenging the very nature of the American government: "We need a new conversation about the appropriate role of government" and the "weakness of the original Articles of Confederation, in the structure of the U.S. Constitution." Advocates of the apocalypse thesis believe there is an "unreasonable reliance on free markets."[22] Recognizing the implications of such an assertion, they are quick to assert: "We have to reject the canard that addressing climate change threatens our liberty."

In a climate-at-all-costs worldview, energy policy will leave liberties in place, but they will just be constrained by very different and far more limited energy choices and (much) higher energy costs. "For the climate accord to work, governments must resist the lure of cheap fossil fuels in favor of policies that encourage and, in many cases, require the use of zero-carbon energy sources. But those policies can be expensive."[23]

A new formulation for energy policy has thus emerged and is gaining traction. The proposition, in a nutshell, is that theoretical calculations of putative *future* costs relating to theoretical future climate consequences trumps *all* other cost considerations in meeting *today's* energy needs. Period. The argument is that the key to the very survival of civilization requires that society completely and rapidly replace anything that resembles traditional energy policy, and even traditional structures of governance and national sovereignty.

The climate forecasts, of course, are all based on computer projections associated with the indisputable fact that carbon dioxide *is* being added to the atmosphere from burning the hydrocarbons that supply 85% of the world's, and America's, energy.

It bears noting that carbon dioxide occupies a unique place in the pantheon of "pollutants" since it is an essential nutrient for all flora on earth without which there would be no life. The climate-science debate is not about this irrefutable fact. A higher carbon-dioxide concentration, for example, enhances plant growth and is used as a technique in commercial greenhouses. (A reality many cannabis growers have eagerly embraced.)[24] And there is no dispute over the fact that mankind's emissions of carbon dioxide must be evaluated, keeping in mind that the earth's natural annual flux of carbon dioxide is 20-fold greater than civilization's contribution.[25] The debate is about whether or not humans are creating some critical and catastrophic concentration that constitutes a tipping point in an ostensibly delicate and perfectly balanced planetary system.[26]

The climate apocalyptics are nothing if not breathtakingly ambitious. But we find that actor Leonardo DiCaprio may have most succinctly and accurately summarized the prospects for the kind of transformations proposed. In a recent interview about climate change, DiCaprio concluded: "Are we going to come together as a world community? Are we going to evolve as a species and actually combat this issue? The human race has never done anything like that in the history of civilization."[27]

One needs no knowledge about or position on the veracity of extreme claims about the future climate to know that there are two things the human race has never done, ever, in history: Come together as a world community, whether voluntarily or by coercion, for any reason, much less to form the kind of world governance imagined by the climate apocalyptics; or allow a sustained trajectory toward deliberately more expensive energy.

Thus, insofar as U.S. energy policy is concerned, the issues that matter can be reduced to one central question: Given that world governance over energy, or anything else, will not happen, and that there is no magic wand to make non-hydrocarbons radically cheaper any time soon, what policies make sense in the energy world as it is?

SCALE AND DEMAND

Religious zeal and moral certainty have frequently plagued American politics. To be sure, such fervor helped sustain the civil-rights movement itself in its darkest hours. But since the 1960s, these tendencies, and the rigidity and inflexibility associated with them, have become pervasive and institutionalized. And in our decades-long debate over immigration, these political dynamics have encouraged immigration advocates to not take their opponents seriously, indeed to cavalierly dismiss them.

Physics dictates that energy is essential to everything that makes life and society possible. This means, *a priori*, that energy policies reach into and affect every aspect of society. And, unlike climate models and forecasts, the physics of energy and the engineering economics of energy systems are both clear and dispositive.

The energy equivalent of ten gallons of oil are needed, for example, to fly or drive one person about 300 miles, or power one lecture hall for one hour, or produce the beef for 15 hamburgers, or deliver 100 GB to a smartphone. The annual consumption of these kinds of activities is measured in the billions and trillions of air and road miles, lecture-hall hours, pounds of food, and gigabytes.

In general, three activities account for nearly all energy consumption: transporting people or goods, consuming or using goods (food, housing), and consuming data. The first is utterly oil-dominated (95%), and the second is largely electric-dependent (65%). The third category — information-communications technology (ICT) — used little to almost no energy until recent history and is now nearly entirely electric-dependent.

The ICT ecosystem is now not only a major driver of economic growth, but it has also become a significant energy-consuming sector in its own right. Global ICT activities today use more energy than global aviation.[28] In different terms, since ICT energy is almost exclusively consumed as kilowatt-hours, global ICT now uses more electricity than that produced by the entire grids of Japan and Germany combined. This calculus excludes, by the way, the energy cost related to manufacturing info-tech products.[29] Digital-centric products require roughly 1,000 times more energy per kilogram to manufacture than the materials that dominated the 19th-and 20th-century economies, and the world produces tech products by the megatons per year.[30]

Because of energy's profound importance, energy policy has traditionally focused first on issues of security, reliability, and cost. For nearly all of human history, obtaining adequate fuel and food consumed most of a nation's or a family's income, a condition still true for much of humanity today. In the U.S., however, the cost and availability of energy is no longer a primary economic worry. This has been a monumental technological achievement. Even at $100 per barrel oil (an episodic price that has never lasted for long), spending on all forms of energy combined accounts for less than 10% of America's GDP.

But while energy costs have receded into the economic background, the absolute consumption of energy has not. The relationship between economic growth and rising energy use is long-standing with no evidence of a de-linking at the global level.[31] As economies and populations continue to grow, now accelerated by the efficiencies from the still-widening ICT revolution, global demand for energy will rise. Most of the people in the world today live in energy poverty; billions have no car, little or no electric illumination, no internet connection, and no air conditioning. The potential world electric demand to run residential air conditioning is 45 times greater than that used for the same purpose in the U.S.[32] And both global air-miles and road-miles are forecast to more than double in the next two decades.

Thus it's unsurprising that every respected forecast reaches roughly the same conclusion: World energy demand over the coming two decades will rise by the equivalent of adding another United States worth of consumption. Even though energy demand is expected to grow far more slowly in the mature economies of the U.S. and Europe, such growth is on top of a base of already enormous consumption. Thus there will inevitably be increasing competition for, or opportunities to supply, more energy to meet rising global needs.

From the "world as it is" perspective, the policy challenges necessarily involve how to ensure a reliable and low-cost supply of energy to keep lights and computers on, cars and planes moving, and factories and homes humming. For the aspirational "world as it should be" posture, the focus is first on how to use fewer hydrocarbons everywhere.

The latter worldview was for years reinforced by the Malthusian conviction that oil and gas were severely limited resources and that coal simply was too old and too dirty to use, regardless of its abundance. The fact that modern clean-coal technology can make the extraction and combustion of coal far more environmentally acceptable for all of the relevant and regulated effects considered in policies of the past half-century is in the aspirational worldview now obviated by concerns over carbon-dioxide emissions. In that worldview, even low-cost clean coal is unacceptable.

Low-cost oil and natural gas are also unacceptable in the aspirational worldview. Now that oil and gas are obviously abundant, the aspirational energy worldview has adopted a keep-it-in-the-ground posture. And, since the aspirational worldview has had to surrender its idea that alternative energy forms can become quickly cheaper than hydrocarbons, in order to convince (or force) society to avoid using abundant, low-cost hydrocarbons, policy positions now focus on a combination of continued or expanding subsidies together with the imposition of new taxes on hydrocarbons.

The carbon-tax argument has been successful at gaining some bipartisan support, in part as a way to thread the needle to avoid the global-warming debate, and in some cases as a way to engage a political trade for reducing middle-class income taxes. The challenges with a carbon tax reside in economic reality: Because 85% of all U.S. and global energy supply comes from hydrocarbons, by definition a carbon tax will be highly regressive, affecting lower-income citizens the most (in relative terms). The tax code would have to be used to offset "unfairness" — the effect of which will mean little if any reduction in hydrocarbon energy demand, since unwinding the regressivity will just keep energy cheap for the segment of the population where the potential to influence demand is most significant. But if it were implemented in a "progressive" way, the carbon-tax burden would fall mainly on the wealthy where energy-use behavior is far less sensitive to price because energy is such a small share of spending.

Subsidies in one form or another are the preferred virtual taxation method for overcoming the economic disadvantages of non-hydrocarbon energy. America's wind and solar tax credits and subsidies were extended at the end of 2015 (in a political exchange for the elimination of the ban on exporting American crude). Subsidies of course have significant costs, and at sufficient scale lead to overall higher costs for taxpayers. And, like carbon taxes, they are highly regressive. A recent analysis at U.C. Berkeley found that the aggregate $18 billion in U.S. subsidies provided between 2006 and 2014 for various alternative energy choices (electric cars, rooftop solar, and the like) have accrued to the benefit of the wealthy over the working class; the top income quintile received 60% of overall subsidies and 90% of electric-vehicle subsides.[33] In Britain, Germany, and Spain, where subsidies and credits for wind and solar have been more extensive and aggressive than in America, electricity costs have increased over 100% in recent years.[34] Energy subsidies are now under attack or in retreat in many European nations.[35]

The keep-it-in-the-ground movement has recently sought to promote the idea that today's hydrocarbon energy costs must include an "externality" fee or tax that reflects a future estimated cost arising from the theoretical consequences of more carbon dioxide in the atmosphere. This "externality" argument is not a new concept. But in this case it is just another tax with a new name.

The policy debates around subsidies and taxes will continue. However, from the broad perspective of forging national energy policies, the core issue is whether it is possible, at any cost, for alternative energy technologies to radically reduce, never mind eliminate, global hydrocarbon fuel use. It is here that physics and engineering establish clear boundaries.

THE CHALLENGES OF ALTERNATIVES TO HYDROCARBONS

Those advocating the aspirational worldview point to what they consider to be promising alternatives to the use of hydrocarbons in transportation and in the generation of electricity. None of them, however, can meaningfully reduce the use of accessible, low-cost hydrocarbons. With transportation, the problem is primarily scale; with electricity, the challenges are far more complicated.

The two main options for displacing petroleum used in transportation are biofuels and batteries. For biofuels, even setting aside the subsidies, the inherently high economic costs, and the environmental impacts (such as prodigious water use), the basic fact remains that with 40% of America's corn harvest now distilled into ethanol, farmers still supply under 5% of domestic transportation energy (or about 1.5% in global terms).[36] Even if every single kernel of American corn along with all Brazilian sugarcane were used to make ethanol for cars, the need for petroleum would not be materially altered.

Meanwhile, although global biodiesel production rose 400% in the past four years, it remains far more expensive than ethanol, never mind petroleum, and displaces less than 0.1% of world oil use.[37] Even an unaffordable 100-fold increase in biodiesel use, which no serious analysis forecasts or anticipates, would be strategically irrelevant.

Then there is the promise of electric cars, for which the technology has improved radically in the past decade. There is no doubt electric vehicle (EV) sales are on track to grow substantially as batteries continually get better. Indeed it is likely the U.S. will, in due course, exceed by ten-fold President Obama's 1 million electric-car goal, (though it won't happen until long after the original target date). But even that will displace less than 10% of U.S. petroleum use.

In the carbon-free vision for EVs, the electricity would need to come mainly from windmills, the least expensive non-hydrocarbon alternative (other than conventional hydroelectricity of course). A barrel-equivalent of energy is produced by a wind turbine once per hour, while a shale well (which costs roughly the same to create as a wind turbine) produces an actual barrel of oil every two minutes. And, to be useful for vehicles, one needs storage, and it takes about $400,000 worth of Tesla-type batteries to store a *single* barrel's worth of wind electricity.[38] Even if batteries become twice as good as they are today—which is not on any production roadmap—that still won't overcome such enormous economic and physics disadvantages. Such huge disparities can't be hidden by subsidies for long.

The inherent characteristics of the molecules used to store energy determine what engineers can accomplish for transportation. Pound for pound, the chemicals comprising gasoline store at least 40 times more energy than the best chemicals in batteries. Pounds matter in all transportation, and they are utterly determinative for aviation. Liquid hydrocarbons are not just denser but also are remarkably safe, and easy to store and move. In biofuels and synthetic chemistry, the essential goal is to invent a synthetic, organic, oil-like molecule at the same or lower cost as a "natural" one from hydrocarbons.

The disparities in theory are revealed in practice. Batteries are also consumed (i.e., they have a finite useful life), albeit more slowly than oil. If the battery cost is amortized over its useful life and calculated in terms of the cost per fill-up, then driving 200 miles in an electric car uses about $5 of electricity and about $50 worth of the battery. It's the inverse for a gasoline car, in which 200 miles uses $15 of gasoline but $0.25 of the amortized cost of the steel fuel tank. This does not obviate the potential for significant applications for EVs in dense urban markets; it just means that even batteries twice as good as those of today are not going to displace a major share of transportation fuel for the foreseeable future.

It is somewhat more difficult to summarize the challenge with displacing hydrocarbons in the production of electricity because of the idiosyncratic physics of electricity. Unlike the transportation sector where there are precious few options at scale, there are many ways to make electricity. The key issues around the grid, while ultimately about costs, originate with a critical singular fact about electricity: nearly all kilowatt-hours consumed need to be generated at the instant they're used. This is not the case for any other energy form (nor for practically any other product in our economy).

On average, there are months' worth of annual national demand in storage at any given moment for every key commodity from oil and natural gas to grains and metals. Electricity is the exception. The total amount of electricity stored at any given moment in all the batteries in the market for all purposes is countable in minutes — there is not even a day's worth of national demand in storage.

The technical and economic issues around the electric grid are and will be vigorously debated and now litigated (shortly, at the Supreme Court) because of the Obama administration's 1,560-page Clean Power Plan (CPP).

The CPP lays out a roadmap, consistent with the aspirational worldview, which will require national electric supply to radically reduce the use of hydrocarbons and increase the use of wind and solar power. The costs arising from the CPP will of course be relevant to state decisions; national average electric rates have been rising since 2005, reversing an earlier 25-year trend of declining rates.[39] But cost aside, the central practical challenge for wind and solar is the self-evident fact that neither can produce energy continuously.

There are two critical technical aspects to the episodic nature of wind and solar: capacity factor and availability. To use automobiles as a stand-in for electricity, "capacity factor" measures how often a car engine operates. "Availability" is the probability that the car will actually start when needed. Both features have practical and economic relevance for electric grids.

Capacity factors determine the inherent economics of a power plant. Wind turbines have low capacity factors compared to conventional power plants: a megawatt wind turbine delivers one-third as much energy as a megawatt gas turbine.[40] Solar electric facilities are similar. Simplistically, three wind or solar megawatts of capacity are needed to equal the energy produced by one megawatt of gas turbine capacity. (The exact ratio depends on the wind or sun conditions at a specific locale.) This means that it is entirely inaccurate to claim a solar or wind plant with a capital cost per "nameplate" megawatt equal to a conventional power plant has achieved what is termed "grid parity." Grid parity is achieved only when both capacity *and* availability are taken into account. And even if you build extra wind and solar capacity, that extra capacity is worthless if it's not *available* when it's needed.

In order for the grid to deliver power continuously and nearly instantaneously following normal daily and hourly demand cycles, and in the face of inevitable challenges (plant failures, weather, and the like), operators must have access to unused capacity that is *available* to be called upon — or "dispatched," in utility jargon — any time. Wind and solar have not only low *average* availability compared to conventional power plants but, more important, zero availability for many hours at a time every day — periods when, for reasons of weather or time of day, wind and solar can't be dispatched. (There are other important technical issues to consider as well, including those relating to maintaining grid stability.)

Today, 90% of America's power comes from highly available sources: A total of 65%, roughly equally split, comes from coal and natural gas, 20% from ageing nukes, and 5% from big, old hydroelectric dams.[41]

It is availability that matters when it comes to the engineering challenges, and derivatively the economic challenges, of keeping a grid continuously operating and stable. To return to the automobile analogy: If an individual car is not available, one is forced to borrow, rent, or catch a ride in another that is available. That's how solar and wind successfully operate on the grid today. For example, in Iowa, the nation's second biggest wind-producing state, coal still produces 50% of electricity.[42]

The standard answer to managing the wind and solar availability challenge is to propose greater use of batteries, transmission, and the internet (the latter to control demand).

Lithium batteries in particular have become far better and cheaper and are widely touted as the solution to storing grid-scale amounts of energy. But to illustrate the challenge of storing electricity at the grid-level, consider the enormous $5 billion Tesla battery factory under construction in Nevada — the so-called "gigafactory."[43] Once completed (if completed), it is slated to produce more than all of the world's existing lithium-battery factories combined — a quantity of batteries each year that can store 30 billion watt-hours of electricity.[44] The U.S. economy uses about 10,000 billion watt-hours every day. Thus, it would take more than 100 years of production from the gigafactory to produce enough batteries to build storage capable of holding one-third of a day's electric demand for when the wind or sun are not available. This says nothing about the high cost or short lifespan of batteries, which can be counted in years rather than the decades needed for grid-scale power systems.

More transmission is another solution for the low-availability problem for wind and solar power. Since it is (almost) always windy or sunny somewhere on the continent, perhaps we could simply build a big enough grid and enough extra capacity everywhere. But the economics of this option are inescapable: Every extra $2 million-per-mile of long-haul transmission built to offset a low-availability source is a *de facto* additional cost of that source. This says nothing about the need to spend capital on excess wind and solar capacity so that it is available for long-range sharing, and the collateral reliability challenges for a far longer grid.

The other solution for the episodic nature of supply from wind and solar is to use modern information technology to encourage (or force) matching episodic reductions in demand — so-called Demand Side Management (DSM). Utility DSM programs, dating back over a half-century, have long been used to encourage big electric users to shut down when grid demand peaks or supply is lost for any reason. DSM programs offer discounted "interruptible" rates for large consumers. That the internet now makes DSM easier is useful, but much of the easily harvested industrial savings have long ago been captured. What's left are consumers with minimal significant uses of interruptible demand, or many business operations that cannot be turned on and off. Data centers are one good example.

The bottom line is that, despite billions already invested in efficiency to stifle demand growth, and despite a devastating recession that did stifle growth, U.S. electric demand today is about 10% greater than in 2001.[45] That seemingly modest rise at the scale of America's grid represents a demand increase equal to Italy's *entire* electric grid. And despite depressed electric growth in recent years (almost certainly a hangover from the Great Recession and continued anemic GDP growth), the EIA forecasts at least another 10% rise in overall U.S. demand by 2030.[46] That increased demand will require adding capacity equal to Germany's entire current grid.

The challenge for states and state utility regulators will be that the CPP pushes planning toward power sources that will make the grid less reliable at precisely the time when modern society needs greater reliability.

The demand for "always on" power to keep the digital and information-centric economy lit has never been greater.[47] The share of the U.S. GDP associated with information — which is entirely dependent on electricity—is now three times bigger than the share associated with the oil-dependent transportation sector. Meanwhile, the average incidence of grid outages has been rising at an 8% to 10% annual rate since 1990.[48] And the duration of outages has also been rising by about 14% per year.[49] There is also increasing concern about grid cyberattacks, an entirely new class of risk. Aside from the social and human costs and inconveniences arising from electricity outages, the overall economic costs to the U.S. from outages are estimated at $150 billion a year.[50]

Finally, a brief observation with respect to another proposition offered within the aspirational worldview: Advocates of rooftop solar-battery generation suggest that the "old" utility model is due for "disruption" by distributed generation and "smarter" grids. It has become popular to assert in various ways that America has a 19th-century grid for a 21st-century world.

Yet just over ten years ago a seminal National Academy of Engineering report ranked the invention of the electric grid at the top of a list of the 20 greatest inventions of the 20th century—not just one of the great engineering achievements, but first among them all.[51] The Academy ranked the internet 13th. There have been no changes in technology that would suggest that today's electric utility model is "obsolete," despite popular media claims otherwise.[52]

In fact, the "utility" model, with its enormous, well-managed, low-cost central plants supporting distributed users, represents precisely the evolutionary direction for the ICT industry. Distributed, small data centers in businesses, industries, research, and academic institutions are rapidly giving way to far less expensive, more efficient, more powerful, and more massive central computing, connecting to users on a grid of glass and radio frequency "wires." The ICT community refers to this as the "cloud" architecture—functionally a synonym for the utility model.

The ascendant challenge for both electric and information utilities in the future will be ensuring reliability and security. A future electric grid that is both more expensive and less reliable will be economically destructive and politically toxic.

MOORE'S LAW AND 'MOONSHOTS'

A common response to all of the aforementioned observations about the limits to disrupting the status quo is to propose that the government launch the energy equivalent of the Manhattan Project or the Apollo

Program — a "moonshot" energy program. But fueling society is not like putting a man on the moon (or building a military weapon). It's more like putting *everybody on earth* permanently on the moon. The former was a one-time engineering feat; the latter would take miraculous technology. With time, advances in science do create the equivalent of miracles, but they are not common or predictable, and can't be summoned on demand.

There is no doubt there is much to be discovered, many new technologies yet to be invented and companies to be created. But this reality is frequently conflated in energy domains with a kind of "irrational exuberance" associated with the engineering prowess of Silicon Valley. To note just one iconic example: Vinod Khosla, one of the prominent and successful pioneers of Silicon Valley venture capital, made billion-dollar venture bets on biofuels, asserting in 2007 that "I have no doubt that 100 percent of our gasoline use can be displaced in the next 25 years."[53] He has since recanted. The world is nowhere close to seeing that goal achieved.

Khosla was not alone then, or now, in making such assertions. Many tech entrepreneurs still believe that "disruptive" energy innovation is imminently achievable. The analogy commonly offered is the "miracle" disruption of the legacy landline phone business with the advent of cell phones — or the disruption of taxis by Uber, or hotels by AirBnB. Oil "disruptors" believe, in effect, that the engine in a Pontiac can follow the same tantalizing technology trajectory as the Pentium in a laptop. The problem is that the physics of information doesn't translate into the world of energy.

Moore's Law — which describes the relentless and astonishing gains in computing power — has yielded technologies that do seem miraculous. Today's smartphones are more powerful than a room-sized IBM mainframe from 30 years ago.

The essence of digital-silicon technology is that more and more information can be stored and transported in ever-smaller ways that, individually, use profoundly *less* energy. On top of this, software engineers, enabled by increasingly powerful microprocessors, can use clever mathematical codes to parse, slice, and shrink information itself, compressing it without loss of essence. The combination is powerful. Compared to the dawn of computing, today's information-moving hardware consumes *one hundred million* times less energy for a logic operation and can store data in a physical space one million times smaller.

But in the world of atoms and aircraft, as opposed to algorithms and Amazon, the hardware tends to expand not shrink when more is needed, whether it's more speed or greater carrying capacity. The energy needed to move a ton of people, or heat a ton of steel, emerges from properties of nature with immutable boundaries dictated by laws of gravity, inertia, friction, mass, heat transfer, and the like.

A Moore's Law type of energy disruption isn't just unlikely, it can't happen with the physics we have today. If energy technology could follow a Moore's Law trajectory, today's Pontiac engine would produce a thousand-fold more horsepower and collapse to the size of an ant. Engineers *can* build ant-sized engines, but they produce 100 billion times *less* power than a Pontiac.

No amount of innovating will cause an aircraft or car engine to disappear into your wallet. Nor will the quantity of fuel needed to power it. And in the physical world there is no analog to compression software, the mathematical trickery that puts more information more efficiently into smaller spaces. Only in science fiction can you digitize, transmit, and then re-assemble physical objects or humans.

Such physical realities do not mean that Silicon Valley and information technology have no potential to make dramatic impacts on the energy landscape. But the changes and improvements will come from new materials, some that have never existed in nature (designed by supercomputers) and have radically superior control systems (the marriage of sensors, networks, and algorithms). There is enormous potential to wring far more efficiency out of physical and energy resources. But all these gains will accrue to all energy sources—including and especially to those that have inherent physical advantages.

For example, shale technology has provided over 100 times more energy supply to America in the past decade than has solar.[54] Measured in terms of energy produced per unit of capital spent, solar technology is about 300% cheaper now than it was 15 years ago. By the same measure, shale gas and oil rigs improved 300% in five years. Both will continue to improve. But the former (solar) has no known path to totally displace the latter (hydrocarbons).

Google engineers reached similar conclusions. Six years after launching a project to develop renewable energy that would be cheaper than coal (titled "R<C"), Google closed it down. The lead engineers made it clear their task was not physically possible: "Incremental improvements to existing [energy] technologies aren't enough; we need something truly

disruptive.... We don't have the answers. Those technologies haven't been invented yet."[55] Even the most climate-policy-centric forecasts for accelerating and subsidizing renewables see far more hydrocarbons consumed in all future scenarios.[56]

All of this is consistent with the position that Bill Gates has recently articulated in a high-profile set of interviews, lectures, and meetings. Gates concluded: "[W]e need innovation that gives us energy that's cheaper than today's hydrocarbon energy, that has zero CO_2 emissions, and that's as reliable as today's overall energy system. And when you put all those requirements together, we need an energy miracle."[57] Gates went on to clarify that he didn't view energy "miracles" as impossible, but that the options don't yet exist, and thus the single most important policy action is for a radical increase in support for basic scientific research.

GEOPOLITICAL REALITIES

The realities of what is possible in domestic energy policy have foreign policy and geopolitical implications.

Oil's centrality to global commerce is the reason that the 1973 Arab oil embargo—the geopolitical event that framed 40 years of American energy policy—shocked both the United States and the world. Following that embargo, the U.S. became increasingly import-dependent, and America lost the geopolitical petroleum power that it had enjoyed for the previous half-century. It is understandable that for the past four decades U.S. policy has been fixated on achieving "energy independence" through conservation and the pursuit of petroleum alternatives. But the world has changed. America is now far less import-dependent, while the world is now far more oil-dependent.

Consider the key oil-consuming changes since 1973: Global automobile use has increased by 300%; maritime shipping has risen over 300%; and global air travel has grown 700%. And oil fuels about 95% of all the transport of all goods and people. While one-third of the world's GDP was involved in trade in 1973, that share is now over 60%.[58] World trade and commerce are thus more oil-dependent than ever before in history.

Until recently, the OPEC nations and Russia were the dominant sources expected to meet rising global oil demand. The entirely unexpected emergence of America's shale industry not only doubled U.S. oil production, returning it to levels last seen 50 years ago and cutting imports by 60%, but it also accounted for three-fourths of the new global oil supply over the past decade. Even before the U.S. begins exporting crude and natural gas in quantity, American production already rocked markets, triggering price collapses for both fuels because a rapid decrease in imports glutted the markets—and the prospects for imminent exports from the U.S. triggered renegotiations of long-term contracts from traditional exporters. Next begins the re-emergence—after a half-century of absence—of the U.S. as a significant exporter of those hydrocarbons.

Shale technology has reversed America's geopolitical posture as a supplicant state to one with the potential to influence the global hydrocarbon trade. U.S. policymakers and strategists now have the ability to think in terms of restoring "soft" power as a vital option in America's arsenal, and as an alternative to the costs and risks of over-dependence on "hard" power in domains where energy geopolitics are in play.

This is happening at a critical time. Petroleum and geopolitics are intertwined from the Middle East and Russia to Central and South America. Geopolitical tensions pivot around oil precisely because petroleum, and increasingly natural gas, are so critical. Wishful thinking about the world using fewer hydrocarbons and nonsense phrases such as "addiction to oil" don't erase the realities, or the opportunities.

ENERGY PRIORITIES

The world will use more energy in the future and will burn more, not less, hydrocarbons regardless of subsidies or policies that aim to persuade countries to do otherwise. This reality is the consequence of laws of physics, economics, and human behavior, claims of an impending climate apocalypse notwithstanding.

Even so, nothing about this reality obviates a growing future role for non-hydrocarbon energy sources. It is possible, though it would be remarkable, for solar and wind technologies to grow from supplying about 2% of America's energy today to, say, 20% or 30% in the coming decades. Such growth would represent a staggering increase in the scale of wind and solar industries and, assuming it was achieved at close to cost parity with hydrocarbons, would also constitute astonishing profits for investors. But such an unprecedented rise in wind and solar would not obviate the need for low-cost hydrocarbons to supply the other 70% to 80% of energy needs.

Over the decades, the U.S. has developed a vast labyrinth of federal energy policies and programs. Some policies have been important and effective in achieving strategic, economic, and social goals. But too many policies have emerged that are now duplicative and too often counterproductive. And invariably many policies, even if initially well-structured and well-intentioned, suffer from mission creep or outmoded rationale.

As a first order of business, the next administration should form a task force to undertake a thorough inter-agency and inter-policy review looking for opportunities for consolidation and elimination of energy policies that are counterproductive or have outlived their original purpose. Only then can the administration create bold new policies that seize the opportunities created by technologies that exist while dealing with the realities of the world as it is. In doing so, it will be critical to sort through the inevitable proliferation of issues and objectives that will continue to clutter the inherently broad domain of energy policy.

As the next administration thinks toward such policies, it should frame its priorities in a way that addresses the three central macro trends of the 21st century.

First, the growth in world populations and economies will increase the importance of global trade. And because oil supplies 95% of the energy used to move goods and people in trade, petroleum's importance will increase in coming years — not just because oil is the largest single traded commodity, but because it is inherently central to commerce and geopolitical stability. Trade in oil and natural gas and derivative chemicals comprises 25% of all global trade in all goods of all kinds. Oil-consuming services — transportation and travel — comprise 50% of all global trade in all services of all kinds. And both of those domains have been the fastest growing aspects of world trade in the past decade.[59]

Second, continued urbanization and ever-deepening societal dependence on ICT and digital systems will not only increase the demand for electricity, but also increase the criticality of grid reliability and security in the face of every-present natural disruptions and rising threats of both physical and especially cyberattacks on grids. Over the coming two decades, EIA forecasts 40% of additions to global electric supply will come from heavily subsidized renewables and 45% from gas and coal (twice as much from the former as the latter), but by then 60% of global kilowatt-hours will still come from burning hydrocarbons.[60]

Third, the astronomical scale of prospective global demand for all kinds of goods and services will create unprecedented increases in stresses on land use and environmental goals. This will make it more important to find radical, not just incremental, improvements in the energy ecosystem and, ideally, even "miraculous" new energy technologies that can address two issues relating to social "justice": cheap energy that enables and allows access to goods and services, and a radically smaller environmental footprint for society's energy requirements.

KEY POLICY ACTIONS

To address these three realities, the next administration should focusr its overarching policy frameworks on three key policy actions. First, it should re-orient oil and natural gas policies to capture the economic and geopolitical benefits from stimulating a Shale 2.0 revolution. Second, it should re-focus electricity policy around the primacy of security and reliability to decrease exposure to rising physical and cyber threats. And third, it should restructure federal support for research by increasing the focus on *basic* science—new "miraculous" technologies are ultimately inevitable but certainly won't emerge from subsidies or corporate welfare.

None of these recommendations obviates the need for policies that support today's non-hydrocarbon energy sources, or improvements in efficiency and conservation. Rather, all such "alternative" domains have for all practical purposes become the "conventional" approach to energy policy and enjoy either more than adequate funding or are over-funded in terms of meeting stated goals in meaningful timeframes. Indeed, over the past decade, 80% of all federal energy support has been directed at renewables and efficiency, and the total spending has been more than twice as great in that decade as the cumulative total spending directed at hydrocarbons in the prior two decades.[61] The proposals offered herein are thus an alternative to "business as usual," and are based on the realities of what the world will look like in the near term, and a realism about what it takes, and how long it takes, to effect transformational changes in the energy landscape.

The three framework directives above each suggest some specific policy actions. First, to harness the benefits for the shale revolution, the next administration should consider how to enhance shale hydrocarbon technology and infrastructure.

Over the past half-dozen years, the United States became the world's fastest growing oil and natural-gas producer, without incentives, special subsidies, grants, or stimulus. Policies should now focus on taking advantage of this unprecedented, unplanned, and largely unsupported revolution in shale hydrocarbons. The potential to have an impact on America's economy and geopolitical posture is unparalleled in modern times. Policymakers no longer need to think in terms of minimizing economic and strategic import dependencies, but instead can focus on maximizing future domestic and geopolitical opportunities from petroleum and natural-gas abundance. The U.S. has a substantial lead over all other nations in unlocking its underlying Saudi-level hydrocarbon resources in domestic shale fields. This advantage has created unprecedented opportunities for trade arrangements with our allies and others to reduce geopolitical dependence on high-risk sources or high-threat transit routes for oil (and natural gas). But there are as yet no organized geopolitical policies or principles designed to take advantage of, rather than simply ride (or tolerate), the shale revolution. At the same time, the technologies that underlie the shale revolution are new and have only just begun to unfold, and the global price war now in play is putting substantial financial stress on an industry that is dominated by small and mid-sized firms.

There are a number of specific federal oil and gas policies a new administration could implement to help the U.S. take advantage of its position as the leader of the shale movement. For one, it should implement a time-out on imposing more regulatory constraints on the tens of thousands of small and mid-sized business that are responsible for the shale revolution and that now collectively produce 75% of America's oil and natural gas.[62]

The next administration should also create an interagency review of the state of U.S. seaports and related infrastructure relevant for crude and natural-gas exports in order to identify impediments to and opportunities for expedited expansion. For example, the Louisiana Offshore Oil Port is well positioned for rapid conversion into a major export terminal; built in 1982 to import crude, it is the only U.S. port capable of berthing low-cost supertankers.[63] [64] (Note: Exports constitute an important but stymied opportunity for U.S. coal producers as well.)

The federal government should work with industry to develop a near-term and long-term plan for trade missions designed to provide our allies and other nations with new, stable, long-term sources of critical oil and natural gas, in order to offset the geopolitical risks associated with many nations' rising dependence on the Middle East and Russia.

Furthermore, the next administration should facilitate the demonstration and validation of emerging shale technologies — sensors, advanced materials, analytics, robotics, and control systems—that are key to enabling an expansion of domestic industries at the "new normal" of low-priced oil and natural gas.[65]

In addition to the cost-neutral resetting of priorities within existing budgets, additional funding to support the above proposals can be achieved by freeing up capital inherent in the excess quantity of petroleum now in the Strategic Petroleum Reserve (SPR). The SPR was established in 1985 to ensure that sufficient oil was on hand in the event of "significant disruptions" to U.S. supply (both the domestic supply and specifically imports). Thanks to the productivity of the shale industry, the SPR now holds nearly double the 90 days of imports considered necessary for disruption protection, and holds four times more than needed if imports from Canada are not included in the dependency calculus.[66] The 2015 Bipartisan Budget Act directed the sale of 100 million barrels, about 12% of the SPR, to free up funds for deficit reduction and SPR maintenance.[67] At least another 20% to 30% of the excess petroleum in the SPR could be sold (in a measured, strategic fashion) without compromising the strategic utility of the reserve, freeing up billions of dollars to meet the above goals at no cost to taxpayers.

The second major point of action on energy policy for the next administration should be securing the electric grid. Electric power is for modern society *the* fundamental infrastructure on top of which the rest operates. It enables more than lights and heat; electricity pumps gasoline, water, and sewage, keeps food cool and elevators moving, and powers citizen and emergency communications and the entire internet ecosystem. The electric dependency of every aspect of modern society is hypertrophied in cities.

Physical and cyber threats to the grid are increasing at the same time that reliability and resilience are more critical for a more electric-dependent economy. While there are those who claim that one can't do much planning in the face of so-called "black swan" events, Stanford University professor and risk expert Elisabeth Paté-Cornell says that "perfect storms" are "lame excuses for bad risk management."[68] Threats from cyber terrorists to Mother Nature are within the scope of our imagination. The U.S. Department of Energy has spent less than $150 million over the past decade on cybersecurity, compared to $25 billion on smart grid[69] programs and over $100 billion funding cleantech.[70]

Thus, the next administration needs a specific plan to guard against threats to the electric grid, and there are a number of electricity policies the federal government should pursue. For one, it should formulate, in collaboration with industry, a program to create a certification protocol for "leadership" focused on cyber and physical resilience. The program can be modeled on the principles that underpin energy efficiency goals, such as LEED (Leadership in Energy & Environmental Design) certifications.

It should formulate public-private partnerships with Silicon Valley software and cybersecurity firms to determine how to develop next generation Information of Things and grid cybersecurity. Physical cybersecurity has to advance at the speed of entrepreneurs and not a bureaucratic crawl.

The next administration should form an interagency working group to apply cybersecurity lessons learned from the Department of Defense Cyber Command. It is not reasonable to expect private companies to defend themselves from nation-state, or nation-state-sponsored, cyberattacks any more than from physical invasions from the same.

It should also re-examine the Critical Infrastructure Protection (CIP) requirements for the long-haul grid to ensure they fully address the threat of physical threats to the grid (natural threats and terrorism), and the operational reality of grids as they exist. In addition, mechanisms are needed to fund "insurance" for warehousing long-lead-time grid hardware, and, for the longer-term, to fund R&D to develop power-electronic solutions for inter-operability of critical grid equipment.

Finally, the third major action the new administration should take to advance energy policy is to radically increase basic R&D. In the modern era, basic scientific research has been foundational to innovation broadly and thus to economic growth and social progress. But it is exactly this open-ended, *basic* research that can yield the kinds of fundamental or "miraculous" breakthroughs sought to revolutionize everything from health care and security to energy and the environment.[71]

The federal government has long been and continues to be the primary supporter of basic research. While the private sector spends far more on R&D in general, at best about 5% of that spending goes to *basic* research.[72] The vast majority of support for basic science comes from federal funding, most of that directed to universities. Over 80% of federal civilian R&D spending is concentrated in four agencies: NIH, DOE, NASA and the NSF.[73] But lately, federal agencies are increasingly focusing on applied research — emphasizing near-term problems and projects — competing, in effect, with the private sector which already spends 400% more on *applied* R&D. This alarming trend represents a *de facto* conversion of federal R&D policy into industrial policy, and it drains money away from the opportunity to fund undirected, transformational, basic science.

Thus, if the next administration wants to pursue the aspirational, and by definition long-term, goal of finding radical new energy technologies through R&D, it should focus on a few specific policies. For one, it should reform and give priority to basic research and collaterally reduce spending on all types of energy-related industrial-class projects within Department of Energy R&D budgets. Cutting the latter in half would, on average, double the spending on basic science, with no increase in the overall budget.

It should also increase the spending allocated to basic sciences at DOE, rather than specific technologies, devices, or products. These basic sciences are the domains where the equivalent of the discovery of the photovoltaic cell may emerge, or perhaps a radical new catalysts that could convert gases to liquids. This kind of discovery would have obvious applications for methane (natural gas) or carbon dioxide.

Specifically, the next administration should increase the spending allocated to basic sciences associated with shale hydrocarbons, including geophysics, geology, chemistry, and related analytics. DOE takes credit for having played an early supporting role in the basic research that helped pave the way for America's shale revolution.[74] But there are many features in the underlying science that remain poorly understood; better science can lead to better technologies. (Less than 8% of the DOE's energy R&D budget relates to hydrocarbons[75], the fuel sources that supply 85% of U.S. energy.[76])

The administration should also adopt the Hughes Medical Research model, wherein support for (most) basic research is directed at talented *scientists* in basic disciplines, rather than at projects with specific directed outputs.

These actions would create a policy environment that, by taking a realistic, world-as-it-is approach, could bring us closer to a revolutionary energy innovation.

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ENERGY POLICY FOR AMERICAN LEADERSHIP IN THE 21ST CENTURY

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