The End of Carbon Fuels?

A New York street photographed in 1900 showed almost every vehicle pulled by horses. Just twelve years later, a photo of the same corner showed mostly cars. Few saw the complete disruption in transportation coming.

Today, some experts, including Stanford's Tony Seba, argue that the efficiencies of solar energy and electricity storage technology have made quantum improvements in just the last eighteen months. These improvements threaten to disrupt the energy industry. The surprise is not the emergence of these disruptive technologies, but the speed with which they are coming on stream.

By 2030, predicts Seba, all new energy will be provided by solar and wind. All new mass market vehicles will be electric. And there will be fewer of these vehicles, as autonomous vehicles make a dramatic mass entry into the market. "Oil, gas, coal, and nuclear will become obsolete," he argues.

Assume that the demise of fossil fuels becomes a reality. What will be the economic and geopolitical fallout for the OPEC countries, Russia, Turkey, Africa, the United States, and Canada?

How will the disruption of the automobile industry affect Germany, China, and Japan (with Germany and China now working so closely on electric vehicle development?) How, if at all, will NATO be affected? The Paris Climate Accord?

If these predictions are correct, a lot of capital stock worldwide will become obsolete. Who will gain from new investment opportunities, and who will be stuck with worthless debt?

Who will be the winners and losers? And how should today's policymakers plan for these potential shocks to the global system?

GEORGE GRANTHAM BAIN COLLECTION (LIBRARY OF CONGRESS)

Easter morning, Fifth Avenue, New York City, 1913.

Fifteen noted thinkers offer their views.

Replacing horses was very different than a transformation from the internal combustion engine.

ROGER B. PORTER
IBM Professor of Business and Government, Harvard University

Life is filled with periodic enthusiasms. Some are cultural, others economic, still others political. They often produce intense activity, but inevitably this activity is grounded in reality. Such is the case with predictions regarding the end of carbon fuels. Consider two central realities.

First, the challenges associated with climate change have fueled sustained efforts by businesses, governments, and not-for-profit organizations to diminish the use of fossil fuels. Automobile companies have committed to produce an expanding number of models of electric-powered and hybrid vehicles. A high level of research and development has been devoted to battery technology as well as to developing wind and solar power to generate the necessary electricity. Tesla, Volkswagen, General Motors, Volvo, and Ford Motor Company, among others, including the government of China, have invested billions of dollars in this effort.

Moreover, there have been considerable current and projected investments by Volkswagen and others in the infrastructure to support electric and hybrid vehicles.

Not least, governments have provided massive financial subsidies and imposed regulatory requirements to facilitate replacing fossil fuels and to incentivize the purchase of electric and hybrid vehicles. All these developments suggest that electric-powered vehicles are not a passing phenomenon.

The transformation of transportation by replacing horses with automobiles, however, was very different and more easily accomplished than a transformation from the internal combustion engine and to electric powered vehicles.

The number of internal combustion engines globally is now around two billion—including 1.2 billion passenger cars and 800 million other vehicles (trucks, buses, and so forth) that rely on such engines. Several decades of technological change have dramatically reduced the pollution from such vehicles. A passenger car today pollutes less than 2 percent the emissions of a similar vehicle in 1970. And more such emissions control progress is on the horizon.

Despite the advances in battery technology and immense government subsidies, there are approximately two million electric powered vehicles—roughly 1 percent that of those relying on the internal combustion engine.

Beyond regulatory mandates, what will govern the adoption by consumers of electric vehicles? Convenience, reliability, price, and range per charge. Until there is a quantum change in battery technology, few owners will rely exclusively on electric vehicles. The major exception may well be in China, where the government has made a concerted effort to develop battery technology.

Current battery technology relies heavily on lithium and cobalt. Three-quarters of the world's reserves of lithium are in China and Chile, according to the U.S. Geological Survey. Sixty percent of global cobalt production is concentrated in the Democratic Republic of Congo, an unstable political environment. Absent a breakthrough that would diminish the need for cobalt in batteries, one would need twice the known global cobalt reserves to produce electric batteries for a billion cars.

Not least is the challenge of generating the required electricity. Wind and solar power still account for a fraction of the production of electricity globally. In short, the coming transformation will be slower, more expensive, and less complete than the electric vehicle enthusiasts currently claim.

The transformational consequences will be awesome.

ROBERT A. MANNING
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It is coming, perhaps by 2050 or sooner, and the transformational consequences will be awesome. Yet many nations, most notably the United States, whose quixotic president wants more coal, are ill-prepared for the transition to a post-petroleum economy. This is but one component of a technology transformation of epochal magnitude

(also known as the fourth industrial revolution) just beginning, a synthesis of artificial intelligence/big data, robotics, three-dimensional printing, biotech, and new materials that increasingly will drive global economic growth.

In this tech transformation, there will be three broad tiers of nations: those who innovate and adapt; those who adapt; and those on the periphery, partially adapting. These categories overlap—some will innovate in some technologies, adapt in others.

In regard to energy, those planning for and investing in the transition—mainly wind and solar energy as primary energy sources, and critically, energy storage—will be best positioned economically. Prices for wind and solar have been dropping dramatically since the 1980s. From 2000–2017, prices of solar photovoltaic and wind turbines fell by three-quarters and 50 percent, respectively. China, the United Kingdom, and France have banned combustion engine autos after 2040, accelerating the transition, as evident in surging global auto industry investments in electric self-driving vehicles.

The wildcard with regard to the pace and scope of change is energy storage, which has been incrementally improving over the past two decades. It still needs to improve by an order of magnitude before intermittent energy sources—wind and solar—become fully cost-competitive with oil and gas.

This energy/technology revolution will thus occur, more in bursts than increments, over the coming three decades, reshaping geoeconomics and correspondingly transforming the geopolitical landscape.

China and Germany are most holistically prepared across the spectrum of energy and other emerging technologies to position themselves for the energy/tech transition. The United States is still ahead in all key tech sectors, and is competitive in renewables due to legacy public research and development at the national level, and private sector dynamics and state and local emphasis on renewables.

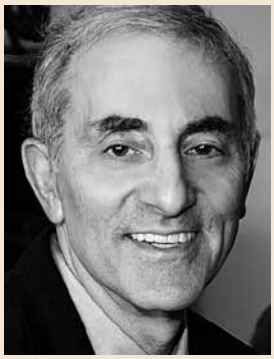
In this new geostrategic landscape, there are some obvious shifts as well as winners and losers. What will be the strategic importance of the greater Middle East to the major powers—the United States, China, the European Union—absent energy concerns? What will be the nature of strategic competition?

Key petro-nations, Saudi Arabia and the Gulf states, with impressive foresight, are frenetically investing tens of billions of petro-rents in solar and wind as well as in science and technology, seeking to beat the clock and transform the structure of their respective economies. To the degree that they succeed, they will be stable political economies. In the region, Iran seems a likely loser, with unsustainable regional ambitions absent petrodollars.

Russia, already facing huge demographic challenges and a belated and politically constrained effort at tech innovation, also appears likely to decline as a major global actor.

Emerging economies in Africa, Latin America, and South Asia are likely to be on the periphery, and with some exceptions, will struggle to adapt. If India, relatively well-positioned technologically, implements its renewable energy goals and improves its educational deficits, it may be an important regional and global actor.

But it will be a world with the United States and China at its apogee, with growing economic divides that bode for a disorderly future.



The transition to a carbon-free world very likely will come too late to prevent major disruptions.

ROBERT LITAN
Non-Resident Senior Fellow, Brookings Institution

The riskiest thing for any economist to do is to give both a forecast and a date when the projected outcome—be it an increase in GDP or inflation, or a reduction in unemployment—will occur. So it is with the end of carbon fuels. It will eventually happen, but no one knows when.

Tony Seba may be right that the day of reckoning will be as early as 2030, but I strongly suspect it will be at least one or two decades later.

Regardless of the timing, I am highly skeptical that policymakers in democratic countries run by elected officials will do much to ease the transition and its costs, mainly those suffered by displaced workers and their communities. We haven't done it well for dislocations induced by trade, outsourcing, or automation. There is little reason to expect a different result for shifts in energy supplies.

Some autocratically ruled countries, whose leaders have a longer time horizon (only if they are comfortable they will not be overthrown) might do better. One thinks of Singapore or China, which is using the power of the state to win the "solar race," and can readily move workers to new industries and locations by fiat. The ruling family in Saudi Arabia has been planning for an oil-free era, even as it cuts back oil production to increase its price to generate income presumably to ease that transition—which higher oil prices ironically will hasten by encouraging innovation in renewables.

Markets have a way of doing the "planning" that governments fail to do, however. Cheaper, cleaner energy will benefit those who produce it, quite obviously, but also energy users. The cost savings will be akin to those from automation and will be spent by individuals and firms on other things—one suspects more on health care, education, leisure, and entertainment. Shifts in employment will follow.

As for the geopolitical impacts, large fossil fuel producing countries that are not making plans for transition—notably Iran, Nigeria, Russia, and Venezuela—will see their relative power decline (though Russia, and possibly Iran, will still have nuclear weapons). Countries that make equipment for renewables—China, Germany, and one hopes the United States—will gain (although not so much, in the case of the United States to offset the losses from the decline of fossil fuels).

The transition to a carbon-free world very likely will come too late to prevent major disruptions caused by carbon dioxide-induced climate change, however. Increases in global temperatures, and their economic fallout, already are "baked in" by past increases in carbon dioxide emissions, and those likely to occur before we reach zero day for fossil fuels.

The real battles over decarbonization are about the twentieth-century fossil fuel giants versus the rest of society.

JEFFREY D. SACHS
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The world must decarbonize by mid-century. The extreme dangers of climate change require the world energy system to shift from coal, oil, and natural gas to zero-carbon energy based on wind, solar, hydro, geothermal, bioenergy, and nuclear power. The facts are clear though petrostates, including the United States, tend to resist the facts. Yet as climate disasters mount, the climate imperative will prevail. Today's oil and gas industry will shrink decisively; coal use for energy will completely disappear.

The only alternatives would be to ignore the climate threats, or to engage in massive carbon capture and storage to offset the emissions from fossil fuels. Neither is likely. Here's why.

Climate threats are not likely to be ignored. Last year, the United States suffered a record $309 billion of losses from extreme hurricanes, massive forest fires, and other major hydrometeorological disasters. Such losses will mount in the future. The public will know. The courts will hear more and more lawsuits claiming damages from the oil majors. Financial regulators will increasingly scrutinize assets held in fossil fuel-linked industries.

Nor is carbon capture and storage likely to save the day for fossil fuels or the Earth's climate. CCS is expensive, unproven, and dependent on leak-proof and economically accessible large-scale geological storage. Energy-related emissions of carbon dioxide today are around forty billion tons per year. It's hard to imagine even a fourth of that being stored geologically each year, given the low-cost options for zero-carbon energy. Most fossil fuel use will end; a small fraction might be sustained with CCS. (Some limited uses of carbon capture are likely, notably the direct air capture of carbon dioxide for conversion into synthetic hydrocarbons using renewable energy, for aviation, shipping, and other needs for liquid fuels.)

Thus, the world will move towards decarbonization. It will likely to do this via zero-carbon electricity (based on renewables and nuclear), plus electrification of vehicles, heating, and many industrial processes. Remaining applications (such as aviation) will find niche solutions.

Yes, decarbonization will have some geopolitical ramifications. Today's fossil fuel exporters, notably the Gulf region, Russia, Australia, Canada, Indonesia, and a few others, will suffer a loss of income, both through lower prices of fossil fuels and lower quantities produced and exported. Indeed, that process is already underway. Many companies will go bankrupt, led by the coal industry. But none of this, I believe, is likely to be of decisive geopolitical importance.

Interestingly, many of the fossil fuel regions are rich in renewable energy as well: the Gulf and solar power; Canada and wind and hydro; the United States and wind, solar, hydro, and geothermal; and so forth. And many of today's fossil fuel-importing countries, such as China, are likely to import renewable energy instead, both as electricity carried on long-distance ultra-high-voltage transmission lines, and (in the future) as synthetic hydrocarbon liquid fuels.

The real battles over decarbonization are not about technologies, costs, or geopolitics. They are about the twentieth-century fossil fuel giants (ExxonMobil, Chevron, Koch Industries) versus the rest of society. Big Oil had the run of politics for around one century (ever

since Winston Churchill decided to put the British fleet on oil, and Henry Ford put the United States on the path to an automobile in every garage).

Big Oil and Big Autos virtually defined U.S. politics for decades. No matter President Trump's rantings about the Paris Climate Agreement, or EPA Administrator Scott Pruitt's rollbacks of vehicle efficiency standards, the days of Big Oil and fossil fuels generally are drawing to an end.

Fossil fuels will continue to be widely used for a long time.

MARTIN NEIL BAILY

Bernard L. Schwartz Chair in Economic Policy Development and Senior Fellow and Director of the Business and Public Policy Initiative, Brookings Institution

Wind and solar power and battery technology have made faster progress than expected, which is good news for the planet because it helps reduce the risks from global warming. Carbon dioxide in the atmosphere is higher today than at any time in the past 800,000 years and drastic measures are needed to preserve global civilization as we know it.

Despite the technological progress made in renewables, fossil fuels will continue to be widely used for a long time. It is difficult and costly to operate the transportation infrastructure without fossil fuels. Airplanes and heavy trucks will continue to use them indefinitely.

There are barriers to the rapid expansion of renewables, such as finding enough cobalt and lithium for batteries and manufacturing them at sufficient scale. Meanwhile, the technology of finding and developing fossil fuels is also improving rapidly, keeping down their prices. Coal power will gradually disappear in the United States, but oil and gas will remain cost-effective and coal will continue to be used in developing countries, absent a policy shift.

America's economy has benefitted from its reserves of fossil fuels and the technologies it has developed to access those fuels. It has a widely diversified economy that will benefit from the investments being made in alternative energy. Texas is increasing employment in oil and gas even as it has gained jobs from being a center of wind power.

The automobile industries in America, Europe, and Asia are facing a transformation, but a slow one. At present, America's demand for large gas-powered SUVs and pickups is much greater than its demand for electric vehicles. It will take decades before Americans are all driving electric cars. The European auto industry bet on fuel-efficient diesels and some engineers faked the exam on how well they had done in making the engines less polluting. Now their industry has to make a costly adjustment, but they have the skills to do it. Due to shorter driving distances and higher gas taxes, Europe may move more quickly to electric cars than the United States.

The shift to new forms of energy is a disruptive technology and experience says the costs to those holding the old capital stock can be high. The price of a taxi medallion in New York fell from over $1 million in 2013 to around $190,000 in 2017. However, the transition away from fossil fuels is not happening all that quickly and is unlikely to disrupt the fossil fuel industry. In fact, the transition is too slow, not too fast. The need to reduce greenhouse gas emissions is so great that we cannot wait for the forces of the market. Policies are needed to speed the transition, penalizing the use of fossil fuels and supporting investments in new forms of energy. If necessary, let's buy out the coal mines and retrain the miners. That's cheaper than the cost of endless floods and hurricanes, and more humane than pushing Bangladesh underwater.

While an energy transition is warranted, it will be tricky.

DEBORAH GORDON

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Carbon energy sources have always been deeply embedded in human society. Thousands of years ago, raw quarried petroleum was used in small amounts as building mortar and weapon adhesives. Over the past century, increasingly intricate engineering processes have

been developed to transform hydrocarbons into refined products that enable our daily lives—from fuels and fertilizers to fabrics and pharmaceuticals. The industrial efficiency of refining is high, so essentially every input is turned into something with market value. In order to realize Tony Seba's energy vision, we must remake complex commercial supply chains that co-produce hydrocarbon commodities along with carbon fuels. While an energy transition is warranted, it will be tricky.

This quest goes well beyond electrifying the world's two billion motor vehicles and recharging them with renewable electricity. It requires drilling deeply into refining. Solar and wind energy may displace automotive fuels, but they can't supply the myriad of other essential petroleum products we consume. Refineries will have to find technically feasible, cost-effective, and cleaner uses for every portion of the oil barrel. If they don't, product shortages such as lubricants and jet fuel will ensue and their prices will rise. Challenges will be compounded by new energy resources, such as oil sands and condensates, for which refineries were recently reconfigured to maximize production of automotive fuels. Lastly, vehicle electrification won't take place in a vacuum. Numerous disruptive technologies, such as autonomous vehicles, city-to-city rocket travel, 3D printing, and bitcoin mining, could shift petroleum demands to rocket gas, printer plastics, and petroleum for power. And there's no certainty about the disruptive innovations petroleum companies themselves will pursue in response to external forces.

Geoeconomically, the consequences aren't limited to oil- and gas-producing nations like Russia, Iran, and Canada. Oil-consuming countries such as India, China, and Saudi Arabia—where increasing demand for petroleum products is driving refining expansion—will also be affected. For example, since 2010, India's refining capacity has increased by 68 percent. Even if India's pledge to electrify the nation's vehicle fleet materializes, they still require diesel for trains, asphalt for roads, LPG for stoves, and jet fuel for air travel. The investment of trillions of rupees is planned to further expand refining capacity, which India can consume domestically and export regionally. If non-OECD countries like India can't afford, won't embrace, or don't forgo benefits from the carbon fuel status quo, this will jeopardize a clean energy transition.

As momentum builds to end carbon fuels, it is critical to start thinking about how these efforts will affect a strategically honed industry like oil refining. Dismantling century-long advances from kerosene in lamps to gasoline in cars, jet fuel in planes, and petrochemicals everywhere is a mammoth undertaking compared to trading in horses for Model Ts. To minimize unintended energy, economic, and environmental consequences, a road map for the future needs to account for all petroleum shifts, not just the ones that capture the most attention.

Over-reliance on diesel technology will make Germany highly vulnerable.

WOLFGANG MÜNCHAU
***Director, Eurointelligence Limited, and columnist,* Financial Times**

One of the countries least prepared for a fast phasing-out of fossil fuels is Germany. The biggest issues for Germany are over-reliance on Russian gas and oil, which will increase with the construction of the Nord Stream 2 pipeline, and over-reliance on the diesel technology for cars. The latter is probably the bigger issue.

The last comprehensive study on the economy's dependence on the car industry, by ZEW, dates back to 2005. Its conclusion was that the German economy was more dependent on the car industry than any other country. This was before the effect of structural reforms in the last decade strengthened the relative position of the car industry further.

The consensus view in Germany is that any future technologies have to be compatible with the interests of the car industry. I have even heard the argument that it is impossible to phase out fuel-driven cars by 2030, or even 2040, simply because the German car industry will not be in a position to supply the required number of cars. Those who put forward such an argument do not even consider the possibility that manufacturers from other countries might. Nor is there any discussion on the combined effects of the impact of artificial intelligence and electrically powered cars—a combination that changes the nature of the product fundamentally.

A recent ruling by the federal administrative court in favor of local councils' right to impose diesel bans has accelerated the decline in demand for diesel cars. There are reports that second-hand car dealers no longer buy diesel cars at any price. Official statistics also record a rapid decline in new registrations of diesel cars. It is technically possible to upgrade diesel cars, but these upgrades are costly. We have heard estimates of €5,000 per car. As German car makers are facing costly legal challenges in the United States and in Europe because of fraudulent emissions tests, there is little financial capacity left to invest in upgrades. One development to watch out for is whether the German government will decide to finance the upgrade as a means of saving the car industry.

German car makers hold a significant percentage of patents in respects of electrical engines and artificial intelligence systems. But the number of patents may be a misleading metric for the industry's readiness to capitalize on the new technologies. The companies remain heavily dependent on diesel technology.

There remains a presumption among German politicians, journalists, and car industry experts that it is possible to stop the tide against diesel if only German cities can be persuade to hold off on diesel bans. What they overlook is that Germany will not be able to prevent the diesel bans in neighboring countries starting as early as 2020. Both Rome and Paris are committed to banning diesel cars in 2024. A car that cannot be driven into the major urban centers of Europe can surely not hold its value. As the current fall in demand for diesel cars already demonstrates, is forcing a change much faster than what experts had predicted. This is a change for which Germany is not prepared.

The energy supply revolution will be a blip on the screen.

W. BOWMAN CUTTER
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The world economy is being fundamentally disrupted by two simultaneous, independent, but entangled forces—the information and energy revolutions. The automobile industry is at the point of the spear with respect to both revolutions. While the focus of this question is on the energy revolution, the information revolution will in all likelihood proceed much more rapidly and be far more disruptive economically. The energy revolution is real and is happening, but its pace will be slower—it is unlikely that all new energy will be provided by wind and solar by 2030 (twelve years from now), or that all new mass market vehicles will be electric, or that oil, gas, and coal will be obsolete by then.

Despite the fact that almost all past predictions about the economic and social implications of profound technological shifts have made the predictors look foolish, I'll suggest several implications.

First, the energy supply revolution will steadily erode the geopolitical importance of Russia and the Middle East. And it will impose increasing pressures on the regimes of all oil-intensive economies to find mechanisms for restructuring their economies and their governments. It is in the nature of the intrinsic inertia of political systems that most governments will not meet this challenge.

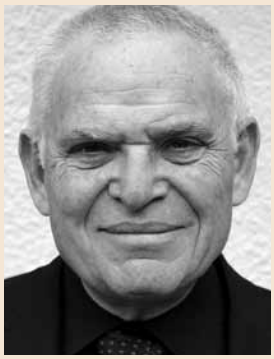
Second, the energy sector itself will adjust fairly easily. In countries where the energy sector is largely private but regulated, investment will shift and the losses implied as some infrastructure is stranded will be paid largely by the rate payer—as always. As a percentage of the economies of the United States and Europe, the stranded assets are small. And the investment costs required to transit to new supply infrastructures are easily within the capacity of capital markets to take on.

Third, the energy supply transition should help in the effort to slow down or limit climate change. As an example, basically all the improvement or reduction of greenhouse gases in the United States comes from an ongoing switch from coal to natural gas. But there will be enormous political/economic tensions between the new major emitters—China and India—and the more mature developed economies. Both China and India use vast amounts of coal for energy production and while they will shift, the shifts won't happen as rapidly as the climate issues require. This could emerge as the single greatest source of tension in the whole climate issue and will make the Paris accord an important but difficult forum.

Fourth, the effects of the information revolution on transportation and the automotive sector will be far more profound and pervasive than the impact of the energy revolution. To take a negative example, the emergence of autonomous vehicles (defined more broadly than just driverless cars) is already causing enormous change in logistics and delivery and will almost certainly lead to the substantial loss of current jobs. Long-distance trucking will probably feel the first major impacts.

However, finally, the changes in the automotive sector itself will be largely positive. There will be little or no job loss in basic automotive production—and perhaps even an increase—because the number of jobs in automotive plants around the world has declined substantially already. And as a whole new concept of the automobile evolves, there will be a large amount of ancillary job creation as well as new opportunities for small business.

As a guess, when we look back, the energy supply revolution will be a blip on the screen except for the likelihood that oil-intensive economies and their regimes will not anticipate the revolution fast enough. On the other hand, the information/digital revolution will alter how economies function, how governments work, and how war is carried out. The next field on which national competition will play out will be—and already is—technology.



Not so fast, Mr. Seba!

EDWARD N. LUTTWAK
ENL Associates

Not so fast, Mr. Seba! First, there are important infrastructural as well as economic pre-conditions. Many places still have no electrical supply and many of their inhabitants cannot afford their own solar/wind generating systems, but some can buy a second-hand internal combustion pickup truck to make a living in transport. More generally, much of the planet is sadly behind Palo Alto in the supporting infrastructures including neatly demarcated roads for autonomous vehicles (just as Palo Alto is sadly behind Bangkok and other cities in public transport—one can see the maids awaiting the few buses in front of the multi-million-dollar cottages without even a bench to sit on).

In other words, 2030 is a bit too early—and not only for the remote poor but also for many others, because when it is not the market forces that reduce the use of fossil fuels but rather government policies, exactions, and prohibitions, the outcome is invariably perverse in one way or another. Thus virtuous Germany, led by Saint Merkel, a real world leader in talking up renewables, relies on burning lignite and some regular bituminous coal for 40 percent of its total energy consumption, versus the 30 percent of the reactionary United States with its pollution-loving president. Ditto for wind projects brought into existence by subsidies—in some cases their lifetime output is a mere fraction of their manufacture, construction, and erection energy costs.

But of course Mr. Seba does imply that it is the market and not easily perverted good intentions that will bring about the downfall of fossil fuels. That is not an unrealistic expectation, but it does require industrial realignments that have yet to happen.

For example, in 2018, only twelve years away from his date, the automotive industry is still driving fast in the wrong direction. Hydrogen goes inside a tank, in and out, just like liquid fuels. But electricity must be stuffed into dense batteries that punish rapid charging with rapid decay. With Tesla leading the way, the industry has missed the turn to hydrogen—as will become obvious in the form of sad resale values when entire battery packs must be replaced. The superiority of the hydrogen car has already been demonstrated by the largest manufacturer, but 2030 is too early to replace classic propulsion, hybrid propulsion, and battery propulsion with solar-generated hydrogen-powered cars.

Yes, it will happen, but not so fast. And some of the fossil fuel champions, including Texas and Saudi Arabia, are well placed to produce hydrogen from sun and wind. In the end, as usual, it is Russia that will be the hardest hit, being absurdly over-dependent on fossil fuel exports. But then again, there is always global warming that is even now turning immense Siberia into a vast garden in which only utterly perverse policies can prevent an explosion of agricultural output (as it is, in many places there are already splendid grasslands in place of lichen and sage).

Emerging market economies and investors have already embraced a post-fossil fuels future.

GARY KLEIMAN
Senior Partner, Kleiman International Consultants

Emerging market economies and investors have already embraced a post-fossil fuels future even though it entails a paradigm shift from traditional energy export reliance and dominant oil and gas company bond and stock issuance.

China and India lead the clean solar, wind, and hydro push, but the historically resistant Persian Gulf top OPEC producers have also promoted diversification, as in Saudi Arabia's 2030 Vision. The environmental "E" in ESG socially responsible allocation is part of a $25 trillion industry, and 60 percent of global investors integrate these factors into their screening process, according to a recent survey by French bank Natixis. Forty stock exchanges mandate sustainability reporting on "green" issues, and dedicated bonds have grown to a $30 billion annual asset class with specific ratings agency metrics.

In the developed world, the United States has lagged Europe, but a new Sustainable Accounting Standards Board has proposed carbon emission-related disclosures, alongside the Bloomberg task force organized under the auspices of the IMF-hosted Financial Stability Board.

In emerging market private equity, clean energy is among the most popular themes and serves as a dual consumer and industrial play. Hundreds of mainstream portfolio managers have signed United Nations principles and partnered with its environmental program to eliminate fossil fuel exposure and promote alternatives over the medium term, while banks were early adopters of the World Bank's so-called Equator Rules emphasizing loan preference and returns for new energy adaptation and efficiency ventures.

Gulf Cooperation Council countries, shocked by budget and external imbalances with the secular oil price drop, have launched detailed plans and infrastructure projects to strengthen the non-hydrocarbon economy and the private versus state sector share. Russia, Central Asia, and African commodity exporters have recognized the same path even if they have not articulated sweeping policy and practical breaks, although many have at least moved to phase out energy subsidies. In Latin America, leading candidates in the Colombia and Mexico presidential elections have campaigned on post-oil foreign investment changes, as the developing world prepares to attract even higher direct and portfolio inflows in different commodity forms over the next decade.

There are reasons to question Tony Seba's claim.

ANDREW DEWIT
Professor, School of Economic Policy Studies, Rikkyo University

Disruption in energy and mobility is diverse, rather than simply towards wind, solar, and electric vehicles. Nor do fossil fuels and nuclear appear about to become obsolete.

Among myriad reasons to question futurist Tony Seba's claim that all new energy will be provided by solar and wind, three are prominent: competing energy inputs, material constraints, and our voracious appetite for petrochemicals.

First, big hydro remains the key decarbonizing energy source, and continues to grow. The International Renewable Energy Agency's March 31, 2018, summary of global renewable generation capacity reveals that hydro represented 53 percent of the 2,179 gigawatt total. The International Energy Agency's Technology Roadmap also advises that hydropower (both reservoir and pumped hydro storage) is both flexible and helps balance variable wind and solar. At 150 gigawatts, pumped hydro storage provided 95 percent of global power storage capacity in 2016. IRENA's 2016 *Roadmap for a Renewable Energy Future* suggested that just doubling global renewables by 2030 would require more than doubling pumped hydro storage to 325 gigawatts. Plans to decarbonize Europe's continental grid rely on the "green battery" afforded by Norwegian hydro.

Moreover, hydro's value compounds when dams are digitized and networked in a framework of resilience against worsening flood and drought threats. Thus Japan's 2017 "Dam Revival Vision" aims to double the country's hydro output while linking dams to advanced radar and the internet of things/artificial intelligence. This Vision is already being implemented and will enhance Japan's prospects in emerging markets, where hydro is expected to grow most.

One could also add marine energy, geothermal, advanced nuclear, and other decarbonizing energy inputs. Current policies, especially in Asia, indicate they will be elements of diversified energy portfolios.

The second issue is material constraints. Solar, wind, and electric vehicles are even more dependent on such metals as copper, cobalt, and nickel than are conventional fuels and mobility. These materials will never disappear. But in April of 2018, McKinsey, Moody's, and other analysts warned that declining ore grades threaten to slow the diffusion of battery electric vehicles. Declining ore grades lead to increasing energy and water costs for extraction, raising prices.

The evidence already suggests most countries will not bet everything on solar, wind, and batteries. Hence the growing role of hydrogen in mobility, complementing electric vehicles. The Hydrogen Council's 2017 inauguration has created an international alliance of automobile, fuel, and other heavyweight CEOs. This private-sector mobilization is matched with ambitious industrial policies in China, Germany, Japan, and elsewhere. By 2030, China aims for one million hydrogen-powered vehicles, with Japan's 800,000 target close behind. Hydrogen is also advancing in aviation, shipping, and energy storage, increasing the incentives to scale its production and thus cut its cost.

Finally, any claim that oil, gas, and coal are finished needs to examine feedstocks for the over US$3.5 trillion global chemical industry. Its expansion is outpacing global GDP growth. Some projections indicate petrochemicals will account for about 60 percent of oil demand growth between 2020 and 2030.

While inconsistent with what some observers see as "green," such diversity may be better at realizing the Paris agreement and minimizing further disruption to already restive geopolitics.

Despite real advances, these technologies don't follow a Moore's Law path.

BRET SWANSON
President, Entropy Economics, and Fellow, U.S. Chamber of Commerce Foundation

The dramatic reduction in U.S. carbon dioxide emissions over the last decade is, paradoxically, the result of the massively increased use of a fossil fuel—natural gas. The shale technology revolution produced so much low-cost natural gas, and replaced so much coal, that U.S. emissions from electricity generation have fallen to levels not seen since the late 1980s.

Over time, electric vehicles—and later, autonomous ones—could reduce the need for oil. But natural gas will only rise in importance as the chief generator of inexpensive and reliable electricity.

The Energy Information Administration projects that fossil fuels will still represent 81 percent of total energy consumption in 2030. Natural gas, EIA estimates, will be the largest source of electricity, generating between 50 percent and 100 percent more than renewables.

Sure, but don't technology revolutions often surprise even the smartest prognosticators? Renewables have indeed been growing from a tiny base, and some believe solar power is poised for miraculous gains.

Despite real advances in solar power and battery storage, however, these technologies don't follow a Moore's Law path. Solar will grow, but we won't solve solar's (nor wind's) fundamental intermittency and thus unreliability challenges by 2030. Nor can we avoid their voracious appetite for the earth's surface, a fundamental scarcity which environmentalists and conservationists of all stripes should hope to preserve. Amazon's Jeff Bezos even dreams of a day when we move much heavy industry into space to preserve the earth's surface for human enjoyment.

But shouldn't we pay extra in land area (and dollars) today to avoid carbon dioxide's climate effects tomorrow? Fear not. The latest estimates of the climate's carbon dioxide sensitivity suggest any warming over the next century will be just half of previous estimates and, therefore, a net benefit to humanity and the earth. Satellites show us that carbon dioxide greens the planet.

Economic growth is the most humane policy today, and it opens up frontiers of innovation, including new energy technologies. Premature anti-carbon dioxide policies can actually boost carbon dioxide emissions, as happened in Germany, where ill-advised wind and solar mandates (and also nuclear decommissionings) so decimated the energy grid that the nation had to quickly build new coal plants. New nuclear technologies are technologically superior to solar and wind but remain irrationally unpopular politically. Emitting more carbon dioxide today may thus accelerate the date when economical, non-carbon dioxide emitting technologies generate most of our power.

We will see a complete transformation of the energy grid.

MARCO ANNUNZIATA
Co-founder, Annunziata + Desai Advisors, and Entrepreneur in Residence, GE

Once technological advances in renewable energy and energy storage make fossil fuels obsolete, they will reshape the global geopolitical map: countries which are excessively reliant on oil and gas production and have not yet been able to diversify their economies will suffer a sudden and dramatic reduction in living standards and global economic and political relevance. But these technological advances will have an equally disruptive and profound impact across all economies, as innovations in the energy field combine with a new wave of digital technologies.

We will see a complete transformation of the energy grid: energy consumers, both residential and commercial, will also be able to produce, store, and sell energy back into the grid. The entire energy value chain will become intelligent, thanks to a network of "digital twins," software

doubles of individual pieces of equipment and energy systems, powered by artificial intelligence. These will enable much greater efficiency in the production and use of energy. Distributed power generation will bring greater flexibility in the location of economic activity around the world, from factories to hospitals. Autonomous electric vehicles will contribute to reshaping cities as well as supply chains and distribution networks.

Policymakers should focus on identifying the right kind of investment in new infrastructure, as well as the new regulatory frameworks that can best enable this transformation of the entire energy value chain. Countries that get this right will secure a major comparative advantage in energy efficiency, translating in competitiveness gains for their companies and faster growth in living standards for their populations.

Companies operating in the energy space will need to identify new business models and new ways of providing value—which will increasingly depend on their ability to identify the right partnerships. Here the winners are likely to be companies that manage to capture and leverage the value of the data in the system, and to develop a close relationship with the ultimate users.

The year 2030 is a lot closer than it looks. To satisfy the energy demand of a rapidly expanding global economy, we will probably need to rely on fossil fuels for a while longer. But the transformation in energy infrastructure brought about by digital innovations and advances in renewable and energy storage will already disrupt the distribution of winners and losers at both the country and company level.

When output is limited by demand, action on climate change doesn't require sacrifice.

J. W. MASON
Assistant Professor of Economics, John Jay College-CUNY, and Fellow, Roosevelt Institute

The response to climate change is often conceived as a form of austerity—how much consumption must we give up today to avoid the costs of an uninhabitable planet tomorrow? This way of thinking is natural for economists, brought up to think in terms of the allocation of scarce means among competing ends. By some means or other—prices, permits, or plans—part of our fixed stock of resources must, in this view, be used to prevent (or cope with) climate change, reducing the resources available to meet other needs.

The economics of climate change look quite different from a Keynesian perspective, in which demand constraints are pervasive and the fundamental economic problem is not scarcity but coordination. In this view, the real resources for decarbonization will not have to be withdrawn from other uses. They can come from an expansion of society's productive capabilities, thanks to the demand created by clean-energy investment itself. Addressing climate change need not imply a lower standard of living—if it boosts employment and steps up the pace of technological change, it may well lead to a higher one.

People rightly compare the scale of the transition to clean technologies to the mobilization for World War II. Often forgotten, though, is that in countries spared the direct destruction of the fighting, like the United States, wartime mobilization did not crowd out civilian production. Instead, it led to a remarkable acceleration of employment and productivity growth. Production of a Liberty ship required 1,200 man hours in 1941, only 500 by 1944. These rapid productivity gains, spurred by the high-pressure economy of the war, meant there was no overall tradeoff between more guns and more butter.

At the same time, the degree to which all wartime economies—even the United States—were centrally planned, reinforces a lesson that economic historians such as Alexander Gerschenkron and Alice Amsden have drawn from the experience of late industrializers: However effective decentralized markets may be at allocating resources at the margin, there is a limit to the speed and scale on which they can operate. The larger and faster the redirection of production, the more it requires conscious direction—though not necessarily by the state.

In a world where output is fundamentally limited by demand, action to deal with climate change doesn't require sacrifice. Do we really live in such a world? Think back a few years, when macroeconomic discussions were all about secular stagnation and savings gluts. The headlines may have faded, but the conditions that prompted them have not. There's good reason to think that the main limit to capital spending still is not scarce savings, but limited outlets for profitable investment, and that the key obstacle to faster growth is not technology or "structural" constraints, but the willingness of people to spend money. Bringing clean energy to scale will call forth new spending, both public and private, in abundance.

Of course, not everyone will benefit from the clean energy boom. The problem of stranded assets is real—any effective response to climate change will mean that much of the world's coal and oil never comes out of the

ground. But it's not clear how far this problem extends beyond the fossil fuel sector. For manufacturers, even in the most carbon-intensive industries, only a small part of their value as enterprises comes from the capital equipment they own. More important is their role in coordinating production—a role that conventional economic models, myopically focused on coordination through markets, have largely ignored. Organizing complex production processes, and maintaining trust and cooperation among the various participants in them, are difficult problems, solved not by markets but by the firm as an ongoing social organism. This coordination function will retain its value even as production itself is transformed.

The world's chief trouble spot, the Middle East, will be even more problematic.

DANIEL PIPES
President, Middle East Forum

As the region with well over half the world's carbon fuel reserves, the Middle East is disproportionately affected by the price of oil and gas, from cases of extreme national dependence (tiny Qatar with its outsized global role) to ecological disaster (Saddam Hussein's burning of Kuwait's oil wells in 1991) to geopolitical tensions (over eastern Mediterranean Sea gas). So, should the price of hydrocarbons collapse, the area from Morocco to Iran will be the most affected.

Yes, some economies, such as those of Tunisia, Turkey, Israel, Bahrain, and Dubai, do not depend heavily on fossil fuels. Yes, some leaders, notably Saudi Crown Prince Mohammad bin Salman, realize that the rentier model cannot be sustained and seek to diversify.

And yes, the demise of oil and gas will bring some good news: More water desalination plants, less Islamism (petrodollars basically fund it), and Israel's enemies weakened.

But the negative implications of a gas and oil price collapse will be much greater. Foreign direct investment will shrivel. The majority of Middle Eastern economies will convulse. Regimes such as the Islamic Republic of Iran or the People's Democratic Republic of Algeria will not survive, leading to more anarchy (already rampant in Afghanistan, Egypt, Iraq, Lebanon, Libya, Somalia, Syria, the West Bank, and Yemen). Disagreements over access to scarce resources will spur new conflicts. Guest workers will return home in droves, upsetting those economies. Economic and other migrants will pour out of the region, headed mostly to the West, further upsetting the politics of Europe. Key airline and shipping routes will be disrupted. U.S. disengagement will enable nuclear weapons programs.

In brief, the world's chief trouble spot will retain its role, only more so. Attention to the Middle East, still the world's premier irritant, will continue long after the decline of oil and gas. ◆

THE INTERNATIONAL ECONOMY
THE MAGAZINE OF INTERNATIONAL ECONOMIC POLICY
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