THE NEW MAP

ENERGY, CLIMATE, AND THE CLASH OF NATIONS

DANIEL YERGIN

WINNER OF THE PULITZER PRIZE

Chapter 41

ENERGY TRANSITION

Mapping the path to a lower-carbon world will be a defining challenge in the decades ahead. Climate change caused by humans has been a topic of serious study for four decades. But the mobilization of public opinion on climate is more recent, driven not just by studies but by an increasingly intense focus on events around the world—forest fires, droughts, torrential rainfalls, coastal flooding, heat waves, melting ice, and hurricanes.

This alarm about climate is the great motivator for the "Energy Transition." The term is widely embraced—possibly the two most used words in talking about the future of energy. It aims to limit temperature rises to less than two—or 1.5—degrees centigrade above preindustrial levels, but beyond that there is no clear consensus. Is it to be a transition to a "lower-carbon energy" system—that is, one in which CO_2 emissions from human activities go down over time? Or is it to "deep decarbonization," in which emissions go down much faster? Or is it a "zero carbon energy" system—no human-related emissions? Or a "net zero carbon" system, in which emissions are canceled out by mechanisms that absorb the carbon? There is certainly no consensus as to the speed of the transition, nor as to what the transition will look like decades from now, nor as to the cost—nor as to how it is all to be achieved.

Energy transitions are not new. They have been going on for a long time and unfold over time. Previous energy transitions have primarily been driven by technology, economics, environmental considerations, and convenience and ease. The current one has politics, policy, and activism more mixed in.

The first energy transition began in Britain in the thirteenth century with the shift from wood to coal. Rising populations and destruction of forests made wood scarce and expensive, and coal came to be used for heating in London, despite fumes and smell. The need for coal for warmth became more urgent during Europe's several-century-long Little Ice Age, from which the world has since warmed. It was so cold that the Thames froze over; and it was said that Queen Elizabeth I strolled on the ice. Coal's advantage was price and availability, not superior or differentiated performance.

For a specific date in the first energy transition—coal's becoming a distinctive industrial fuel, superior to wood—January 1709 could well do. That month, Abraham Darby, an English metalworker and Quaker entrepreneur, working his blast furnace in a village called Coalbrookdale, figured out a way to remove impurities from coal, thus turning it into coke, a higher-carbon version of coal. The coke replaced charcoal, which is partly-burned wood, and had been the standard fuel for smelting. Darby was convinced, he said, "that a more effective means of iron production may be achieved." He was also ridiculed. "There are many who doubt me foolhardy," he said. But his method worked.[1]

Though it took a few decades to spread, Darby's innovation lowered the cost of smelting iron, making iron much more available for industrial uses, helping to spur the Industrial Revolution. Coal was the fuel source for Thomas Newcomen's steam engine, developed around the same time as Darby's innovation to pump water out of coal mines, and for James Watt's much-improved engine, the commercial introduction of which in 1776—the same year as the outbreak of the American Revolution and the publication of Adam Smith's *Wealth of Nations*—was a decisive moment in the Industrial Revolution. But as energy scholar Vaclav Smil observes, "Even with the rise of industrial machines, the nineteenth century was not run on coal. It ran on wood, charcoal, and crop residues." It was not until 1900 that coal reached the point of supplying half of the world's energy demand. Oil was discovered in northwest Pennsylvania in 1859. But it took more than a century—not until the 1960s—for it to supplant coal as the world's number one energy source. Even so, that hardly meant the end of coal, for consumption has continued to grow. As for natural gas, global consumption has increased 60 percent since 2000.[2]

—

The framework that has shaped the global discussion of climate change has been the periodic reports of the Intergovernmental Panel on Climate Change, known as the IPCC, under the auspices of the United Nations. This is a self-governing network of scientists and researchers that issues periodic reports, with each one raising further the crescendo of alarm. The first, in 1990, said that the earth was warming and that the warming was "broadly consistent with the predictions of climate models" as to largely "man-made greenhouse warming." But the changes, it added, were also broadly consistent with "natural climate variability." By 2007, in its fourth report, the IPCC was much more categorical—it was "very likely" that humanity was responsible for climate change. The actual report was not as categorical in all dimensions as the summary for policymakers. "Large uncertainties remain about how clouds might respond to global climate change," it said.

That same year, the Nobel Peace Prize was awarded to Al Gore, the former U.S. vice president who had become a leading climate activist and who declared that the world faced a "planetary emergency." Sharing the prize was the IPCC, represented by Rajendra Pachauri, its chairman for thirteen years. Shortly thereafter, he told the CERAWeek conference in Houston that the IPCC's warning is "not based on theories and supposition. It's based on analysis of actual data which is now so extensive and overwhelming that it leaves no room for doubt." He would later describe "the protection of Planet Earth" as "my religion."[3]

The fifth IPCC report, issued in 2014, was the starkest yet. "Human influence on the climate system is clear," and "emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems. Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia." Some raised questions about aspects of the IPCC report—disagreements among the several dozen different models, observations about the frequencies of hurricanes and the rate of ocean rising, understanding of feedbacks, and underestimation of natural variability. But they were a distinct minority.[4]

The 2014 IPCC report set the stage for what was to unfold in Paris a year later, which would give a whole new import to "energy transition" and make it a central global topic.

—

The Paris Climate Conference—otherwise known as United Nations COP 21—convened in the northern Paris suburb of Le Bourget at the end of November 2015. Just two weeks earlier, an ISIS jihadist assault had savaged the city, leaving 130 people dead and hundreds more injured. And so security was now extremely tight as fifty thousand people descended on the French capital to debate climate policy.

The organizers were determined that this meeting be decisive after the chaotic COP 20, held in Copenhagen six years earlier, which then–secretary of state Hillary Clinton had at the time described as "the worst meeting" she had attended "since eighth-grade student council."

The essential formula for avoiding another "Copenhagen" had really been set out in the Great Hall of the People in Tiananmen Square in Beijing a year earlier, in 2014. The United States and China—together responsible for over one-third of global greenhouse gas emissions—had until then been adversaries on climate. China and other developing nations had asked why they should "pay" for all the emissions that the developed nations had been putting into the atmosphere for a century by restraining their own energy use and thus holding back their own development. But in November 2014, standing together in the Great Hall, Barack Obama and Xi Jinping announced a joint commitment that their two countries would adopt significant new measures to reduce emissions. But their respective commitments had different timelines. The United States, Obama promised, would reduce its CO_2 by more than 25 percent in 2025 compared to 2005, much facilitated by increased natural gas use in power generation. China's carbon emissions could continue to rise, peaking only by 2030.[5]

Altogether, representatives of 195 countries and the European Union, joined at various times by 150 leaders of countries, attended the Paris conference, which began on November 30, 2015, to be followed by almost two weeks of arguing and grappling.

Just after seven in the evening on December 12, after an unexplained delay that left nerves fraying in the audience, French foreign minister Laurent Fabius strode out to announce a final agreement. The room erupted in cheers, thunderous applause, ovations, whistling, embracing, and even weeping. The UN secretary-general called it "truly a historic moment." There was, he said, "no Plan B."

What they had adopted was not a treaty but rather a compact to take actions that were intended to prevent temperatures from rising to two degrees centigrade above preindustrial levels in this century—and, it was hoped, no more than one and a half degrees. It was up to each country to come up with its own "nationally determined contribution"—what became known as NDCs—based upon its particular situation, laws, regulations, volition, and mood. These NDCs would not be binding, but rather voluntary. "Nonbinding" was crucial for Barack Obama, for a treaty would have to be submitted to the U.S. Senate, where it would never get the votes required for ratification. While not mandatory, these NDCs would have the power of declarative policy and the compelling force of the global consensus. Developed countries promised $100 billion a year in aid to developing countries to help them meet climate targets. "Make no mistake," Obama said. "This gives us the best possible shot to save the one planet we've got."

The agreement went into "force" a year after the conference, on November 4, 2016. As events would turn out, however, Donald Trump was elected president just four days later. He viewed the agreement decidedly differently. The compact, Trump said, "gives foreign bureaucrats control over how much energy we use on our land, in our country." He called climate change a Chinese "hoax." In the spring of 2017, Trump took to Twitter to announce that he was beginning the process to withdraw the United States from the agreement.[6]

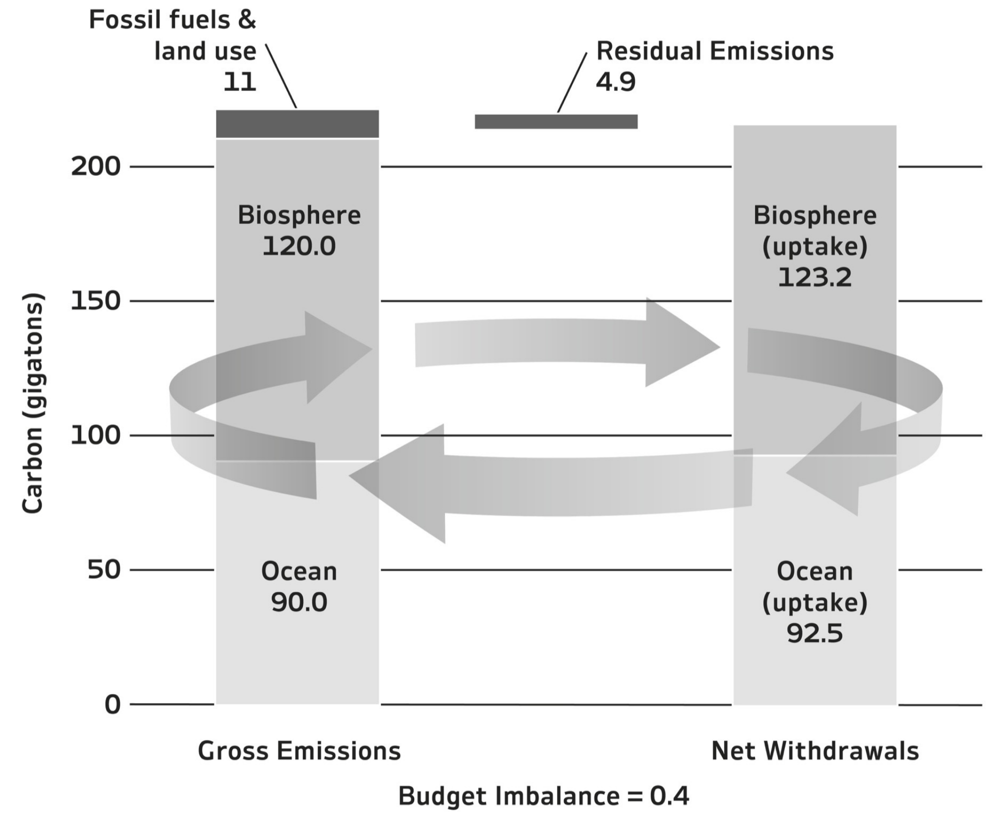
—

Notwithstanding Trump's announcement, which in any event would take three years to implement according to the agreement, "Paris" changed the global debate. For the most part, the time was past for discussing uncertainties about aspects of climate change—

rising sea levels, intensity of hurricanes, or climate models. The subject now was the warming planet, and now there were two distinct political eras when it came to the politics of climate: "Before Paris" and "After Paris."

Figure 1: The Carbon Cycle

Average Annual 2009–2018 estimated



Data: Global Carbon Project

While the degree of "confidence" rose with each new iteration of the IPCC, the basic argument was consistent. Here is how the logic works, using average annual data from the years 2009–2018 (see Figure 1): Some 210 gigatons of carbon were annually, on average, naturally released by such processes as the decay of plants and breathing by people and animals. But 9.5 gigatons came from fossil fuels and 1.5 from land use. This added up to a total of 221 gigatons released. But only 215.7 were captured in the natural annual cycle—that is, absorbed by vegetation and the ocean—leaving a residual 4.9 gigatons in the atmosphere uncaptured. (There is also a budget imbalance factor.) That uncaptured 4.9 gigatons is only 2.2 percent of the naturally captured CO_2. That may seem a very small amount in any given year. But, over the years, it accumulates and builds up in that band of gases known as earth's atmosphere. Water vapor is the most prevalent greenhouse gas. Others include nitrous oxide and methane. Some of these gases dissipate after a year or ten years; others last much longer. Some are more potent than CO_2.These greenhouse gases become a shield of sorts, a global "greenhouse" around the planet, retaining more of the sun's heat, which otherwise would flow back into space. The result is greater warming for the earth—thus known as the "greenhouse effect."[7]

As the climate consensus has crystallized, concern and fervor have risen, fueled by the fear that an approaching "tipping point" will lead to "runaway climate change." The growing dread is reflected in the vocabulary; "global warming" and "climate change" have given way to "climate crisis" and now "climate emergency" and "climate catastrophe."

The Swedish activist Greta Thunberg became the voice of this urgency, beginning when, in August 2018, as she put it, she "school-striked for the climate" outside the Swedish Parliament. Her message became zero carbon. "Expansion of airports," she told the British Parliament in the spring of 2019, "is beyond absurd." At the U.N. Climate Summit the following September, she said, "You have taken away my dreams and my childhood with your empty words," adding, "How dare you?" She warned that a new "mass extinction" loomed unless climate was quickly addressed. Not long after, she elaborated in a coauthored article her thinking as to the sources of the global warming: "Colonial, racist, and patriarchal systems of oppression have created and fueled" the "climate crisis," adding, "We need to dismantle them all."[8]

Finance and energy investment have become a new arena for climate. The claxon was sounded by Mark Carney, the then-governor of the Bank of England, in 2015, several weeks before the Paris conference in a speech to the venerable insurance organization Lloyd's of London. Climate, he said, has become "a defining issue for financial stability" and created "systemic risk" for the world's financial system, which, in central bank language, harked back to the global financial crisis of 2008. He warned that investors and insurers faced the growing risk that oil and gas companies' reserves in the ground would remain in the ground—"stranded"—unable to find their way to market because demand had faded away, or, as Carney put it, be "literally unburnable" over thirty years because of policies imposed to achieve the "two-degree world." That would mean that the value of the companies would plummet, he argued, perhaps even becoming worthless, leaving investors holding equity that had also become worthless. He called for a "sweeping reallocation" of investment away from traditional energy companies to finance "the de-carbonization" of economies.

Some, in response, pointed out that companies' oil and gas reserves are not valued over thirty years by investors, but only about ten years. In any event, most of the world's oil and gas reserves are owned by national governments, and not shareholders in Britain or the United States.[9]

Thereafter, the Financial Stability Board, whose members are central banks, focused on "climate-related financial disclosure" that requires companies to disclose how their investments and strategies comport with achieving the objectives of the two-degree world.

Pension funds and other investors are now pressing energy companies to explain how their strategies and profitability would fare under the terms of the 2015 Paris Agreement. In his 2020 annual "Letter to CEOs," Larry Fink, head of BlackRock, the world's largest investment company, declared, "Climate change has become a defining factor in companies' long-term prospects" and that "in the near future—and sooner than most anticipate—there will be a significant reallocation of capital." BlackRock, he said, will "place sustainability at the center of our investment approach" and will require companies to "disclose climate-related risks." When BlackRock—$7.5 trillion under management—speaks, companies listen. One example of the "reallocation of capital" is the growth in "green bonds." These provide financing for infrastructure related to renewables and infrastructure. From $50 billion issued in 2015, the total reached $257 billion in 2019.

Divestment—the movement to get investors to sell their shares in energy companies, and banks not to lend to them—is gaining momentum. There is also pushback. Microsoft founder Bill Gates, who is investing billions in seeking technology breakthroughs for lower-carbon energy, has said, "Divestment, to date, probably has reduced about zero tons of emissions." Consumer demand still has to be met. There is no obvious way that people around the world can any time soon dispose of their 1.4 billion cars that run on oil, and people will still need to heat and air-condition their homes. There are other aspects as well. Dividends from BP and Shell were funding 20 percent of all pensions in Britain.[10]

On many college campuses, divestment has become a contentious issue. One of the great traditions in American football is "The Game"—Yale versus Harvard—which has been played since 1875. During halftime at the November 2019 game, hundreds of students carried the fight against climate change to the football field, suddenly pouring onto it, delaying the second half. Their targets were the investment offices of Yale and Harvard, which they wanted to divest of their energy holdings. One student warned, "Life at Yale cannot go on as usual until Yale divests."

Their particular ire was directed at David Swensen, the legendary head of the Yale endowment, whose investment returns had, among other things, financed the scholarships of many students. "If we stopped producing fossil fuels today, we would all die," Swensen had recently said. "We wouldn't have food. We wouldn't have transportation. We wouldn't have air conditioning. We wouldn't have clothes." He added, "The real problem is the consumption" and "every one of us is a consumer." The president of another major university was surprised when told that the financial loss from divesting energy would be greater than the university's entire budget for undergraduate scholarships.[11]

Pressure comes in other forms. Annual stockholder meetings of banks and energy companies have been disrupted by activists rappelling down from the ceiling, and opponents of hydrocarbons have stepped up their efforts—both physically and in courts—to block pipelines and other projects. A plan was developed at a meeting in La Jolla, California, in 2012 to plot out a "tobacco" strategy—that is, to brand oil and gas companies as peddlers of a dangerous and addictive product, like the tobacco companies. The difference, of course, is that tobacco is a habit, while oil and gas are enablers of modern life.

This strategy has played out in the years since. In line with the spirit of La Jolla, the British newspaper *The Guardian* announced that, as a self-described climate campaigner, it would no longer accept advertising from oil and gas companies. It added, however, that it would have liked to accede to demands by Greenpeace and other "readers" that it also reject advertising from automobile and travel companies. But if it did so, it explained, it would be a "severe financial blow" that would force it to fire many of its journalists. But it did promise, from thereon it would no longer use the term "climate crisis" in its news columns, but now all references would be to "climate emergency."[12]

"Fighting climate change" has now become a broad social movement, engaging people not only in terms of policy and business decisions but also increasingly in their personal lives and sense of personal responsibility. In Britain, the Royal Shakespeare Company terminated an eight-year gift from an oil company because, it said, of the "strength of feeling" among young people. Some people have become vegans so as to give up meat and dairy products from methane-producing cows. Invoking "flight shaming" that has emerged in Scandinavia, a headline in the *New York Times* asked, "How Guilty Should You Feel About Flying?" The answer seemed to be if you did more than six flights a year. So significant has this personal dimension become that one of the major U.S. television networks invites "those who care deeply about the planet's future" to go to its "confessions" page on its website to share how personally "you have fallen short in preventing climate change."[13]

Chapter 42

GREEN DEALS

Climate has risen to the top rung of policy in a number of nations. Of the G20 countries, fourteen deploy or have announced plans to deploy carbon pricing mechanisms or some kind of carbon tax. The United Kingdom announced that it will legally commit to zero carbon emissions by 2050. Two dozen other countries are promising the same, though the path for most is far from clear.

Europe, more than anywhere else on the planet, is seeking to build an "After Paris" world. And, more than anywhere else, it is seeking to use government policy to drive this energy transition. Declaring that climate is Europe's "most pressing challenge," Ursula von der Leyen, president of the European Commission, has pledged to turn all of Europe into "the first carbon neutral continent in the world." The head of the European Investment Bank, in announcing an end to finance for natural gas projects by 2022, went even further, saying, "Climate is the top issue on the political agenda of our time."

The EU's "green deal" aims to make net zero carbon legally binding for the Continent by 2050. "Net zero" requires a further word of explanation, for it will be fundamental to future discourse. The World Resources Institute explains, "Net zero carbon" is not the same as "zero carbon." "Net" means minimizing "human-caused emissions" to "as close to zero as possible," with "any remaining" emissions balanced out by the "equivalent amount of carbon removal"—for instance, by "restoring forests" or with carbon capture. In other words, carbon can be released, but in some way an equal amount of carbon must be captured. Today, Europe is responsible for about 12 percent of the CO_2 emissions released by burning carbon (see Figure 2).

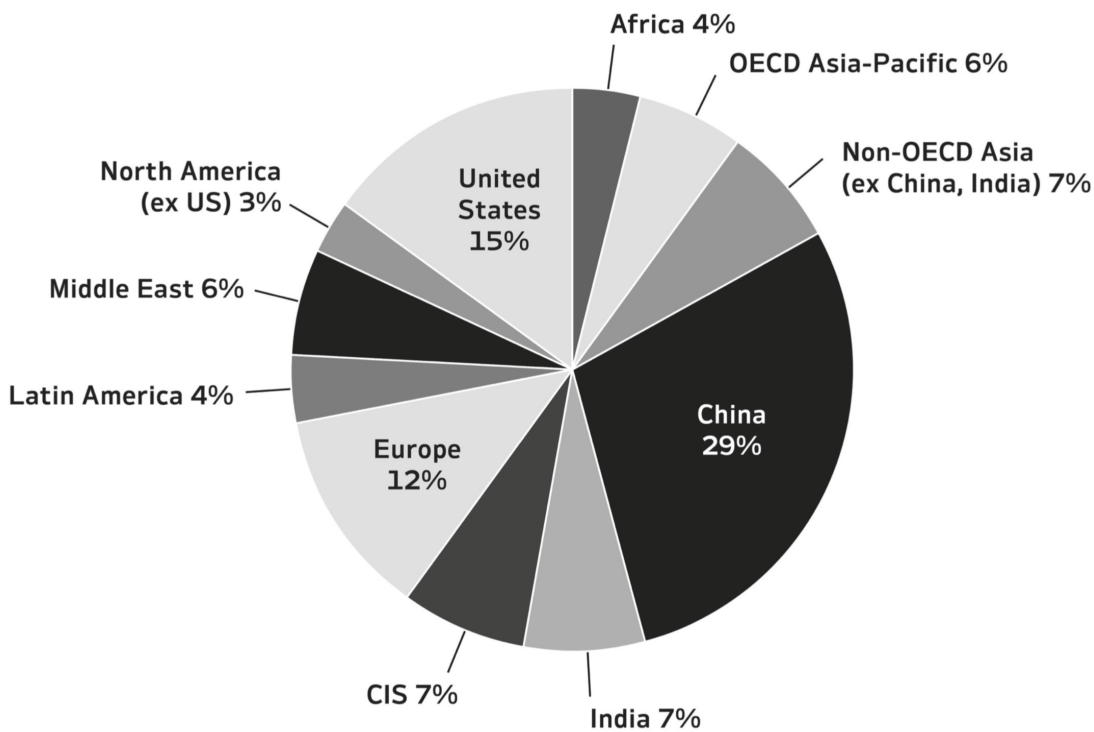
A basic tool for Europe's achieving net zero is the *Taxonomy*, a 66-page report, backed up by a 593-page technical analysis, by dozens of "leading thinkers" that evaluates sixty-seven economic activities as to "environmental friendliness" and "sustainability." It is meant to direct investment flows. The EU will require investment managers to label how "Taxonomy-compliant" their funds are. The *Taxonomy* will be used to guide new regulations and government programs for "green investment." While "very clean" natural gas may be acceptable, most natural gas and all of nuclear are problematic under the *Taxonomy*, coal is to be eliminated, and all coal mines to be shut down. In addition, six thousand firms with over five hundred employees in Europe will be required to identify which of their activities are environmentally sustainable. The EU is also considering "border taxes"—otherwise known as tariffs—on goods from other countries that do not have equivalent carbon-pricing programs to Europe's. This is sure to create contention with Europe's trading partners.[1]

Altogether, the EU has staked out a position on the parapets of "green commanding heights." For Europe's 2050 goal is breathtaking: nothing less than reshaping economic activity, directing investment, and rebuilding Europe's economy over the next three decades. The program will aggregate power to the European Commission in terms of regulating businesses and allocating capital. As to why this should be the EU's "first priority," as von der Leyen calls it, given all its other issues, including its own future, one European businessman close to the European Commission hypothesized that also "they are looking for a new narrative for the European ambition."

"The costs of the transition will be big," von der Leyen said, "but the costs of inaction will be much bigger." The EU has established a 100-billion-euro "Just Transition" mechanism to help buffer the impacts for countries still reliant on coal. Yet, at this point, the costs of "net zero carbon" are murky. As a paper from the Peterson Institute for International Economics explained, "Whether the transition to a climate-neutral economy will improve or hurt growth is a quantitative issue. Unfortunately, we know too little about it." While arguing that prosperity depends long-term on decarbonization, it said that over the next five to ten years, "decarbonization will inevitably reduce economic potential."

Figure 2: Emissions by Country/Region

Global CO_2 emissions from fuel combustion, by major country/region (2019)



Source: IHS Markit
based on IPCC methodology

The green deal got a jump start in an $825-billion anti-crisis package that von der Leyen introduced in May 2020. The presentation described "the European Green deal as the EU's recovery package" and as "Europe's growth strategy," with a substantial share of that $825 billion going for wind, solar, "clean hydrogen," renovating buildings, "clean mobility in our cities," and the installation of a million charging points for EVs.[2]

The overall objective—net zero carbon by 2050—is a daunting ambition. How daunting is underscored by the estimate that, for Europe to achieve its target, per capita emissions will have to decline to the level of India, where the per capita income is about $2,000 a year, compared to Europe's $38,000.

—

For some, the year 2050 is too far away and a transition over thirty years is too long. That is the essence of the Green New Deal launched on the steps of the U.S. Capitol by the left of the Democratic Party in 2019, led by Representative Alexandria Ocasio-Cortez, who had decided to run for Congress after joining the protest against the Dakota Access pipeline. In its content, this Green New Deal synced up closely with the Green New Deal platform of the Green Party candidate, Jill Stein, in the 2016 presidential election.

The talking points released just prior to the official release of the Green New Deal called for the United States to be powered by 100 percent clean and renewable energy by 2030. The role of the private sector would be secondary in this endeavor, as "government is best placed to be the driver," mobilizing "massive federal investment." The program would seem to ground existing airplanes because there is no large-scale alternative to jet fuel. Among the many proposals, farmers and ranchers would be pressed to be "greenhouse gas free," which would mean doing away with all their cows, owing to their bovine methane emissions. The non-energy proposals included government-guaranteed jobs. "The world is going to end in twelve years," Ocasio-Cortez said, "if we don't address climate change."

The talking points reflected the viewpoint of some of the advocates, but not all. They were pulled back just prior to the official launch of the Green New Deal. Ocasio-Cortez's partner in launching the program, Senator Edward Markey, a veteran of decades of legislative battles, explained that the 100 percent was not a forecast, but rather was "aspirational." The actual congressional resolution was more general, calling for a ten-year "new national, social, industrial, and economic mobilization on a scale not seen since World War II and the New Deal" to generate a Green New Deal that would meet a host of objectives—for instance, "counteract systemic injustices"—but principally "to achieve net-zero greenhouse gas emissions" and "100 percent of the power demand in the United States through clean, renewable, and zero-emission energy sources."[3]

In the 2012 U.S. presidential debates, not a single question was asked about climate. In the 2016 president debates, climate got a total of five minutes. In 2020, CNN hosted a seven-hour climate town hall on the subject. Climate became a major issue in the

Democratic primaries. Some candidates called for a ban on fracking. Climate now polled as a major issue, especially for millennial voters.

During the primary campaigns, candidates vied over climate action plans. Joe Biden's $1.7 trillion program and Elizabeth Warren's $4 trillion paled next to Bernie Sanders's $16.3 trillion. Sanders's long list of would-be initiatives included $35 billion for people to reforest their front lawns or turn them into "food-producing spaces" as well as "ensure fossil fuels stay in the ground" and ban both exports and imports of oil. But how you ban imports and exports of oil and at the same time ban domestic production of oil—and still have a functioning economy and society—was left unexplained. Nor what happens to the 12.3 million jobs in the United States associated with the oil and gas industry.

Still, for many the determination and commitment to speed an energy transition are there and deeply felt. But will the money be there after the costs of the coronavirus crisis and the trillions of dollars and pounds and euros of government debt wracked up to deal with it?

Chapter 43

THE RENEWABLE LANDSCAPE

What will the energy landscape look like twenty or thirty years from now? Yes, it will be "lower carbon." But what comprises that system? At this point, it appears that the energy system in the next decades will continue to be, as it has been in the past, a mix, but a shifting mix, differing considerably among countries, but also certainly lower-carbon than today's.

One will see a multitude of solar panels and wind turbines across the energy landscape. These are the "modern renewables," as opposed to the traditional renewables of hydropower, wood, and biomass. They will be among the main engines for achieving the climate goal of a transition from CO_2-producing electricity generation to carbon-free generation. Nuclear power remains today the largest source of carbon-free generation, but the gap is narrowing with wind and solar. Although wind and solar are called "modern" renewables, neither is exactly new. Both are about half a century old.

The theoretical foundation for today's solar panels—photovoltaics (PVs)—was provided by Albert Einstein in his 1905 paper "Concerning the Production and Transformation of Light." The light arriving from the sun, he said, was composed of photons, packets of energy, which could dislodge electrons surrounding the nucleus of an atom, creating an electric current. Einstein was awarded the 1922 Nobel Prize in Physics for this paper, his "discovery of the law of the photoelectric effect." But it was not until 1953 that the photovoltaic effect was demonstrated at Bell Labs in New Jersey.

The modern solar industry really began in 1973, with the launch of two ventures. One was a unit of Exxon. The other was by two scientists who had worked on the U.S. space program—Joseph Lindmayer and Peter Varadi—both of them refugees from Europe. Over the following three decades, other ventures were launched, mainly by oil companies, hedging against an uncertain energy future, and by Japanese tech companies, sparked by Japan's alarming lack of natural resources. The appeal of solar has been enormous ever since. As Professor Martin Green, a leader in solar research for decades, puts it, "The whole photovoltaic technology itself is a bit magical. Sunlight just falls on this inert material and you get electricity straight out of it." But for many years the markets for PVs remained niche for off-grid uses—to bring electricity to isolated homes or remote locations or, for that matter, to marijuana growers, who did not want oversized utility bills to call the attention of law enforcement to their illicit businesses. The first introduction to solar power for many people was the solar-powered pocket calculator.[1]

What catapulted solar into the mainstream was the marriage of Germany's environmental politics with Chinese manufacturing prowess. Beginning in the 1990s, Germany's "feed-in" tariff laws required utilities to buy renewable electricity at high prices from generators and then spread the cost over all electricity bills. This law laid the foundation for a broad shift—Germany's *Energiewende*, the "energy turn"—which aimed to replace conventional energy with wind and solar. The generous subsidies from the feed-in tariffs speeded renewable deployment, while also leading to the highest residential energy prices in the European Union.

Companies rushed in to meet the large and growing demand for solar and wind. However, while the solar market created by the *Energiewende* may have been in Germany, the panels could come from anywhere. In time, most of them would come from the new solar juggernaut that would rise in China and eventually extinguish German manufacturers.

As late as 2006, China had barely a walk-on role in photovoltaics production. But then came the big push by Chinese entrepreneurs, backed by China's central government and regional and local authorities, in the form of land, large low-cost loans, and other subsidies. This coincided with the increased push for solar not only in Germany but also in Spain and Italy, fueled by substantial subsidies. By 2010, there were 123 solar panel manufacturers in China.

Between 2010 and 2018, China's manufacturing capacity for solar cells increased fivefold, which was well beyond the global demand. Many more solar panels were pouring out of China than the market could absorb. Prices came tumbling down. As they gained market share, Chinese companies also struggled under great financial pressure. Some went bankrupt. Over two years, the Chinese Development Bank extended $47 billion in credit to keep money-losing Chinese companies afloat.

To ease the pain of this overcapacity, as well as to support employment, the Chinese government set out to create a new market within China for the beleaguered solar manufacturers. This was also aimed at meeting the critical national need—reducing the suffocating pollution from older coal-burning plants while continuing to meet the country's surging demand for electricity. By 2013, China had overtaken Germany as the largest market for installed solar panels, and by 2017 it alone represented half of the entire global market.[2]

China now produces almost 70 percent of the world's solar panels. Adding in Chinese companies that manufacture in other countries brings the total share up to almost 80 percent. China makes 70 percent of the photovoltaic solar cells that are the heart of the panels. When it comes to the solar wafers out of which the cells are produced, China's share is even greater—almost 95 percent. This means that, in green energy, China has already reached the "Made in China 2025" goal of a dominant role in this century's new industries.

China's overwhelming competitive advantage arises from many factors—government support and cheap financing; scale (much bigger factories); reductions in polysilicon prices; focus on costs; proximity to supply chains; standardization of products; and continuing technology improvements. Martin Green points to one other factor. "Present low photovoltaic prices," he says, are also "the outcome of serendipitous combinations of events and personalities," including that a number of leading figures in different Chinese companies worked at various times with his teams in Australia. The cost of solar panels came down an extraordinary 85 percent between 2010 and 2019, driven mainly by Chinese manufacturing and massive capacity, and by technological improvements. Like the advent of shale, a price drop of this magnitude is proving revolutionary for energy. Total installation costs have also gone down substantially, but not to the same extent.[3]

China has also established a decisive position further upstream in the supply chain for solar. It now produces almost 60 percent of the key raw material, polysilicon. It has also made a major effort to build up the domestic PV equipment industry and reduce dependence on Western suppliers.

Solar's ascent has been extraordinary. Global installed capacity in 2019 was 642 gigawatts, fourteen times what it had been little more than a decade earlier. While panels on roofs may be more visible, over half of total capacity installed between 2010 and 2019 is utility-scale—that is, solar parks that feed into the grid.

Overall, the global growth in capacity has been fueled by two things. One is that huge decline in prices and what the renewable advocacy organization REN calls "cutthroat pricing" resulting from the overcapacity in Chinese PV manufacturers. The other is a growing global system of incentives, subsidies, and mandates at national, state, and local levels, requiring increasing amounts of renewable energy in electric systems. The PV electric generating capacity added globally in 2019 was bigger than the additions from fossil fuels and nuclear. But that requires an important caveat —"operating time" is much less than "capacity." Much of the fossil fuels and the nuclear are base load or can be managed to correlate with demand for electricity at any given hour. Solar is intermittent, depending for the most part on the availability of sunlight, and actual generation may only equate to about 20 percent of capacity.[4]

—

Though the modern wind industry, like solar, goes back to the 1970s, its real growth has only been in this century. In 2000, just 17 gigawatts of wind capacity had been deployed worldwide. By 2019, it had grown to 618 gigawatts. Over 40 percent of total installed wind capacity is in Asia, with three quarters of that in China.[5]

The growth is propelled by forces similar to those that have driven solar, beginning with technical innovation. Taller towers, longer blades, new materials, more sophisticated controls and software, better wind models and weather prediction—all these transform more of the wind into electricity. While 95 percent of total wind capacity is onshore, the industry is venturing offshore, where the winds may be steadier and stronger and the towers larger and the wind resource potentially much greater, but the technical challenges of waves and wear are greater. To date, offshore wind development is concentrated in Europe, mainly in and around the North Sea, although growing in China's offshore, and projects are being pursued off the east coast of the United States.

The second force is the incentives and subsidies, and the strong mandates requiring more renewables in electric generation. And the third is falling costs, the result of what REN, echoing its solar comment, calls "fierce competition in the industry." The last has put great pressure on companies, leading to bankruptcies, restructurings, and mergers.

As with solar, the often-cited "capacity" can be misleading, because wind, like solar, is intermittent. It depends upon the wind blowing. But capacity factors are increasing with the technological advances. Today, the global weighted average is about 25 percent, though higher with new turbines.

Europe has the highest share of wind in electricity generation, accounting for almost 12 percent of total electricity supply. China is about 5 percent, the United States about 7 percent. In the United States, the state with the most electricity generated by wind is not California, as some might expect, but Texas, at 15 percent. If Texas were a nation of its own, it would rank sixth among the countries of the world in terms of installed wind capacity. A good part of the state's wind turbines are in West Texas. It turns out that the Permian Basin in West Texas is bountiful not only in oil and gas but also, above ground, in its wind resources.

—

THE RAPID GROWTH OF SOLAR AND WIND IS UPENDING THE WAY THE electric power industry has operated for over a century, changing its strategy and structure. "People understand that we need more wind, solar, and hydro," said the CEO of one European utility. "This is fundamentally challenging the model of all the energy companies." They are shifting from traditional "central" generation, based on coal and gas and nuclear power plants, to "distributed and intermittent" generation based on wind farms and solar panels that are spread across the landscape. But “distributed” systems create new challenges, especially in terms of grid stability and reliability, which is a fundamental mission of utilities. “With the advancement of distributed generation, with the monitoring of two-way flows on the system, with managing circuit overload potentials, more technology is going to have to be put into storage and control mechanisms,” says Christopher Crane, CEO of the U.S. utility Exelon and chairman of the Edison Electric Institute.[6]

—

How fast will the transition be, and what will it look like on the other side? Predictions vary widely. In the IHS Markit scenarios, global electric consumption grows by up to 60 percent by 2040. Wind and solar constitute 24 to 36 percent of total generation by that date. Either is a big increase for wind and solar from today’s 7 percent globally. The reasons for the variance result from what one would expect—uncertainties and varying assumptions about technology and innovation, and policies and economics.

Wind and solar together have grown dramatically, from 2 percent of U.S. power generation in 2010 to 9 percent in 2019, and they will continue to grow rapidly. Yet U.S. electricity is very unlikely to be 100 percent renewable by 2040. There’s neither the technology nor the investment dollars to do that, nor the grid to support that, nor the magic wand to obliterate America’s current energy infrastructure and transform the regulatory and political landscape and at the same time assure that the needs of electricity-dependent consumers for reliability are met. Further electrification of the economy will add to demand, which will make reaching 100 percent even more unlikely.[7]

The global picture underlines the same point. Even Denmark, which at times produces more wind electricity than it can consume, also depends on imports of electricity generated by nuclear in Sweden, hydropower in Norway, and coal in Germany to maintain the stability of its power supplies.

One factor to be taken into account is the huge capital investment that is in the ground today, in the long-lived investment of the electric power industry around the world—and the new investment currently being made. In 2011, following the Fukushima nuclear accident in Japan, Germany set out to close its seventeen nuclear reactors by 2022. Yet between 2011 and 2019, China added thirty-four new nuclear reactors, double the number of reactors that have closed in Germany. A few nuclear reactors have closed in the United States because of the difficulty of competing against inexpensive natural gas, but close to a hundred reactors are operating, providing 20 percent of U.S. electricity. As for natural gas, the growth of its contribution to total world energy in 2018 was more than double that of renewables. Adding it all up, energy transition is complex and requires some perspective.

—

The world is increasingly electrified, but that also increases the need for reliability and predictability of the electricity supply. The positives of wind and solar are clear. Once the capacity is in place and paid for, there is no cost for the fuel. There are costs, however, both for maintenance and for the overall electric power system in managing renewable power. The variability of wind and solar—that is, their intermittency—poses major challenges. The first is how to integrate large and fluctuating amounts of wind and solar into an electric grid that generally operates on the orderly dispatch of electricity from conventional power plants, correlated to the demand at any particular time of day, and assures reliable power to consumers. As the amount of wind and solar grows, this becomes a larger problem. In his generally positive book on solar power, Varun Sivaram warns, "Rising solar penetration could make the grid less reliable." He adds, "Much more solar is on the way, bringing with it wild swings in power output that could increase the risk of blackouts." He also cites economic risk for the solar power industry—what he calls "value deflation." When solar (or wind) floods into the grid, the swelling tides drive costs down toward zero, lowering investors' returns and potentially undermining the investment made in the solar infrastructure (unless bailed out by government).[8]

In other words, at this time at least, solar and wind cannot go it alone. They need partners. Natural gas generation is a flexible partner for solar and wind. Gas is lower-carbon and lower emissions (with methane control), and gas generation can be ramped up and down to provide balance against the fluctuations of wind and solar.

Integration of renewables will require increasingly complex management of the grid. It also depends on solving the second challenge—storage. Oil can be stored in tanks, natural gas in underground caverns. At this time, however, there is no redoubt for storing large amounts of electricity not just for a few hours, but, as former U.S. energy secretary Ernest Moniz says, for several days. The only notable capability today comes from what is called "pump storage," which is a form of hydropower. But it is very small and limited in growth.[9]

A great deal of effort is being poured into trying to develop utility-scale batteries, economically capable of storing large amounts of electricity that can be dispatched in an orderly way.

—

Not so long ago, wind and solar were called "alternatives." That is hardly the case today. They are now mainstream and will become mainstays of future electric generation. Over half of that total investment in renewables was, again, concentrated in Asia—with the majority in China. It happens to be the country that, by itself, consumes a quarter of all the electricity generated in the world. And its growing economy needs more electric generation capacity. Even as China continues to build out wind and solar at a rapid rate, it is also adding three new highly-efficient coal-fired plants a month.

Chapter 44

BREAKTHROUGH TECHNOLOGIES

We don't have the technologies for advancing the energy transition to net zero carbon," Ernest Moniz says. What are those technologies that will accelerate and reshape the energy transition? A new study, *Advancing the Landscape of Clean Energy Innovation*, led by Moniz and myself, conducted for the Gates Foundation and the Breakthrough Energy Coalition, identified twenty-three technologies with "highest breakthrough potential." They fall into several areas: Storage and battery technology for the intermittency that bedevils large-scale use of wind and solar. Advanced reactors and a new generation of small reactors that would revitalize carbon-free nuclear power. Today, there are more than sixty advanced private-sector nuclear research projects in the United States.[1]

Hydrogen had its false starts almost two decades ago with the hydrogen "freedom car" and a "hydrogen highway" in California. But a renewed focus has emerged on hydrogen to substitute for natural gas in heating and for fuel cells as an alternative to electric vehicles. There's no great mystery here. Hydrogen is already used extensively in oil refining and for making fertilizer. While it is the most common element, hydrogen does not naturally exist by itself, except in rare instances. It is derived by breaking up molecules. Today most hydrogen is produced from natural gas and coal. (A typical natural gas molecule contains one atom of carbon and four of hydrogen.) It can also be made with electrolysis—that is, an electric current running through water. And the source of that electricity could be renewable power, using the excess electricity generated at certain times by wind and solar. Scale will require advances in technology and cost reduction—and spending on infrastructure.[2]

Hydrogen could end up a 10 percent or more player in the energy mix in the future. Indeed, some see hydrogen today as where renewables were two or three decades ago in terms of development. It is striking, too, that hydrogen does not seem to involve geopolitical issues. It is either a tool for countries to meet ambitious decarbonization goals or an opportunity for export, becoming a globally-traded commodity.

Advanced manufacturing, including 3D printing, could have a major impact on energy use by reducing transportation costs. New technologies for buildings could make them much more energy efficient. Electric grid modernization and smart cities could apply digital technologies, increase resilience, and create two-way flows between energy suppliers and customers.

Of critical importance will be large-scale management of carbon itself. Some dismiss carbon capture because they want a world in which there are no carbon emissions from human activity. But that seems quite unrealistic given what is necessary to get to a "net zero carbon" world. The UN Intergovernmental Panel on Climate Change (IPCC) accords an important role to carbon capture, as does the International Energy Agency.[3]

Carbon capture is integral to how the natural system—the lungs of the world—works. What plants do is absorb CO_2 from the atmosphere, store the carbon in the trunk of a tree or the roots of plants, and release the oxygen back into the air for living creatures to breathe. Farmers cultivating their crops have been in the business of capturing carbon back to the beginnings of agriculture twelve thousand years ago.

A decade or so ago, there was a surge of interest in capturing CO_2 (especially from coal-fired power plants), compressing it into a liquid, and then transporting it by pipeline and storing it underground. A few projects were launched, but proved expensive and involved heavy engineering, and traction was slow in coming.

The 2015 Paris climate compact provided new impetus to develop "carbon capture and storage," or CCS. Around the same time, a "U" for "use" was added to the acronym. It became "carbon capture, use, and storage"—CCUS. That meant finding commercial applications beyond putting the fizz into carbonated soft drinks. After Paris, the Oil and Gas Climate Initiative—the group of thirteen oil and gas companies mentioned earlier—established a $1.3 billion research fund to work on energy transition technologies with a focus on CCUS. Another major impetus came from the U.S. government, which enacted what is known as "45Q." It provides a tax incentive for CCUS technologies, analogous to the tax credits that have been so crucial in the commercialization of wind and solar in the United States.

CCUS takes many forms today. For instance, captured carbon is being used to manufacture products like cement and steel. "Direct air capture"—pulling CO_2 out of the air—had seemed fanciful, but progress is being made and units are being scaled up.

And then there is going full circle, back to what are called "nature-based solutions," otherwise known as forests, crops, and other plants. It is quite possible that Mother Nature has been underestimated. Reforestation and improved cultivation practices are part of the package. Research projects are also aimed at creating super-plants that have a stronger appetite for absorbing CO_2.

The aim, says the Harnessing Plants Initiative at the Salk Institute, is to "coach plants" to "increase their carbon-storing potential." In other words, plants can play a larger role than now anticipated in closing that carbon gap and become part of the CCUS repertoire. "Back to nature" takes on a new meaning.[4]

Advancing these varied technologies will take money and time. By 2030, if not before, the signals and cadences will indicate the rate of progress on these fronts, as well as on others that may not have much visibility today.

day, poverty and economic growth cannot be separated from energy. The energy issues India faces reflect, in a giant-sized way, those of many developing countries.

The term "energy transition" has multiple dimensions for India. It is a transition out of poverty and using wood and waste and into commercial energy—and better health and reducing pollution, both in cities (India has seven of the ten most polluted cities in the world) and in village homes, where the traditional "chulha" stoves fill rooms with noxious fumes. And it means ensuring that the country achieves the growth rate required to lift hundreds of millions of people out of poverty. As the government's *Economic Survey* put it, "Energy is the mainstay of the development process of any economy."[2]

How India develops will have global impact. As its economy grows and becomes more integrated with the global economy, its economic and political weight in the world will also rise.

India has struggled with the inadequacy of modern energy for a long time. Noncommercial energy commonly known as "biomass"—wood and agricultural and animal waste—has been the fuel for more than half of India's population. In terms of commercial energy, India depends on coal for over half of its total energy, and almost 75 percent of electricity. Oil provides about 30 percent of the country's energy. But about 85 percent of the oil is imported, raising anxiety about energy security and creating vulnerabilities for the balance of payments, which morph into crises when the oil price spikes. Natural gas is 6 percent of total energy, compared to a global average of about 25 percent. Modern renewables are just 3 percent of total energy; nuclear, only 1 percent.[3]

When Narendra Modi became prime minister in 2014, his government faced a whole set of energy issues that were holding India back. It focused on energy as an essential engine for economic growth. In 2015, to jump-start energy reform, Modi convened in New Delhi the Urja Sangam, a national energy summit, at which he laid out a series of principles to guide energy development—access, efficiency, sustainability, energy security, and, since added, energy justice. He talked about adjusting the "institutional mechanisms" to be more responsive and flexible and more open to market solutions.

Implementing those principles has not been easy. It meant taking on complex, burdensome, overlapping, and often immobilizing systems of regulation, for which "timeliness" often did not seem to matter much. The “permit raj” of government control was still pervasive. The government had been managing prices disconnected from supply and demand. All of this led to inadequate supply and shortages.

Modi subsequently brought together people from government and the private sector to debate how to break the impasse in India’s energy position. Some argued that the “market” was too volatile, too open to manipulation, and could not be trusted; government had to keep control and manage the market. Others said that times had changed; India could not meet its goals on growth and poverty reduction without major reform and an opening to markets and to the world. At the end, Modi looked up from his notes and simply said, “We need new thinking.”

That “new thinking” underpins an energy transition across the entire spectrum. “Our energy requirements are vast and robust,” says Dharmendra Pradhan, minister of petroleum and natural gas and steel. “India will have an energy transition in its own way. Mixing all exploitable energy sources is the only feasible way forward in our context.”[4]

In houses and in villages throughout the country, the smoke from indoor cooking contains carbon monoxide, black carbon, and other pollutants, creating pervasive and severe health problems. In response, the government launched a “blue flame revolution” to deliver cylinders of propane—derived from oil or natural gas—to eighty million rural households for cooking. It has reformed the fiscal, regulatory, and price systems to encourage production and investment in upstream oil and gas by both Indian and international companies and has opened new areas for exploration. Overall, the government, in the words of petroleum minister Pradhan, is seeking to “usher in a gas-based economy.” Some $60 billion is being spent on building a natural gas system of major pipelines and urban distribution. One focus is to replace diesel with compressed natural gas as fuel for cars and light trucks, to help reduce urban pollution.[5]

India is becoming a major player in the global LNG market. It is diversifying its sources and has become a significant buyer of both LNG and oil from the United States. This has brought a significant new dimension to relations between the two countries, one made tangible by the interdependence that comes from the scale of this trade—something that would not have been imagined a decade ago either in New Delhi or Washington. Another initiative is to convert agricultural waste in local plants into biofuels and biogas that can be fed into larger distribution systems.

And with climate change in mind, the Modi government has set out ambitious goals for renewables. It has also put tariffs on solar panels, to try to ensure that Indian companies can compete with cheap imported panels from China. As Pradhan summed it up, “India will pursue the energy transition in its own way.”

What Pradhan is also pointing to is what some regard as a gap in discussion in the developed world about energy transition—underplaying the challenges and human hardship in developing countries and dismissing as “dirty energy” what many in the developing world say is the clean energy they need for healthier and better lives.[6]

Chapter 46

THE CHANGING MIX

Reading the map was more straightforward before the coronavirus. One could ascertain directions and trends, although also noting often-strong disagreement among the readers about the speed and extent. But, as the result of the pandemic, an uncharted chasm has suddenly appeared on the map, which the world is now struggling to work its way around. Yet one can see some of the features of the new topography. Some trends will remain the same, some will be accelerated, some will change direction, and some will simply play out over time.

On the premise that the coronavirus is a finite crisis, whether there are further waves of infection or not, and that science and medicine provide timely answers, what can we now see for the future of energy, trying to look beyond the global economy's recovery period?

In the years ahead, CO_2 and GHG policies will bring continuing changes in how energy is produced, transported, and consumed; in strategies and investment; in technologies and infrastructure; and in relations among countries. Established companies will be tested for their adaptability. New entrants will have to prove their business models. Partnerships and competition will characterize the relationships among different kinds of companies. Energy security concerns will expand to the supply chains supporting low-carbon industries and to the minerals on which renewable energy technologies depend. Climate change is global, but nations will respond in different ways, depending on their own particular situations. Developed countries will have more flexibility. Developing countries will struggle to balance between low-carbon and the need for low-cost solutions to promote economic growth, especially in the aftermath of the coronavirus crisis.

And aspirations will come up against an ineluctable reality—today's energy system, which is more than 80 percent based on oil, natural gas, and coal, with a huge embedded investment in infrastructure and supply chains—all of which will be required to meet the energy needed during the recovery period and get back on the economic growth track (see Figure 3). The scale of this system is enormous and cannot change overnight. So far, the energy transition has actually been, in the words of energy strategist Atul Arya, "the phase of energy addition."[1] Wind and solar have been increasing, but they were doing so atop conventional energy, which was also growing.

In the United States, no new coal plants are being built and the number of operating plants is declining. Worldwide, the picture is different. Asia is on track to substantially increase its coal consumption, with the construction of more-efficient coal-powered plants. Coal may be a declining share, but it is still a mainstay for the world's two largest countries, China and India, important not only for energy but also for employment and energy security.

As observed before, coal still represents almost 60 percent of China's total energy supply. "China is not going to abandon coal," said a senior official. "China is different from Europe. China is a developing country. We need to maintain our consumption, but it also means good use of coal, cleaner coal." China's new Five Year Plan (2021–2025) puts a renewed emphasis on coal for energy security and calls for "safe and green coal mining" and "clean and efficient" coal-fired plants.[2]

—

A LITTLE MORE THAN A DECADE AGO, SOME PREDICTED THAT "PEAK oil"—the "end of oil"—was near and the world would "run out" of petroleum. The argument has now flipped over to "peak demand": When will oil consumption hit the high point and begin to decline?

Ever since that first oil flowed up out of Colonel Drake's well in 1859, the world's demand for oil has steadily risen, though with occasional dips due to recessions, depressions, and price spikes. The great exception, of course, was when the government-mandated lockdowns shut down much of the world economy in 2020, and demand collapsed in a way that had never happened before. But, for trend, we can use 2019, when global oil consumption was more than 30 percent higher than it had been in 2000.

Yet while consumption has continued to grow, the map of consumption has changed. For decades, demand was concentrated in the industrial nations of North America, Western Europe, Japan, and Australia. The developing world's share was relatively small.

No longer. Since 2013, oil consumption in the "emerging markets" and the other developing countries has been greater than in the traditional industrial countries. Between 2000 and 2019, consumption rose a little in the United States, declined a little in Europe, and in aging Japan dropped a lot. Over that same time period, almost all the growth in oil demand has been in the developing world. China is now the world's second-largest consumer, after the United States; India, the third. And it is in emerging markets where the future growth will continue.

Of course, there was always the understanding that at some point global demand would stop increasing. But "peak demand" was something considered to be far off into the future. The reason was simple—rising population and rising incomes would continue to push up demand. The number of autos would increase around the world, as ownership in the developing world caught up with the developed world.

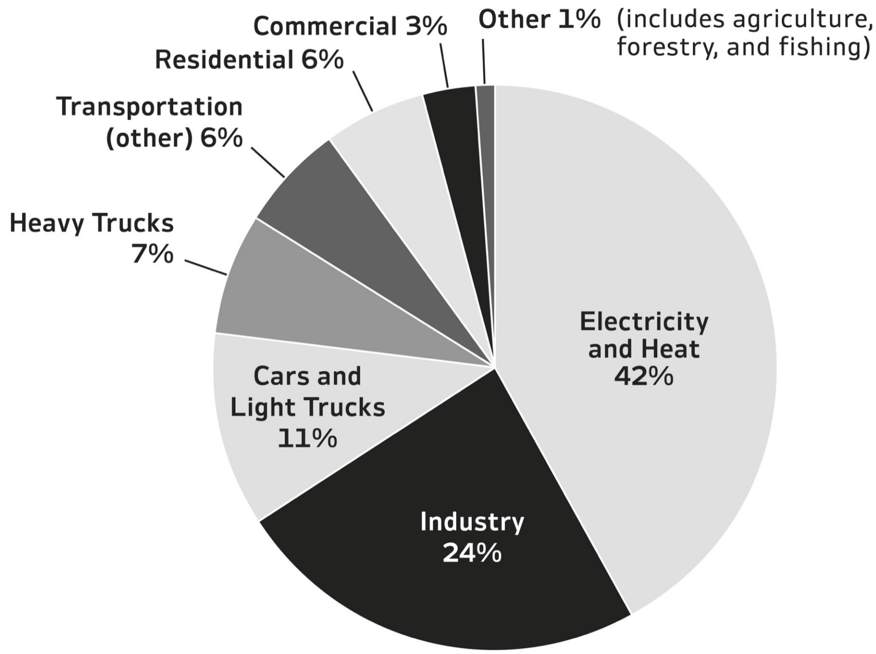
For now, the gap remains very large. In 2018, there were 867 cars for every thousand people in the United States, 520 in the European Union. Compare that to the 339 in Russia, the 208 in Brazil, the 160 in China—and just 37 in India. In other words, the world's auto population will grow substantially as incomes rise and the number of people increases from today's 7.8 billion to 9.5 or 10 billion.

In "Rivalry," IHS Markit's planning scenario, the world's auto fleet grows from its current level of just over 1.4 billion to over 2 billion by 2050. Of that 2 billion, about 610 million are electric vehicles—almost a third of the total. The fleet simply does not turn over quickly. Annual new-car sales represent only about 6–7 percent of the total fleet. Most of the fleet is composed of vehicles that have been purchased over the preceding dozen years—in the United

States, cars on average remain on the road for 11.8 years. But EVs catch up. By 2050, in this scenario, some 51 percent of total new car sales are EVs.[3]

Figure 3: Emissions by Sector

Global CO_2 emissions from fuel combustion, by sector (2019)



Source: IHS Markit
based on IPCC methodology

This is substantial change, but not as fast as some may expect. In light of the economic difficulties and job losses from the 2020 shutdown, regulators may ease up on the steep requirements for reductions in carbon emissions that are pushing a shift to electric cars. Indeed, the world would actually end up with almost the same number of oil-powered cars on the road in 2050 as today. But they will be more fuel-efficient. People may drive more miles in vehicles that require gasoline, but the amount used for each mile goes down. That, in turn, may reduce the incentive to switch away from a gasoline-fueled vehicle. In a more radical scenario, around Auto-Tech, the numbers and kinds of cars will change more rapidly, as they would with stringent climate regulations and larger incentives.

“Electric cars are not the end of the oil era,” is the way that Fatih Birol, executive director of the International Energy Agency, puts it. Even if every other car sold in the world from now on were electric, he adds, oil demand would still grow. Cars and light trucks (SUVs and pickups), as pointed out earlier, constitute 35 percent of world oil demand—cars alone, about 20 percent. The rest of transportation consumption goes into heavy trucks, ships, trains, and airplanes. The global fleet of civilian airliners, while more efficient, was expected to double by 2040. That may now be pushed out a few years by the slower growth in passenger travel. Nevertheless, demand will return; over 80 percent of the world’s people have never been in an airplane. “Flight shaming” may be a social mode in Sweden, population 10 million, but China, population 1.4 billion, is building eight new airports a year. One of the hardest problems is to find alternatives to jet fuel aside from biofuels, the volumes of which are small. And even if there were an obvious solution or one on the horizon, it would take a long time to have an impact, owing to the life span of the existing fleet and the time to design new planes, get them certified, and then out into the fleets of airlines. Heavy trucks, because of their weight, require the energy density of oil in order to propel their loads along the highway, although in China LNG is also being used.[4]

Oil and natural gas are also the feedstock for petrochemicals, from which chemicals and plastics are made. A growing movement focuses on limiting the use of plastic straws and single-use plastic bags, especially owing to ocean pollution and the debris washing up on beaches. In Washington, D.C., “straw cops” hand out fines to restaurants that covertly use plastic straws, which are now banned. Recyclability to replace single-use plastics has become a priority. This is seen as part of the “circular economy,” where products are reused, recycled, or remade at the end of their lives—instead of going into landfills.[5]

But the plastic waste problem is largely not in the developed world. The United States generates less than 1 percent of the plastic waste in oceans. About 90 percent of river-sourced plastic pollution in the oceans comes from uncontrolled dumping into ten rivers in Asia and Africa, which, if properly managed, could dramatically reduce the wastage. Plastic bags and straws may be the most visible use of plastics, but they constitute less than 2 percent of plastics.

Moreover, the coronavirus crisis did demonstrate a health advantage of plastic bags over reused cloth shopping bags.

The omnipresence and versatility of plastics make them a building block of the modern world. They are used in everything from making airplanes lighter (and thus more fuel-efficient) and manufacturing electric cars; to auto dashboards and safety glass in windshields and lenses; to bulletproof vests; to carpets, housewares, pantyhose, clothes, and shoes; to packaging (yogurt containers) and keeping food fresh (and thus preventing disease). They are used for water pipes, eliminating metal piping that rusts, and in solar panels and wind towers and blades, and in the casing of cell phones.

They also are embedded in the health system. "Petroleum products are intrinsic to modern health care," is the way an article in the *American Journal of Public Health* put it. "Plastics are central to the antiseptic model of modern health care." Look at a hospital operating room—gloves, tubing, the bags for intravenous liquids, instruments, and the tools that insert stents into ailing heart patients. Moreover, "[Ninety-nine percent] of pharmaceutical feedstocks and reagents are derived from petrochemicals." As for the N95 face masks that became the emblem of the coronavirus epidemic, they are made with petrochemicals.[6]

Petrochemical demand rises faster than GDP growth, sometimes twice as fast, and that means rising demand in that sector will offset the slack elsewhere.

—

So when will oil demand reach its peak? IHS Markit's Rivalry scenario, which is the planning case, points to the mid-2030s. In the alternative Autonomy scenario, the peak comes much earlier, as a result of strong government policies, a more rapid switch to electric cars, and the economic wounds of the 2020 coronavirus crisis. The actual answer will be determined by a concatenation of many forces —from what national governments and cities do in terms of regulation and incentives, to economic growth, to the availability of minerals, to the legal liability around autonomous vehicles and the security of the cyber systems controlling them, to the values and lifestyles of millennials, to social media, to the increase in air travel and petrochemicals, to geopolitical conflicts and social instability, to start-ups that have not yet started and new scientific and engineering breakthroughs, and so on. And of critical importance will be the long-term changes in behavior in commuting and travel wrought by the coronavirus shutdown. In short, the list is long. Is the "peak" in demand to be followed by a "plummet," as in collapsing demand? More likely is a gradual decline on a downward-sloping plateau. In terms of numbers, the planning scenario posits that the 100 million barrels of consumption prior to the coronavirus is around 113 million in 2050. That's certainly not the end of oil. Even in scenarios in which climate policies become much more aggressive, oil consumption falls to 60 to 80 million barrels per day in 2050.

What, then, is the future of the $5 trillion global oil and gas industry that supplies almost 60 percent of world energy? The industry will continue to need to find and develop another three to five billion barrels a year just to make up for the natural decline in oil fields, which happens after a field has been in production for some time. The International Energy Agency estimates that over $20 trillion of investment in oil and gas development will be required over the next two decades.

"Oil and gas companies" are adapting to the "After Paris" world. The large international companies have generally endorsed some form of carbon price. Some are now describing themselves as "gas and oil companies," owing to increasing emphasis on natural gas as an abundant, lower-carbon fuel. With gas, the industry will increasingly be competing to supply electric generation, meaning that its competitors will increasingly be both coal and renewables. World natural gas consumption is projected to grow at twice the rate of oil. The LNG segment of the business, which is knitting together a single global gas market, will grow faster. By 2050, natural gas demand is estimated to be 60 percent higher than it is today.

Some firms are laying out the ambition to become "energy companies," broadening into electric power, energy services, and new technologies. Whatever the name, the larger companies are increasing investment in new technologies, start-ups, and "low-carbon energy" and are bolstering internal R&D. The aims are multiple: to be more efficient, to meet environmental pressures and investor and regulatory requirements, to "solve" carbon, to participate in renewables and new technologies, to develop economic carbon capture, to play in the future of transportation, to be part of the digital economy, to ensure optionality, and to preserve their "license to operate." They are investing with the "energy transition" in mind—in batteries, in fast charging for electric vehicles, in hydrogen, in wind farms and solar developers, even in fusion. There is a new emphasis on carbon capture. Some have adopted a target of net zero carbon for 2050, which, in addition to the preceding will, among other things, involve greater energy efficiency, biofuels, and reforestation.

Over the next several years, a world trying to regain a $90 trillion GDP and eventually be back on track to $100 trillion, but which is striving to stay below 2 degrees or 1.5 degrees, will still need a lot of energy. Achieving these targets and shifting the supply sources will require the development of major new systems. Many of these will require scale and engineering, and technical and project management skills—all attributes that the oil and gas industry can bring to the table.

A prime example is hydrogen, which, as observed earlier, could potentially meet 10 percent or more of total energy requirements, and is becoming a focus for the oil and gas industry. Some companies are already players in wind; and some, long accustomed to building and managing large complex offshore oil and gas platforms, are now entering the offshore wind business.

If the future is increasing electrification, to what degree will oil and gas companies be moving into electric power? Some already are. Financial returns will be a question. Power and renewable projects —"lower-carbon generation and distribution"—generally operate in highly-regulated markets and deliver lower rates of return than those traditionally of oil and gas projects. How will they square the circle with demands for returns from investors—which have to meet the retirement and pension needs of their fund-holders—and yet deliver an increasingly "green" portfolio for activist shareholders and millennial investors interested in "impact"? At the same time, the electricity business enables companies to participate more broadly in the changing energy value chain, provides more predictability in revenues, and offsets volatility in oil and gas markets, especially in light of what happened in 2020.

With all these pressures around climate, companies will have to concentrate on being technology- and innovation-focused and, at the same time, relentlessly competitive, which means constant focus on costs and efficiency. There will be greater competition across a broad front—to attract talent, acquire low-cost oil and gas plays, develop projects, find low-carbon solutions, and innovate. Ultimately, this wide-ranging competition will determine whether the major energy provider of today will continue to play the same roles tomorrow—whatever the forms of energy to be provided.

Shale, with its growth over the last decade, has become a major segment in the overall U.S. economy. It has been an important market for manufacturing industries. Low-cost gas has benefited consumers and businesses, stimulating several hundred billion dollars of new investment in the United States. It has been a major factor in the development of a competitive global natural gas market. And, of course, shale oil has proved to be the most dynamic element in the world oil market in recent years.

The United States will continue to have an abundance of natural gas, but the hectic growth days of shale oil appear to be over. The United States will remain a major producer and will likely regain some of the output level lost from the coronavirus crisis; but it will not return to that high point of thirteen million barrels per day hit in February 2020, unless circumstances change significantly. The shale industry was already maturing before the coronavirus crisis, and companies were reshaping their businesses to deliver returns to investors. That would have taken time, but the crisis disrupted that process, and access to capital and rebuilding the relationship with investors will be a key challenge.

What about consumers? They are the ones, after all, who use the products. As one energy executive put it, if his company stopped producing oil tomorrow, that would not change consumption patterns. People would still be driving their cars, and another company would step in to fill all their gas tanks. In the absence of a carbon tax or significant incentives or higher gasoline taxes, how many consumers will willingly pay more for greener energy—such as buying an EV or a fuel cell vehicle, or choosing a greener yet pricier energy plan? Some will, some won't. In countries around the world, less economically advantaged communities could face higher energy prices, putting the goals of greener energy at odds with those of equity.

—

What do the changing world energy markets mean for oil-exporting countries? Markets will go in cycles. They always have, and oil exporters will face volatility, although what happened in 2020 was never anticipated. They may well have to live with periods of lower revenues, which will mean austerity and lower economic growth, with greater risk of turmoil and political instability. This emphasizes the need for these countries to address their over-reliance on oil.

The overweening scale of the domestic oil business crowds out entrepreneurship and other sectors in many oil-exporting countries; it can promote rent-seeking and corruption. It also overvalues the exchange rate, hurting non-oil businesses. In the future, even with a rebound in prices, countries will need to manage oil revenues more prudently, with an eye on the longer term. That means more restrained budgeting and building up a sovereign wealth fund, which can invest outside the country and develop non-oil streams of revenues, helping to diversify the economy and hedge against lower oil and gas prices.

Petroleum-exporting countries will also find themselves competing with other exporting countries for new investment by companies that will be cost-conscious, selective, and focused on "capital discipline." That will push countries to shape fiscal and regulatory regimes that are competitive, attractive, stable, predictable, and transparent.

Experience proves how hard it is to diversify away from overdependence. It requires a wide range of changes—in laws and regulations for small-and medium-sized companies, in the educational system, in access to investment capital, in labor markets, in the society's values and culture. These are not changes that can be accomplished in a short time. In the meantime, the flow of oil revenues creates a powerful countercurrent that favors the status quo.

—

As they grow, wind and solar and EVs will need "big shovels" to meet their increasing call on mined minerals and land itself. It is estimated that an onshore wind turbine requires fifteen hundred tons of iron, twenty-five hundred tons of concrete, and forty-five tons of plastic. About half a million pounds of raw materials have to be mined and processed to make a battery for an electric car.

The growth of renewables creates large economic opportunity for mineral-exporting countries—many located in the global South. These nations will face issues similar to those of oil-exporting countries. They will need to ensure the right regulatory frameworks, operating conditions, and business practices. The growth in demand for minerals will also shine a more intense light on the environmental aspects and labor conditions for mining and processing minerals. And as the demand grows, so will concerns about what might be called mineral security—that is, assuring reliable supply chains from mine to consumer.[7]

In a world of great power competition, the fragmenting of globalization, and the rethinking of supply chains, geopolitics will become part of the new energy mix, as it continues to be in the current energy mix.

Conclusion

THE DISRUPTED FUTURE

Where does this new map of energy and geopolitics lead? The collapse of Soviet communism, the transformation of China, and India's move to open its economy—these together brought more than two-and-a-half-billion people into the world economy, creating connections and opportunities that would not have been imagined previously. The result was momentum toward a more collaborative world order that rested on an increasingly connected global economy, one facilitated by the internet and ever-cheaper communication, advances in transportation, and the flows of capital, skills and knowledge—and people. All this was captured in the term "globalization." And it had all been fueled by energy.[1]

But the momentum is now going in reverse. The world has become more fractured, with a resurgence of nationalism and populism and distrust, great power competition, and with a rising politics of suspicion and resentment. Globalization doesn't go away. But it becomes more fragmented, and more contentious, adding to the troubles along the already-troubled path to economic growth.

Before the coronavirus crisis, the $90 trillion global economy was well on its way to $100 trillion within the next five years. But the world economy is now tormented by lives upended and tragedy, unemployment, small businesses fighting for survival, companies under severe pressure, countries impoverished, hope vanquished for many, governments stretched to the extreme by debt, and enormous loss of economic output. It will likely take two to three years for the global economy just to work its way back to $90 trillion, and $100 trillion could be as much as a decade away—and this assumes therapeutics and vaccines arrive in a reasonable time.

Behaviors will be changed by the crisis. At least for a time, there will be an aversion to proximity to large groups, which will affect travel, events, and the way education and businesses operate. When it comes to transportation, people may revert to preferring to "own" their mobility—their personal car—rather than buying mobility when they need it, and, at least for a few years, opt to drive rather than fly when there is a choice. They will also be more cautious about using public transportation. The trend toward digitalization broadly-defined—new ways of working enabled by digital technologies, trading the physical world for the virtual world—has suddenly moved into hyper-gear. Work need not be concentrated in offices, companies can be run from homes, newspapers can be put out with almost no one in the newsroom; time spent commuting can be reduced; business meetings can be replaced by digital connecting. These impacts will last after lockdowns are well in the past. It took three years after 9/11 and more than seven years after the 2008 financial crisis for air travel in the United States to recover to the previous levels. The acceleration of innovation, especially in terms of artificial intelligence and machine learning and automation, will bring change for all kinds of work.

Oil's role will be challenged by these shifts in behavior, work, and daily life. It will, however, take a few years, post-vaccine, to understand the lasting impact on business and leisure travel, on education, on commuting, and on whether the "office of the future" will also now be at home.

The crisis will affect geopolitics as well, reinforcing trends already unfolding. In the face of nationalism and protectionism, the clash among nations will become sharper, international collaboration more difficult, and borders higher. International institutions will struggle to find their footing in a divided global community. The container ships will still set sail, but the global network of supply chains will be under pressure, as governments and companies reevaluate their dependence on those chains—more complex than many realized—and instead put more emphasis on security and resilience and "localization"—and creating local jobs. "Just in time" manufacturing and inventory management will make room for “just be sure.” Automation and 3D manufacturing will facilitate this rebalancing in the world economy.

Nowhere will these divisions show up more clearly than in the divide between the two countries upon which, more than any other, world order depends. The United States and China are not decoupled. Despite their growing differences, extensive ligaments continue to tie them together; they share commonalities and mutual interests, including in a growing global economy and the avoidance of conflict. But they are increasingly at odds. The links are under ever-greater strain, and the divide grows deeper. The result could be, to paraphrase Deng Xiaoping, “one planet, two systems” when it comes to technology, the internet, finance, and commercial relations. The “WTO consensus” has given way to “great power competition” and increasing distrust, and to “strategic rivalry” and a high-tech arms race. All this is adding up to a new cold war. This polarization—and the risks that go with it, including the Thucydides Trap—will be a fundamental factor in world politics in the years ahead. The more entrenched the overall positions, the more difficult to resolve specific issues. This clash will hamper the workings of the global economy and, indeed, will contribute to its fragmentation.

The clash is creating growing quandaries for many other countries, which are so connected to both the United States and China but will feel increasing pressure to align to one side or the other. In the Soviet-American cold war, the Soviet Union was a minor player in the global economy. China, by contrast, is deeply embedded and indeed is one of the linchpins of today’s world economy. In the summer of 2020, as tensions mounted between the United States and China, an alarmed Lee Hsien Loong, Singapore’s prime minister, warned that Asia-Pacific nations “must avoid being caught in the middle or forced into invidious choices.” As a senior official in one of the G20 countries put it, “When the United States and China go at it, everybody else in the world suffers.[2]

Energy—particularly oil and gas—will continue to be an integral part of the new geopolitics in the post-coronavirus world. The shale revolution has changed both the American economy and America’s position in the world. The new oil order is dominated, owing to their sheer scale, by the Big Three—the United States, Russia, and Saudi Arabia. In the spring of 2020, a market collapse like none other brought them together. But their interests will likely diverge again, as markets and their own positions change, and as climate returns to center stage.

For Russia, oil and gas will remain fundamental to its quest to assert itself as a great power, its relations with Europe, the struggle over Ukraine, and its alignment with China. The Chinese economy will not grow as fast as in the past, but it will be growing off a much bigger economic base, and increasing quantities of energy will be required to assure that growth. This is why energy is a key element for China both in the South China Sea—which some see as the "accident" waiting to happen—and in the Belt and Road and the drive to rebalance the world economy. Oil, and more recently natural gas, will obviously remain central to the future of the Middle East—its economic prospects, the rivalries for regional predominance, governance, demographics, stability, and the region's relations with the rest of the world. Yet, ironically, this very centrality—and dependence—creates an imperative to make oil and gas less central for the future of the region.

—

While the perennial and sometimes unexpected geopolitical risks affecting oil will remain, they will be tempered by several factors. Even if the number of vehicles so far is small, the emergence of electricity as a competitor in transportation and the possibility of Auto-Tech provide an alternative to oil-based transportation and the unchallenged dominance of oil. The impact will be enhanced as automakers seek to make good on their promises to electrify their new car fleets, bolstered by governments promoting green recovery. The abundance unlocked by the North American shale revolution, backed up by Canadian oil sands and new production elsewhere, provides a significant security cushion against disruptions of supply. For the most part, wind and solar compete with natural gas and coal to generate electricity, not with oil for transportation. Yet the dramatic fall in the costs of wind and solar—along with their rapidly growing scale—change the balance in the overall energy mix as, at the same time, the world becomes more electric. The coronavirus crisis demonstrated the degree to which digitalization has become a competitor with transportation, using electrons to connect people rather than molecules to move them.

All the above is, in fact, part of the next energy transition—the effort to back away from oil and gas and coal, the products of organic material buried many millions of years ago. The main driver today is not energy security, as in past decades, but climate and the mobilization around it, particularly among younger people. For China and India, the drivers also include pollution and the dependence on oil and gas imports. At the same time, however, for those two countries—today the second and third largest energy consumers in the world—securing energy supplies, including oil and natural gas, is essential for fueling the economic growth they need to lift the incomes of their populations and to reduce pollution.

Will the COVID-19 crisis speed an energy transition or slow it? Some argue for “a green recovery,” with government spending skewed to “climate-friendly infrastructure” and greater financial support for renewables and electric vehicles, as well as increasing restrictions on internal combustion engines and government-mandated “reallocation of capital.” For local governments, “green recovery” and cleaner air become the rationale for restrictions on internal combustion engine cars and autos of all kinds, the closing off of roads to autos, and the multiplication of bike paths and pedestrian walkways.

Yet the notion of a fast track to a wholesale energy transition runs up against major obstacles—the sheer scale of the energy system that supports the world economy, the need for reliability, the demand for mineral resources for renewables, and the disruptions and conflicts that would result from speed. On top of all of that is the high cost of a fast transition and the question of who pays for it—especially given the staggering amounts of debt that governments took on in 2020 to fight the health and economic consequences of the coronavirus. In the spring of 2020, estimates based on OECD analysis indicated that its members, the developed countries, had already accumulated an additional $17 trillion dollars of debt to deal with the COVID-19 crisis.[3] Environmental ministers may seek to push aggressively ahead, but they will have to contend with finance ministers, who are worrying about budgets and deficits and the primary need to heal the economic wounds, promote recovery, and get people back to work. In short, for the next few decades, the world’s energy supplies will come from a mixed system, one of rivalry and competition among energy choices.

In this system, oil will maintain a preeminent position as a global commodity, still the primary fuel that makes the world go round. Some will simply not want to hear that. But it is based on the reality of all the investment already made, lead times for new investment and innovation, supply chains, its central role in transportation, the need for plastics from building blocks of the modern world to hospital operating rooms, and the way the physical world is organized. As a result, oil—along with natural gas, which now is also a global commodity—will not only continue to play a large role in the world economy, but will also be central in the debates over the environment and climate, and certainly in the strategies of nations and in the contention among them.

How fast the mix changes will be determined, of course, not only by politics and policies, but by technology and innovation, which have been the ingredients of energy transitions since Abraham Darby lit up his furnace in 1709. That means the ability to move from idea and invention to technologies and innovation and finally into the marketplace. This is not something that necessarily happens fast—energy is not software. After all, the lithium battery was invented in the middle 1970s but took more than three decades before beginning to power cars on the road. The modern solar photovoltaics and wind industries began in the early 1970s but did not begin to attain scale until after 2010. Yet the pace of innovation is accelerating, as is the focus, owing in part to the climate agenda and government support, in part to decisions by investors, in the part to the collaboration of different kinds of companies and innovators, and in part to the convergence of technologies and capabilities—from digital to new materials to artificial intelligence and machine learning to business models and more. The timing of what eventuates will also depend on the talent engaged, the financial resources that support that work, commitment, sheer grit, and the well of creativity upon which to draw. These will lead to the new technologies, disruptive and otherwise, that will shape the new map of energy and geopolitics.

But the map hardly assures us a straight line, for disruptions will with some frequency inevitably redirect the path. The shale revolution was not anticipated, nor was the financial crisis of 2008, nor the Arab Spring and the nuclear accident at Fukushima in 2011, nor the rebirth of the electric car, nor the plummeting in the costs of solar, nor an incredibly-transmissible bat virus that would lead to a pandemic and an economic dark age, nor massive protests in 2020 in the United States that would rock American politics.

Yet there are some disruptions we can anticipate, indeed clearly see, even if we cannot sketch out the precise routes by which they will take us from here. The struggles over climate will be one. But so also, in this era of rising tensions and a fragmenting global order, will be the clash of nations.