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Energy Transformations:
Technology, Policy, Capital and the Murky Future of Oil and Gas

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Summary

Technology and policy are transforming the industries linked to fossil energy. Large and growing shifts in capital are following. Oil and gas majors who wish to survive, let alone prosper, will need to realign their business around a low carbon future. They must become much more capable of creating and identifying transformative technologies and integrating them into new lines of business. As if that were not challenging enough, they must do this in ways that understand business evolution as a function not just of technology but also of policies that are redefining which firms will thrive in a world where emissions must shrink rapidly.

The skills needed to thrive in this new world do not come naturally to established industrial behemoths oriented for the competitive supply of mature commodities like oil and gas. The incumbent industry's track record in identifying and integrating transformative innovations is not encouraging.

Where innovations have aligned with the core business model, big oil and gas firms have succeeded. For example, innovations in big data have made it easier to gather and process the seismic information necessary for oil exploration and drilling, and innovations in predictive maintenance and systems management have cut the costs of offshore drilling. In such settings, innovation has not much disrupted business models; oil and gas production has expanded. However, even there, the behemoth industry has failed to anticipate many important innovations that have come from outsiders, such as shale oil and gas—a striking transformation in oil and gas production that unfolded over the last two decades and an area where big firms dawdled and then rushed in only after the revolution was far advanced, with terrible financial results. The decarbonization revolution will be even more disruptive as the track record of creating and integrating profound innovation is weaker. Even where incumbent oil and gas companies have played a role in innovations that could thrive and cause big declines in oil and gas use (e.g., batteries or biofuels), they have tended to underweight these areas of investment.

As the decarbonization revolution advances, it will, most likely, radically reduce demand for oil and gas. Gone is the assumption, prevalent in the industry until just the last few years, that demand will always rise. A growing number of credible projections see steep and possibly discontinuous declines, principally due to growing pressure to cut emissions of warming gases. Indeed, about two-thirds of world emissions come from countries that have net zero targets for emissions, most of which are focused on the year 2050.

Under severe environmental pressure, the Western coal industry has already imploded. Oil is likely to feel the next blow. Policy and technological advances are creating niches of energy services that do not require oil at all—most strikingly, electric vehicles, whose market shares are climbing rapidly. The effects of vehicle electrification, other replacements for oil and the ongoing tightening of energy efficiency standards could cut demand for oil in half or more in the next two decades. Because transformative technologies, such as electric vehicles, are such a tiny share of the market today, they are easy to overlook, much as the U.S. coal industry ignored shale gas in 2005 when shale accounted for merely 2% of the U.S. gas supply—only to find themselves crushed after a decade of compound growth in shale gas production. As the technologies of the deep decarbonization revolution improve and expand outside their niche markets, the political winds will shift and so will capital. These reinforcing patterns will beget even stronger polices, bigger market shares and better technological performance.

With flattening and then shrinking demand for the incumbent product, oil, the need for new supplies will lessen. Less demand will shift supply away from the places where Western incumbent oil and gas firms have traditionally made the most of their economic returns. Similar patterns will plausibly unfold for gas but with implosion delayed. Gas is cleaner than the other fossil fuels and is exceptionally useful in electric power, an industry that will grow as the world cuts emissions. Nevertheless, even there, the conventional wisdom of a rosy future for high demand is turning darker.

Some firms, headquartered mainly in Europe where the policy pressures are most acute, have begun to respond. They have announced increasingly bold emission reduction goals, such as net zero emissions by 2050. Firms that are taking the decarbonization challenge most seriously have set goals for cutting emissions not only from their operations but also from the much larger volume of emissions that come from burning their products, such as gasoline, diesel and jet fuel. Making operations cleaner is a familiar challenge for the industry and one that many firms have already proven to be adept at doing. Making the product they sell emission-free is not.

A challenge is that no incumbent firm, no matter how seriously they are taking the decarbonization challenge, has a clear blueprint for how to thrive in a low carbon world. That information, including whether there is a role for these incumbent firms, is unknowable today.

Firms that succeed will be those that have "worked" solutions—the ability, earned through visceral experience and reorganization, to identify and integrate new technologies and business practices that allow them to compete in viable clean industries of the future. In other industries, like much of IT, this kind of disruption has often inspired strategies of "fast following"—watching the leaders bear the cost of failure and then quickly joining the slipstream by choosing the options that work. In oil and gas, where watching is less important than learning how to reorganize, that approach is likely a recipe for a fast death. By the time leaders have demonstrated effective worked models, they have moved on to explore even better prospects.

The firms that have been most aggressive in their response have redirected only about 5% of capital budgets, although the share is rising quickly. All this new investment is going into new businesses that have one (or all) of these attributes: being much riskier than the traditional business; yielding lower returns; involving much bigger roles and exposure to government policy; and being completely unfamiliar with the organizational culture of integrated oil and gas firms and their employees and investors.

Most of the reallocated capital has gone to renewables, in particular to solar and wind electric generation. This approach seems unlikely to be a winner by itself, for the solar electric industry is already highly competitive and maturing. The oil and gas industry has arrived late to the renewables revolution. Total capital investment by large oil and gas companies in solar and wind electricity was just 0.6% of the global total investment in renewable electricity in 2019. Outside of offshore wind platforms, the construction and operation of which require skills that overlap with those of offshore drilling, the incumbent oil and gas industry is struggling to find its niche.

Just a decade ago, some of the better managed oil and gas firms were seeing returns on capital that reliably exceeded 20%, with wide variation across the industry that set the best performers apart in a league of their own. Today, variation across the industry has narrowed massively, and returns have imploded. The end of supernormal returns means that the opportunity costs of change are much smaller than before. At the same time, the risks of inaction have risen.

All western oil and gas firms face a common question of how to successfully create value within an industry that is experiencing profound change. Answering that question is not merely a matter of identifying the right new lines of business—a task that will be hard enough, as the answers are unknown at present—but also a matter of reconfiguring leadership and culture within these firms. New leadership and culture must be more capable of navigating profound changes, executing well in new areas of commercial operations that are unfamiliar, and managing exposures to risk. In addition to emphasizing operational excellence, there is already a rapid increase in the need for cultures and management systems that can search for, and identify new purposes and directions for these incumbent oil and gas firms. Success will require new kinds of leadership, including board engagement, to help realign business units with new missions and aide in identifying and managing the right kinds of partnerships with collaborators outside each firm.

Oil and gas have always been capital-intensive industries. Decarbonization technologies all share the attribute that they have even lower operating costs than today's fossil fuel systems, but, nearly everywhere, those savings in operating costs are offset by higher capital intensity. For an industry that has thrived on managing capital to avoid the stranding of assets, the challenges are now becoming significantly harder as energy systems become even more capital intensive. The assets most likely to be stranded are those that are most familiar. The assets likely to generate the greatest value amortized over long periods of reliable operation are those that are least familiar to the incumbent oil and gas industry. Brave or not, that is the new world.

Part I: The End of an Era?

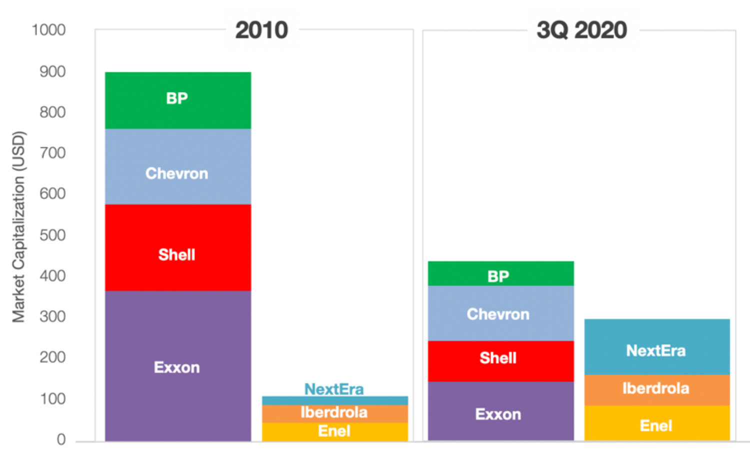
For decades, nearly all energy analysts have assumed that demand for oil and gas would rise inexorably into the future.[1] A growing world population and expanding economy would need energy; most of that energy must come from fossil fuels, as it had since the 19th century. For oil in particular, a rich future was assured because the liquid had a monopoly on an essential service in the modern economy: transportation. Nobody flew airplanes powered by coal or onboard nuclear reactors; liquid jet fuel was a lot easier to store and much cheaper than all the alternatives. Electric vehicles were playthings for the rich and had been since the 19th century.[2] Ships ran on oil and nothing else. Petrochemicals came from oil and, to a lesser degree, natural gas. Meetings in Davos and exhortations on op-ed pages talked about the need for an "energy transition," but not much transitioning was actually happening, for, even now, the global economy still depends on fossil fuels for about 85% of total energy.[3]

For decades, nearly every oil and gas supplier subscribed to these beliefs, and the whole industry was organized to meet the inexorably rising demand. **More demand meant more supply; natural declines in existing oil and gas wells meant there was a need for even more supplies to offset that decline.** Since the "easy" oil and gas deposits in the world were being tapped out, more supply meant venturing into new geologies and locations with a lot more risk. Managed well, that meant more profit.

Often this belief was wrapped in a mantle of goodness and necessity. Fossil fuels were the cheapest way to power the world economy and lift humanity from poverty, as ExxonMobil's boss from 1993 to 2005, Lee Raymond, said in a 1996 speech to the Detroit Economic Club.[4] The future was hard to predict and thus laden with risk, but most people in the industry and most policy makers worried primarily that not enough capital would be mobilized for investment to meet the growing demand.

That picture is now changing. **The consensus that oil and gas demand will continue to grow is ending.** The markets have already seen this reality, which helps explain why, over time, the total value of large integrated oil and gas companies has been shrinking.[5] Since 2010, the top four oil and gas companies have seen their market capitalization shrink more than half from $894B to $433B. At the same time, the value of the largest green energy specialists—all electric companies—has nearly tripled from $111B to $299B (Figure 1). The largest pure play supplier of green energy equipment, Tesla, has risen in market capitalization from $1.7B at its IPO in 2010 to nearly $700B at the start of 2021.

Figure 1: In just a decade, major shifts in market capitalization as the big four oil and gas majors shrink, while the top three global deployers of renewable electricity soar.



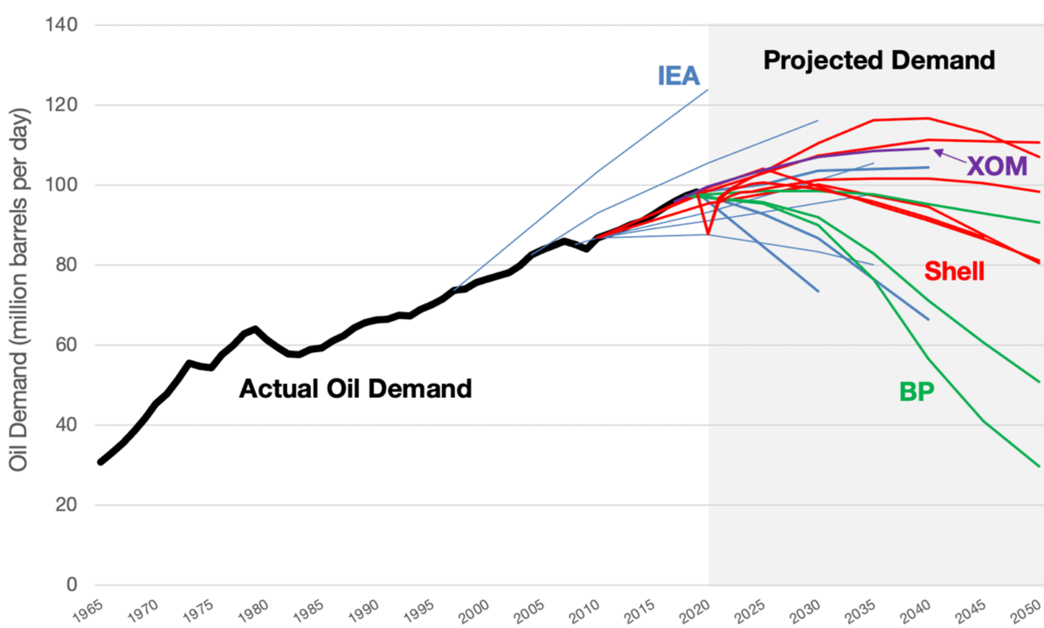
Source: Wall Street Journal, 2020. Katherine Blunt and Sarah McFarlane, original source FactSet.

New outlook for oil demand

For oil demand and prices, there is a long history of wrong forecasts.[6] In the midst of the oil crises of the 1970s, most projections envisioned exponential growth in demand, only to be surprised when people had a strong incentive to become more frugal thanks to high prices and strong energy policies that kept working even when energy prices abated in the 1980s and 1990s. From the late 1990s, surprises appeared in the opposite direction: surging demand from the rapidly industrializing Asian Tigers, led by China.[7] However, one thing was constant: the assumption that demand would always rise. All told, in the 35 years since 1974, which marks the end of the first oil embargo, the year-on-year consumption of oil dropped just six times, always briefly and always in the context of a global economic downturn.[8] For decades, oil analysts have, for the most part, been debating about rates of growth—not whether growth would happen.

At no point since modern forecasting of oil demand began in the 1960s has the range of possible futures been wider than it is today. Figure 2 shows a history of demand forecasts, with a healthy spray of alternative futures. Today's spray is different, for it is not just wider but includes a large number of credible projections with discontinuous steep declines, indicating implosions that could happen much faster than has been widely appreciated.[9]

Figure 2: Rising uncertainty around the future of oil demand.



The main figure shows the history of demand for oil (heavy black line) and projections (light colored lines) for four organizations: the International Energy Agency (selected years, including 2020 scenarios), BP (2020 scenarios), Shell (selected years, including 2021 scenarios) and ExxonMobil (2019 Outlook for Energy). At no point in the history of oil demand forecasting has the range of possible futures been larger than today, and at no point has there been more attention to rapid declines in total demand.[10] Source: International Energy Agency, BP, Shell, ExxonMobil.

When concerns about oil consumption were rooted in energy security, as they were from the 1970s until recently, demand mattered less than reliable supply. Keeping demand in check was important, but the real work of energy security involved worrying about whether too much oil was coming from unsavory and unreliable places. Reliable supply meant diversity in supply, with extra weight on supplies close to home. That mindset is what created policies to support environmentally catastrophic programs, like the generation of synthetic oil from coal; this created preferential leasing and tax programs aimed at boosting supplies of oil from the deep waters of the Gulf of Mexico and from remote Alaska—all places thought to be reliable in supply. However, ultimately, ingenuity in production along with policy support meant that new supplies were always found. As Sheikh Ahmed Zaki Yamani, the Saudi oil minister from the 1960s to the 1980s, reportedly said, "The stone age did not end for lack of stone."[11] For most of modern history, that quip has been a reminder never to question the supply of stone. Today, it means something different: the end of carbon.

Fear of climate change transforms that mindset.[12] **No longer is the central problem adequate supply but excessive demand**; policy, in this new mindset, focuses on eliminating demand where possible and switching to alternative technologies, such as electric vehicles, that serve the needs provided by oil today.

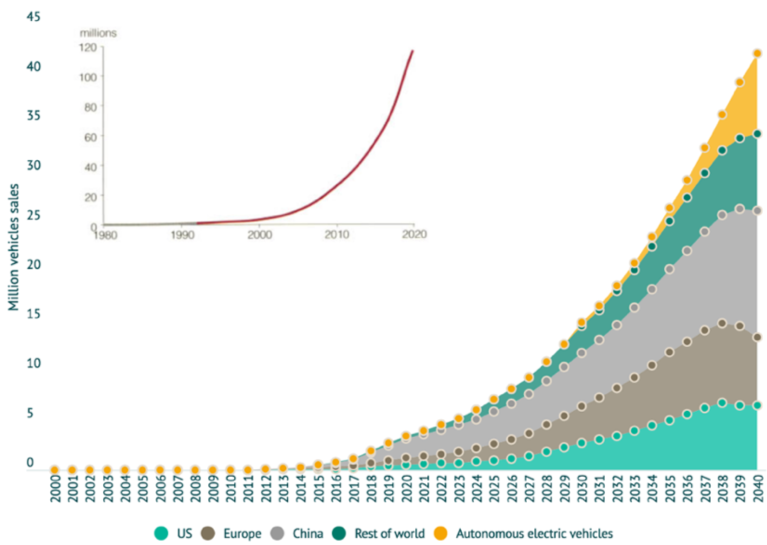
Thanks to the big decline in oil demand in 2020 as a result of the pandemic, **a range of forecasts have oil demand peaking this current decade**.[13] Even OPEC, which has a strong interest in painting a future of higher demand, now offers credible scenarios with little growth and a steady decline in the 2030s.[14] BP, which has the longest and most transparent history of sharing data and forecasts, published new projections in October 2020 that are consistent with a long and accelerating decline in oil demand. For more than a decade, the BP forecasting team envisioned rising demand; this year that consensus cracked.[15] Shell has offered similar futures of waning need for oil.[16]

What remains is a shrinking group of oil majors, notably ExxonMobil, that still cling to old forecasting methods and results. At its annual investor day in March, 2020, which was held as the pandemic started gripping the world economy, ExxonMobil painted a future unaware of how the world of policy was changing: rising demand, a big gap in necessary investment and a litany of concerns about mobilizing the investment needed to fill that gap (see Figure 2, inset).[17] Although other companies also see a continued need for new production, at least in the short term, their outlooks are much less bullish for traditional oil supply.[18]

Demand implosion must be taken seriously because rapid technological change now points in the same direction as policy. The place to watch is electric vehicles, including the emergence of autonomous vehicles (which are likely to be electric). Nearly half of the global oil demand of about 100 mbd currently goes into mobility services that electrification can replace. Figure 3 shows a highly credible industry forecast, with electric vehicles accounting today for just 2.3% of global new car sales but exploding in volume and share.[19] Many other projections similarly see that share rising to approximately 30% by 2030, a date by which some markets from California to major segments in Europe plan to ban new internal combustion car sales.[20] General Motors recently announced that it aimed to phase out petroleum powered cars by 2035; Ford has similarly announced big shifts in its capital expenditure toward electric vehicles.

The electrification of vehicles is a marriage of technology and policy—a story that will repeat many times in the decarbonization revolution. Policy has opened market niches for electrification in which the technology—batteries principally, but also drivetrains, system controls and marketing—gained a footing and improved. Since 2013, the cost of battery packs has declined by nearly 80%, and battery systems are likely to continue getting cheaper and more reliable. In 2020 alone, for example, batteries fell 13% in cost.[21] Now, in a growing number of markets, electric technology can compete on its own with little or no subsidy, which means that it will take off even faster—up the steep slope of typical S-shaped technology diffusion curves—and erase larger volumes of oil demand.

Figure 3: Electric vehicles (EVs) taking off, this time.



The main chart shows WoodMac projections to 2040 for electric vehicle sales by region, following a characteristic S-shaped technology diffusion curve as the technology becomes competitive (used with permission). The inset, from a 1992 Shell Scenario that saw EVs growing to a market >10x the actual size of today's market, is a reminder that forecasting at the early stages of a technological revolution is filled with peril. Source: Wood Mackenzie, Shell.

Why stopping climate change requires near elimination of conventional fossil fuels

Before further examining how energy transitions will unfold, it is worth pausing to understand why stopping global warming requires such radical changes in industry. This is unlike pollution problems of the past, which have been often solved with cleanup devices that did not implicate the existence of the polluting industry. Coal power plants that spewed sulfur, for example, became coal power plants with sulfur pollution controls. **Climate change is different.**

According to the latest major assessment of climate science from the UN's Intergovernmental Panel on Climate Change, about 77% of all emissions of warming gases come from industrial activities.[22] (The rest come mainly from farming and deforestation.[23]) Nearly all those industrial emissions are linked to the burning of conventional fossil fuels. Burning is a chemical process that intrinsically releases carbon dioxide (CO_2). Moreover, the production of fossil fuels, with conventional methods, involves the leakage of methane (CH_4), a potent greenhouse gas that is trapped inside coal and oil (and thus prone to release) and is the main ingredient in natural gas. Pound for pound, CH_4 is up to 120x nastier for the climate than CO_2.[24] However, because the total quantity of CO_2 is so much larger, serious climate policy has the most profound implications for the activities that cause CO_2 emissions.

CO_2 is known as a "stock pollutant" because its lifetime in the atmosphere is very long—the geophysical processes that remove excess CO_2 once and for all work over many decades and even centuries. Therefore, **what matters for warming is not the flow into the atmosphere but the accumulation of those flows over years**, much as the water level rises slowly in a bathtub when the drain is mostly clogged.

Once pollutants of this type have accumulated, radical action is needed to reverse course. Today, the concentration of CO_2 in the atmosphere is about 415 parts per million (ppm), nearly 50% higher than the pre-industrial level of 280 ppm. Just stopping that buildup requires cutting global emissions by at least 80% so that the flow does not exceed the slow drain's ability to drain the excess. However, the real world is a collection of governments that do not align their policies to global climate models, which means that some nations will keep emitting. Taking into account these realities and the uncertainties in how ocean chemistry and the biosphere will respond to big shifts in emissions, the longer the wait, the greater the risks.

These is the logic, rooted in the geophysics of CO_2 pollution and the realities of what the whole world can and will not deliver, that **define the goal of net zero by 2050**. Because what works in the energy system in 2050 depends on what is built today, that has huge implications for immediate investment. Many stones must be left in the ground.

Uncertainty about demand for gas, and increasing downside risks

Fears about climate change mean that conventional coal production must shrink rapidly. Oil will follow. **However, the future for gas is still hard to pin down**. Currently, most mainstream energy projections see a strong demand for gas because the chemical composition of gas is intrinsically cleaner than all other fossil fuels. When burned, natural gas releases a lot more energy for every molecule of CO_2 pollution. Moreover, gaseous fuels tend to have lower levels of other pollutants like sulfur, a noxious source of local air pollution. This is good news when fuel must be burned in places such as in dense cities that are already struggling to keep the air clean. For the last two decades, most of the global growth in demand for gas has come from generating electric power, where these properties of cleanliness and flexibility are a huge advantage.[25]

Not only does gas have intrinsic advantages of relative cleanliness and flexibility, but the cost of tapping the world's huge deposits of gas have tumbled, driving gas prices down. Most notably, the revolution in horizontal drilling and fracturing has unlocked vast quantities of gas from shale. In the United States, where the revolution began, this method of supply accounted for just 3% of natural gas drilling activity in 2005; today, it is approximately 85%.[26] This tremendous success in opening supplies explains why the industry benchmark projection for natural gas prices conducted in 2005 envisioned gas prices would rise to $7.30 per MMBtu by 2019. In a landmark of atrocious forecasting, the actual gas prices that year were less than half that level, at $2.88 per MMBtu.[27] **Standard models used for projecting energy systems perform horribly—especially when technology and policy change quickly—a fact that should give pause when those same models are used to project smooth transitions in the future of decarbonization.**

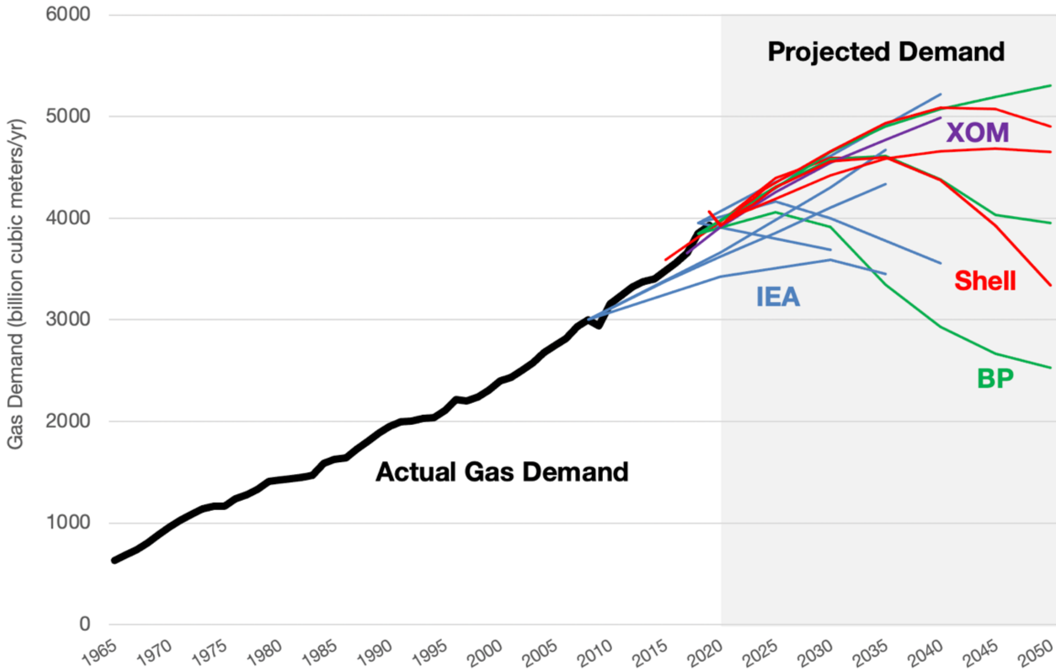
Cheap gas has created many new demands for gas—for example, new gas-using petrochemical plants—which is one reason why analysts stubbornly assume that demand will always rise. Most strikingly, electric power generators have opted for cheaper (and fortuitously cleaner) gas instead of dirtier coal. From 2005 to 2019, the share of coal in generating electricity was slashed from about half to one fifth, while the market share for gas nearly doubled, and emission-free technologies (i.e., nuclear, renewables, hydro) rose by one third.[28] Cheap gas created more demand; more demand created more supply and experience with drilling technology, which begot more cheap gas.

A new wave of shale production may unfold in Argentina and southern Africa where there are similar shale rich geologies. Furthermore, competition from shale has forced costs lower in other parts of the gas supply industry, such as the conventional supplies from Norway, Russia and other places that feed Europe. The result is that coal is now essentially dead or near death in Western nations. In the UK, the heart of the coal-fired industrial revolution, coal has been crushed steadily and decisively by gas and now wind and solar energy.[29] The revolution of inexpensive gas is spreading globally, thanks in part to innovations in technologies such liquefied natural gas (LNG) that make it possible for most countries to gain access to reliable, inexpensive gas even if they do not have big shale supplies and experience themselves.[30] However, LNG remains costly for many importing countries, especially the rapidly growing emerging economies of China and India, where rival fuels for electric power, such as coal, wind and solar, are more competitive. The same gas boom that has been observed in the Western nations (which may now be fading) seems unlikely to occur in the powerhouse economies of the next century.

This story of clean gas and abundant supplies has created a blind spot in the industry and most analyst groups, which have assumed that the narrative of the past will continue. Assuming that these warm chestnuts of a gas-rich future would define the future, nearly every published scenario from the International Energy Agency (IEA) saw growth in gas as inevitable until just last year.

For the moment, the future of gas is a lot less certain, as illustrated in Figure 4. With growing concerns about climate change, the spray for global gas demand projections is bigger than ever before, principally because the downside risks of imploding demand have become more apparent. What has changed is the realization that gas replacing coal, where it happens, only delivers shallow decarbonization—a few tens of percent in lower emissions, not net zero by 2050. Gas, even when burned in the most efficient modern power stations, still emits a large amount of CO_2. Moreover, poor drilling and piping practices can result in leaks of methane, the potent warming gas, and even a small leak can cause significant harm to the climate.[31]

Figure 4: Future demand for gas.



Gas has risen inexorably since the 1960s, and the history of gas forecasting has included underestimates of future demand, including in the IEA's 2010 World Energy Outlook (blue lines starting 2010) and ExxonMobil's 2019 Outlook for Energy. That may now be changing, as shown in projections by IEA released in 2020, Shell (2018 "sky" scenario and 2021 "waves," "islands" and "sky 1.5" scenarios) and BP's three projections released in 2020.[32]
Source: International Energy Agency, BP, Shell, ExxonMobil.

Unlike oil, where most climate policies and technological advances point to lower demand, the effects of policy and technology on gas are still harder to parse. Some technologies could allow for a much larger use of natural gas through the deployment of new power stations with carbon capture and storage (CCS) and aggressive programs to control methane leaks and vents.[33] Those policies and technologies are highly visible to the industry and help reinforce the mindset that conventional fossil fuels will always be needed in large volumes. Meanwhile, there is much more rapid growth in policies aimed at outright bans on the usage of natural gas, such as in new residential and commercial construction. These policies do not withstand most conventional cost-benefit tests yet are often politically very popular. Initially, these policies came from the usual sources, namely fringe agitators against big companies and fossil fuels, such as Berkeley, California. However, they are now spreading.[34] The possibility that demand for gas will shrink in the future—a heresy for decades—is no longer so remote.

Lower demand means radical changes in supply, the traditional moneymaker for oil and gas companies

In a world where it was assumed that demand for oil and gas would expand, every Western supplier followed more or less the same model: expansion of supply, focusing on fields where risks were high and thus returns from good technology and management were generous. **In a world where the need for new supplies is reduced radically, the traditional business model falters.**

The effects of this shift will be most pronounced in oil supply because that is where downside demand risks are greatest and where most oil and gas firms make most of their financial returns. With oil demand flat and plausibly on the cusp of big declines, the risk of stranding production assets is rising quickly.

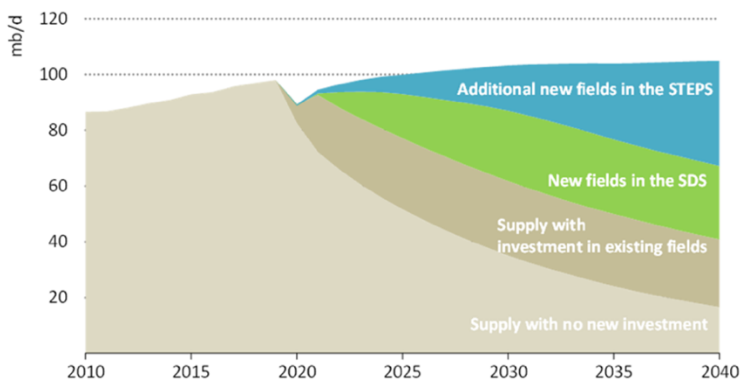
Every firm, to varying degrees, plans its investments in new oil supplies ("upstream," as it is known) by compounding two factors. One is an estimate of the total global need for oil. The other is an estimate of the rate at which existing fields would decline. While people outside the oil industry mostly focus on total demand, this second factor—the decline rates—actually has a bigger impact on investment planning. With steep declines in existing fields, the industry has been able to assume, reliably, that there will always need to be a lot of drilling.

Figure 5 demonstrates the IEA's scenarios for oil supply as a function of these two compounding factors.[35] Where total demand and decline rates are high, there is a huge wedge that must be filled with investment in progressively riskier (and more profitable) types of field. The first layer of investment is mere expansion of production at existing fields—including enhanced oil recovery, where flooding a field with substances such as CO_2 boosts output. Beyond that is the discovery and opening of new frontier fields.

As the industry has tapped fields with high decline rates—most striking, oil from shale—the wedge between demand and baseline supply has grown. Decline rates on shale wells—which are gushers when first drilled and then plummet quickly—are about ten times the rate of conventional oil wells.[36] A survey of drilling activity in the U.S. Permian basin (in west Texas and southeastern New Mexico), completed shortly before the pandemic cratered demand and supply, showed that decline rates, already high compared with other oil fields, were rising to about 40% annually.[37] In contrast, decline rates in large Middle Eastern fields appear to be much lower, at 1% to 2% (with the caveat that reliable data from governments that require secrecy for survival are scarce).[38]

Therefore, even the oil firms most committed to deep decarbonization have been able to tell a story, framed by Figure 5, of ongoing needs for drilling and expansion. However, that story is a lot less robust than it seems. With growing downside risk for total oil demand, the loss in necessary supply comes disproportionately from new fields. **When total world demand for oil drops, more of the supply can be provided by traditional workhorse fields not operated by Western oil companies.** Moreover, the decline rates on these fields are typically lower than frontier production.

Figure 5: Oil supplies from existing and new fields.



The figure, reprinted from IEA (all rights reserved), shows total demand for oil (million barrels per day) under existing policies scenario ("STEPS") and a sustainable development scenario ("SDS"). A wedge is created between the decline from existing fields in the absence of new investment and total demand. About one third of that wedge is filled readily with investment in existing fields. Another third is the necessary frontier (i.e., new field) for discovery and production under SDS.[39] Source: International Energy Agency.

As the wedge varies in size, the core business model of Western oil companies is in play. A big wedge is where Western oil companies traditionally made their money. While even the lowest demand scenarios in Figure 5 suggest that the wedge will not disappear, an oversupply of skilled drillers and equipment will be chasing a much smaller eudaimonic pie. The volume of new field discovery and production is more than halved when demand shifts from existing policies to a more climate-friendly scenario.

In filling the wedge, the Western oil companies made their biggest returns through excellence in managing risk. Ever since waves of nationalization spread across the oil industry in the early 1970s, the world's most lucrative hydrocarbon provinces have been locked up by state-owned firms in countries such as Saudi Arabia or Iran where it was hard or impossible to do business. Therefore, the best-performing Western companies did the opposite—rather than specializing in a particular country, they built a global portfolio of projects on the confidence that the demand for new supply would exist. Exceptional financial performance came from excelling in managing that portfolio. The business favored large companies with technical and political prowess of a special type, namely companies that could make huge bets on whole countries as they emerged (e.g., Equatorial Guinea) or re-emerged as producers (e.g., Iraq) and on particular kinds of geologies that required special technological skills where they had nurtured the skills to excel (e.g., the ultra-deep water with complex geology in the Gulf of Mexico or off Brazil or Angola).[40] Within reason, the riskier the better.

When the wedge shrinks or disappears, this model evaporates.

The consequences of this for gas suppliers are harder to parse. Long before the most profound implications of climate change for demand and supply were apparent, most firms were already rebalancing away from oil toward a larger role for natural gas because demand for gas, especially in generating electricity, was rising.

If gas demand shrinks then the impact on upstream production will be similar to oil, but the effects will play out regionally. Each gas market has its own characteristics, and, despite advances in LNG that allow the shipping of gas across long distances like oil, it is still costly to move big volumes of gas around global markets. Shipping costs for oil are typically a small fraction of the value of the delivered product. Shipping costs for gas via LNG can account for half or more of the product value. There is thus, more or less, convergence in oil prices in a single global market but a weaker convergence in gas.

Within regions that seem to offer huge opportunities for expanded production—for example, shale gas in North America—the structure of the industry is not particularly rewarding for huge incumbents because it is easy for new entrants to join.[41] If demand softens then the pressure on suppliers will mount even further, and the returns from bulk gas supply infrastructure—a capital intensive network of pipeline and delivery systems—will shrink as well, except where regulation allows continued returns to incumbents. **What had been an obvious bet for a future of climate and environmental awareness—namely a shift by all the major firms to boost their dependence on gas—is no longer so obviously rewarding.**

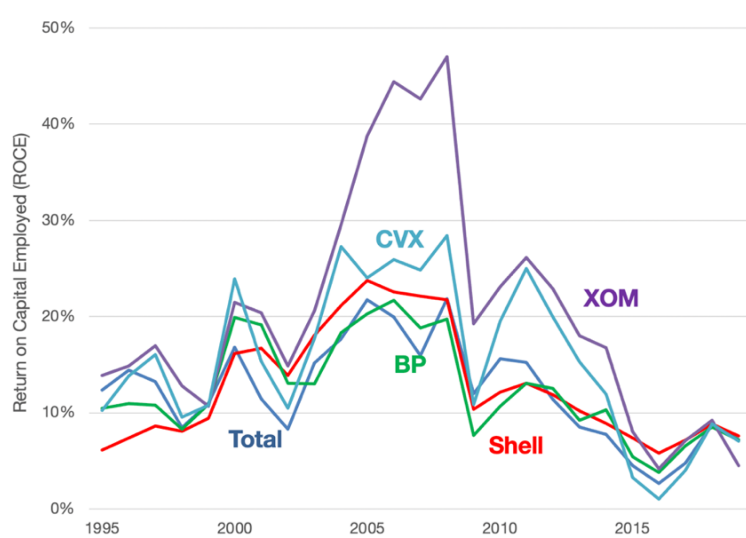
Transformation in demand and supply is already evident in capital returns

When the portfolio of conventional, global oil and gas production was well-managed for long-term risk, the financial returns were often stupendous. One widely used measure, return on capital employed (ROCE), saw returns in excess of 40% some years—especially when global oil prices were high, and supersized returns came from keeping costs under control and earning windfall rents. Not surprisingly, ExxonMobil's Lee Raymond implored the whole industry to use ROCE as the right measure of performance, for his firm seemed optimized at the time to deliver.[42]

A sign of how the business is already changing is that the flattening of demand for oil and the softening of prices globally since the financial recession of 2008 and the spreading expectation of serious climate policy have seen ROCE tumble (Figure 6). Firms that used to stand out for exceptional management, like ExxonMobil and Chevron, have seen their ROCEs converge with other firms. The exceptionalism of good management focused on maximizing the value of liquids has, for the most part, ended.

Figure 6: Return on capital employed (ROCE) for the five Western oil majors, 1995-–2019

Supersized returns, which peaked with high oil prices in the middle and late 2000s, have now come back to Earth to sub-10% levels; the large variation across the industry has also narrowed. Source: Wall Street research.



Part 2: The Dangers of Inaction

Every few years since the first oil crisis woke up energy strategists to the importance of oil supply, a new vision for the "end of oil" has appeared. Some of these visions see coal or nuclear power, both geopolitically more secure, replacing oil; indeed, they have where it was easy to switch from expensive oil to these alternatives, such as in generating electric power. Other visions saw the sheer exhaustion of oil as the problem.

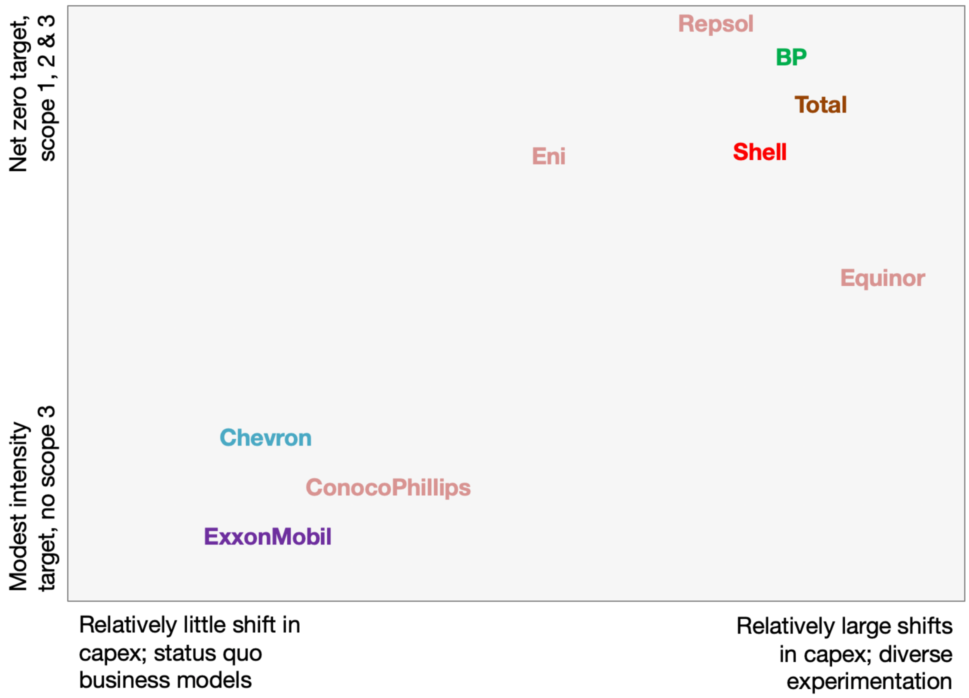
All of these visions for the end of conventional oil and gas have come and gone without making much of a fundamental dent in the industry. Doing better at what is familiar for oil and gas production has always been easy; despite periodic panics, new oil and gas supply has always come online, new technologies have radically lowered the cost of production and fears of energy insecurity have abated. Over the last decade, for example, the cost of some frontier offshore oil drilling has plummeted nearly threefold due to technological and business innovations.[43] Supplies of stones were always ready, often cheaper than the last batch.

This time will be different. What is new is that the decarbonization revolution is being led by technologies and policies that will drive lower demand. **It is dangerous to look to history—where forecasts of declining demand have passed like a seasonal flu—as the method for understanding the new future for demand. The industry is particularly poorly equipped to grapple with shocks in demand because they involve synergies across factors (i.e., policy, innovation, the decentralized rise of new industries) that are far outside the industry's normal scope of competence.** All of these factors are changing simultaneously. It is easy and incorrect to believe that inertia will prevail.[44] Moreover, the effects of technology and policy reinforce each other. A push from policy often makes new technologies that compete with oil cheaper; in turn, that drives oil demand lower while creating bigger markets for rival technologies. Success in that market expansion also creates new expectations, and it makes the new rivals more powerful politically and more capable of passing still more policies that accelerate the shift away from oil and gas. The greater the success of the policy, the lower the cost of the rivals, and the easier it is, politically, to take even more dramatic steps.[45]

Looking across the industry, there is huge variation in whether and how firms are responding to the decarbonization challenge. This can be seen, as illustrated in Figure 7, by examining responses along two dimensions. The first dimension is the aggressiveness of goals for deep reductions in emissions, with the most aggressive goals all stemming from European companies, including Repsol (headquartered in Spain), Total (in France), Equinor (Norway), BP (United Kingdom) and Shell (United Kingdom and the Netherlands).[46]

The other dimension on Figure 7 is significantly harder to identify: the extent to which firms are readying themselves for the transition by investing in—and learning about—new clean energy options. If those options were known and available "off the shelf" then transforming an oil and gas company into a clean energy company would be straightforward. However, since they are not, these options must be worked through to be understood—practical experience through real operations is needed to comprehend what is possible and how to organize and manage new lines of business. The horizontal axis in Figure 7 is a measure of that working—a measure of the level of experimentation by the firm (and by the firm's partner governments, where the firm has those supportive relationships) in clean energy futures.

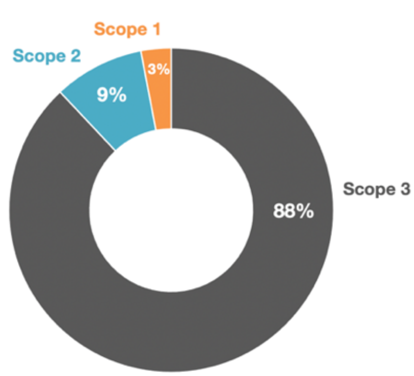
Figure 7: Commitments and readiness for clean energy futures.



The vertical axis is a measure of the breadth and depth of corporate pledges to reduce emissions, with the highest scores for specific commitments to net zero emissions across scope 1, 2 and 3 emissions. The horizontal axis is a measure of relative preparedness for deep decarbonization, with the lowest scores for firms that are essentially unchanged and the highest scores for firms that have the largest and most diverse clean energy portfolios (e.g., as reflected in shifts in their capital budgets, and their corporate efforts to experiment with diverse response strategies in places most likely to yield value.) Such assessments necessarily involve subjective factors. The vertical axis is coded by the author with adjustments to pledges tabulated and assessed by Carbon Tracker. The horizontal axis scoring is based on the totality of assessments by PwC, S&P Global, CDP and IEA.[47] Source: David G. Victor.

CO_2 is unlike other pollutants and social concerns that the industry has grappled with in the past. Those tended to link directly back to the operations of producer firms themselves, thus implicating the need to change behavior and technology inside firm boundaries, such as cutting local oil pollution from operations, reducing payments to unsavory governments or curtailing harmful effluents from refineries. **Assessing readiness for a world of deep decarbonization requires the opposite: looking far beyond a firm's boundary.**

Figure 8: Emissions from operations and products supplied by large oil and gas firms.



The emissions that matter are not just those caused by the firms themselves (known as "scope 1" emissions) or even the energy services, such as electricity, that firms purchase to help with production (known as "scope 2" emissions). Instead, most of the emissions from the oil and gas industry come from how the products are used: scope 3 emissions. As shown in Figure 8, nearly 90% of the total emissions associated with oil and gas operations comes from scope 3.[48]

The chart shows emissions from S&P 500 firms by segment: plant operations (scope 1), purchased energy services (scope 2) and the use of the produced product (scope 3). Source: Urgentum.

Success requires not simply being clean inside the firm's fence line but also changing potentially all the core products currently offered by the oil and gas industry, along with how those products are used. On the one hand, complete transformation implies massive creation of new value. On the other hand, there is no reason to suspect that most or any of the skills needed for that value creation exist within today's incumbent firms. Finding answers to that challenge requires experience rather than waiting for the best industry-wide strategies to become apparent. Nevertheless, gaining that experience is costly, and the best approach will likely vary by firm and market.

Learning to be clean: Five strategies in search of a solution

So far, firms have deployed five major strategies in response to the climate challenge; these are summarized and illustrated in Table 1. To varying degrees, all these strategies overlap. Even firms that are doing a lot to move away from oil, for example, still bet on continued core oil and gas operations to varying degrees. As of yet, silver bullets remain elusive.

Table 1: Five iconic "solutions" to the decarbonization challenge.

"Solution"	What's Attractive	The Risks
Carbon Capture and Storage (CCS) *Example: Equinor's "Northern Lights" project*	Requires managing huge volumes of liquids and keeping them downhole, a core O&G skill	Failure rate for projects, historically, is 95%, and the biggest projects fail most spectacularly
Renewable fuels *Examples: advance biofuels; biogas; synthetic gas*	Requires managing supply and marketing of combustibles	Refining and marketing is low margin and adds value through oil supply integration; most biofuels aren't good for the environment
Clean infrastructure *Examples: EV charging, hydrogen pipelines*	Demand for these services will be high; lots of experience with hydrogen at refineries	Zero experience with EV charging; hydrogen is expensive and hinges on huge subsidy
Renewable electricity *Example: Shell & Total*	"Green Giants" today are all electric companies	Completely different industrial skills
Last Man Pumping *Example: Saudi domination of low cost supplies*	Familiar; some likely growth areas (e.g., chemicals)	Financial death

The table summarizes what industry leaders think attracts them to the solution, along with the risks. Both the attractions and the risks require applying the solution in context—that is, they require investment and experimentation. Source: David G. Victor.

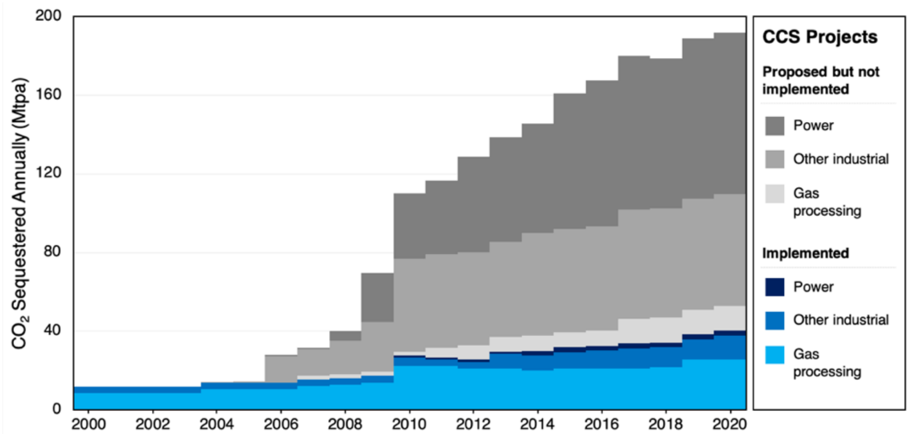
First, firms could invest in carbon capture and storage (CCS). This approach is probably the easiest to graft onto the upstream oil and gas production skills that the major oil and gas companies already have. Some CCS projects involve separating CO_2 that has formed naturally and is often co-mingled in large volumes with methane underground. Drillers want the methane—the combustible ingredient in natural gas—and thus must separate and remove the comingling CO_2 because it dilutes the potency of natural gas. That separated CO_2 is usually vented to the atmosphere, but, with better practices, it could be compressed and injected underground. Drillers already have all the skills necessary to undertake this because putting CO_2 (or other fluids) downhole is commonplace in the industry. Two European companies have done this at scale: Equinor (in the North Sea) and BP (in Algeria). Chevron is conducting large scale separation and CO_2 injection at its Gorgon gas field in offshore northwest Australia, and many other projects are under way, typically at locations where (as in Australia) government policy requires it. ExxonMobil has a similar experience with gas processing at a project in Wyoming, among other locations.[49]

The problem with simple CO_2 removal from natural gas is that it doesn't have much impact on deep decarbonization. Compared with simply venting the CO_2 to the atmosphere, emissions are lower, but the natural gas produced in this way still generates CO_2 when burned.

To have a bigger impact requires different skills, much more risk and supportive government policy. Those skills include capturing CO_2 from industrial processes (e.g., cement kilns, refineries) or building power plants so that they capture the CO_2 somewhere during the combustion process. Those skills must then be linked with expertise in managing the piping of gases and downhole injection. Equinor has led a team that includes Shell and Total to launch the "Northern Lights" project, which will collect industrial CO_2 emissions from many sources around the North Sea, liquefy and transport them by boat to a common location (near Oslo) and then inject them underground.[50] Despite having some of the world's most stringent climate change policies, these firms could not justify moving forward with the project financially until the Norwegian and EU governments offered support. First of a kind projects are expensive; they create revolutions only when firms, often with the cultivated support of governments, invest in early projects with an eye to many future projects—futures where experience can drive down costs and create new markets.[51]

The most profound benefits of CCS may transpire when it is combined with electric power generation. For example, a promising technology that would capture CO_2 from burning natural gas is being tested in Texas. It has modest backing from a consortium of energy companies that includes an oil operator (Oxy), although whether this approach scales depends not just on technology but also on reliable policy support.[52] Making these projects work requires entraining skills outside the core industry and also managing the political support needed for large financial and policy backing.

Figure 9: Life and death of CCS projects.



The figure shows the bold plans for CCS projects over time (grey stacked lines). By 2020, these plans, had they been realized, could have sequestered about 100 million tonnes of CO_2 annually and rising. Instead, actual performance (blue stacked lines) was one fifth of that level. The biggest failures have been in the projects that could be most transformative, namely power plant CCS.[53] Source: David G. Victor.

These risks explain why, as shown in Figure 9, a large fraction of the CCS projects proposed over recent years have all died, most of them long before any firm invested much and gained practical experience. The lowest-risk CCS projects—like removing CO_2 from produced natural gas—tend to be successful, partly because they are required by governments and do not require much new skill. However, they are not transformative for a deep decarbonization future. **The most transformative projects—those involving CCS at power plants—have the highest rate of failure.** To date, 95% of the power plant CCS projects that have been imagined have failed to operate.[54]

The risks are huge, and the business models for CCS success are not yet apparent. Where CCS is used to advance the core industry—such as through injecting captured CO_2 underground in ways that enhance oil production or using CCS power plants to burn natural gas in cleaner ways—the political backing that this nascent industry needs for policy support is more fragile than appears on the surface. Many well-organized interest groups, along with an increasingly powerful zero-carbon industry, seek cost-effective alternatives that move beyond oil and gas completely. This uncertainty helps explain the tentative takeoff of CCS globally. With a few exceptions, reluctant investors, mindful of the risks and how they hinge on policy, have not yet treated CCS as similar to an innovation that they believe is on the cusp of takeoff: a loss leader that, for early movers, will scale to a bigger and more profitable future. Too many CCS projects occur as “one-off” ventures rather than early, sustained steps in learning through experience.

Second, oil and gas companies could focus downstream—on the products, which account for nearly 90% of emissions—and **identify low-carbon replacements that, ideally, are “drop in” substitutes.** The logic for this approach is based, in part, on existing marketing relationships. For oil products in particular, incumbent companies have existing networks of sales relationships to provide gasoline, diesel and jet fuel, along with trading desks that allow for a degree of optimization at scale that confers some commercial advantage to large, incumbent firms. Moreover, if drop-in fuels are viable, they will minimize disruption for users, which could be extremely valuable—with some or all of that value accruing, perhaps, to fuel suppliers.

This playbook is familiar already. In the United States, about 10% of gasoline sold is actually bioethanol, nearly all made from corn. In Sweden, where policy pressure to act on climate change is stronger, about 30% of all diesel fuel sold is a biological substitute, blended with fossil fuel diesel.[55] In 2005, the Swedish blending fraction was just 5%, yet policy and technology combined to quickly change the status quo. A familiar playbook means that many firms know how to do this; the special advantages for large oil and gas firms will be few unless they prove particularly adept at the innovation and delivery of biofuels in new ways.

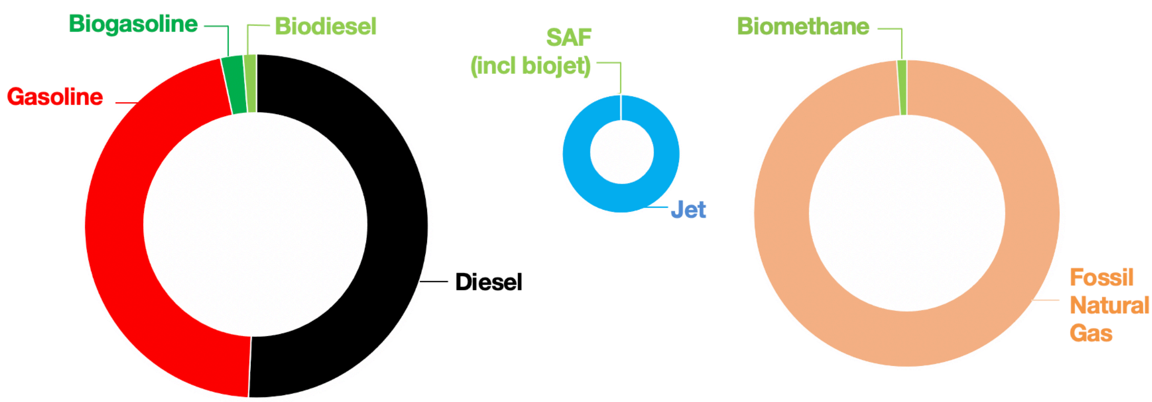
To a lesser degree, there is some blending of conventional fossil natural gas with biomethane captured mainly from landfills and from livestock manure lagoons and injected into the gas pipeline system where fossil and biomethane molecules are indistinguishable. That, too, is a mature industry. Many firms know how to spread a tarpaulin over a landfill, and in markets where those incentives exist, the readily tappable sources have been tapped. Users of natural gas that are under pressure to show that they are reducing emissions purchase biomethane credits that, today, trade for about three times the cost of conventional gas. Prices are expected to rise quickly because the supply of cheap biomethane is nearly tapped out, and alternative methods, such as the gasification of biomass, remain relatively costly.[56] In aviation, biojet—made usually from oilseeds but with a growing volume of "sustainable aviation fuel" (SAF) that is synthesized—has also found a niche market, with the potential for scaling similar to biodiesel because, chemically, jet fuel and diesel fuel are similar.

Turning these product segments into a viable industry requires overcoming several challenges. One is the evidence that many biofuels are not particularly good for the environment; their life-cycle emissions of CO_2 are not zero, as often claimed, and the land uses and nutrient imbalances required to grow these crops cause a variety of ecological harms. Oilseed biodiesel and corn-based bioethanol have received a particularly harsh beating by scientists in this regard. Sugar-based bioethanol performs much better, but that biological fact is politically inconvenient. Sugar growers based primarily in Brazil are not big voters in U.S. elections; corn growers are. Advanced biofuels with lower ecological footprints hold promise, but they have yet to scale. ExxonMobil poured $100m into algae-based biofuels, prospect that still appears to be commercially quite remote. Many other oil and gas firms invested heavily in advanced biofuels with mixed results. SAF will be a key test because its market is poised to grow quickly, with SAF requirements taking hold in Europe as a growing number of governments plan mandates for clean aviation fuel.[57]

Because these fuels utilize existing infrastructure and end-use devices, it is plausible that innovation will generate huge value and returns to investors. **The key tests will lie with whether they can be made, simultaneously, truly clean and scalable. It seems likely that this will depend on fundamental innovations that will come from outside the conventional industry—perhaps in the form of a completely new approach to the biology or engineering of production.** Those skills seem aligned with startup modes of experimentation, rather than big incumbents. A related challenge is that if these clean fuels are anchored in agricultural methods of production then the farming, feedstock and chemical management strategies needed for success may not map well onto the skills of most oil and gas companies. Drilling and farming share few core skills.

So far, as illustrated in Figure 10, the market for oil and gas product replacements is tiny. Only about 3% of the global refined products market is biofuels; an even smaller fraction of natural gas sold globally is biomethane replacement for fossil natural gas. There might be a regional supply story that is more robust and lucrative—for example, supplying biomethane into California (a market that is saturated already)—but the global picture has yet to emerge.[58] The potential for scaling is enormous, and the advantages that accrue to early movers who learn how to develop and deliver products that vary by market could be substantial. For example, biofuels producer Neste has built a massive business from small early pilot investments, with products whose formulations vary by climatic and policy contexts along with consumer needs.[59]

Figure 10: "Drop-in" replacements for oil and natural gas.



The pie charts (which are roughly proportional to the energy value of the different market segments) show the size of conventional oil-based land transportation fuels (left), aviation jet fuel (middle) and conventional natural gas (right). The wedges show the current market sizes for drop-in fuels, which are largest for gasoline (ethanol), diesel (biodiesel) and biomethane.[60] Source: International Energy Agency, BP, IHSMarkit.

While the scalability and cleanliness of biofuels is unknown, there is an additional challenge in aviation. It remains unclear whether drop-in replacement liquid fuels of any type will be decisive because a liquid fuel, when burned, still produces water vapor, and at some altitudes, seasons and flight routes, that vapor becomes contrails. The latest science suggests that most of the warming effects from aviation are actually contrails, not CO_2.[61] Some science and operational experience indicates that modest changes in routing could reduce contrail impacts, but the efficacy of that approach (and its impact on fuel consumption, which denotes more CO_2) is yet unknown.

Because of these contrail effects, one of the most interesting responses to climate change concerns hydrogen. Hydrogen is an energy carrier, like electricity, but it is potentially much more flexible because it is easier to store, can be supplied directly to industries as a replacement for natural gas and for use in chemical processes and can be blended (with limits, given current knowledge) into the pipeline system. Hydrogen is, at present, extremely expensive, and the only substantial large-scale investments are happening in places where there is also strong policy support for decarbonization—such as in Europe and Japan.

A third strategy would **focus on clean infrastructure, such as electric vehicle charging networks and advanced gas networks that could convey pure hydrogen to customers**. This approach is attractive, probably in combination with the second approach above, due to the ability, in principle, to build on existing customer relationships. EV charging might be located alongside gasoline refueling systems, with the balance shifting as EVs rise; the electrons used for charging might be managed alongside power storage systems (that use hydrogen);

hydrogen, in turn, might be used for fueling heavy trucks where electrification seems possibly less practical. Hydrogen might help ensure that existing gas pipeline networks continue to have value in a world of deep decarbonization—thus avoiding the write-down of massive sunk costs in infrastructure.

The EV revolution has put this opportunity—and the risk of inaction—into sharp relief. Plausibly, the world is in the early stages of explosive growth in a new technology; it is situated at the bottom of the S-shaped curve of logistic growth that characterizes so many technologies (see Figure 3 above). At plausible rates of explosive growth, EVs will account for 30% of global vehicles in 2030—a pattern driven by new technologies and supportive policies in many diverse markets from China to California to the UK and most of continental Europe. In 2019, the 7.2 million EVs on the road accounted for 2.6% of global car sales, with total share of cars on the road at 1%. Year-on-year growth in electric cars before the pandemic was 40%, and there are no signs that pandemic disruption will significantly alter that trajectory.[62] Rapid growth in buses and delivery vans, and likely soon other heavy vehicles, is also evident.[63] While there is much attention to the role of Western countries in this revolution, the combination of policy and investment in China has been the single most decisive factor.

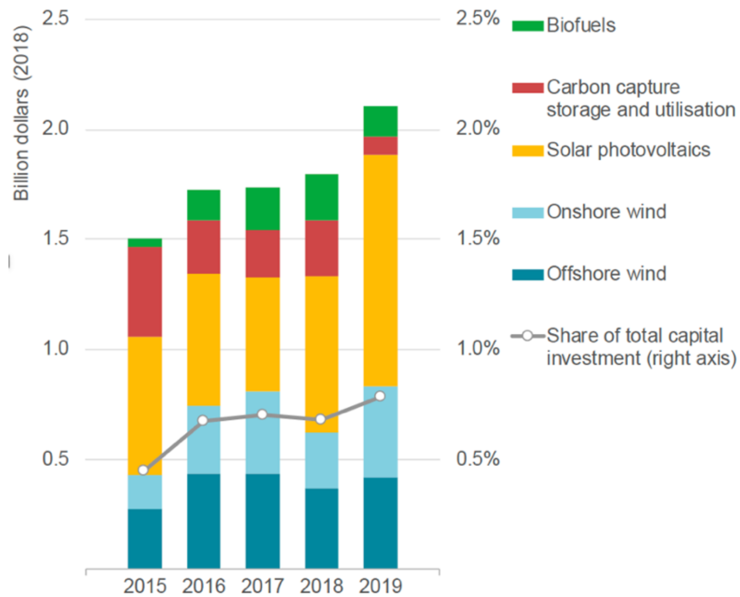
A growing number of countries have announced dates to ban sales of new internal combustion engine (ICE) vehicles—for example, Korea (proposed for 2035), Norway (2025), Ireland (2030) and the United Kingdom (2035). If those stick, the light duty vehicle market will turn decisively to EVs. Some caution is needed, because this future has been forecast before. In the early 1990s, Shell painted an S-shaped, explosive growth for EVs that would have 120 million vehicles on the road by today; California regulators created policies aimed at pushing 10% of new cars on the road as "zero emission vehicles," a concept they initially defined as synonymous with electric.[64] The technology and markets were not ready; grand visions faltered. This time, the technology is a lot more mature and is still improving rapidly.

The challenge in this approach remains the lack of reliable financial return. Governments have focused subsidies on the purchase and leasing of EVs but not, to the same degree, on building the infrastructure. The EV infrastructure business is open and competitive, with standards and business models still being determined. It is a place for oil and gas companies to experiment, but with caution. In the long term, hydrogen may be much more promising in places where firms can work with the government to support the necessary investment, especially while costs come down. Success, though, may require that oil and gas companies build and own more of the gas infrastructure itself—a costly fixed asset that, in most of the biggest markets, is currently owned and operated by other entities.

Fourth, oil and gas companies could invest outside their industry and into renewable electricity supplies: solar and wind. Both technologies are improving rapidly, and both are politically popular and zero carbon. Not surprisingly, many firms have made big pledges to add renewable electricity to their capital investments.[65] Those pledging firms have now started shifting their capital budgets to modest but rapidly growing investments in clean energy. As shown in Figure 11, the biggest of those investments is in solar and wind.

Figure 11: The modest but growing investment in clean energy by oil and gas companies.

Total capital investments by large oil and gas companies in clean energy projects are rising rapidly, but from a very small base. The data here are from IEA (all rights reserved) and are consistent with other sources that track capital redirection company-by-company.[66] Source: International Energy Agency.

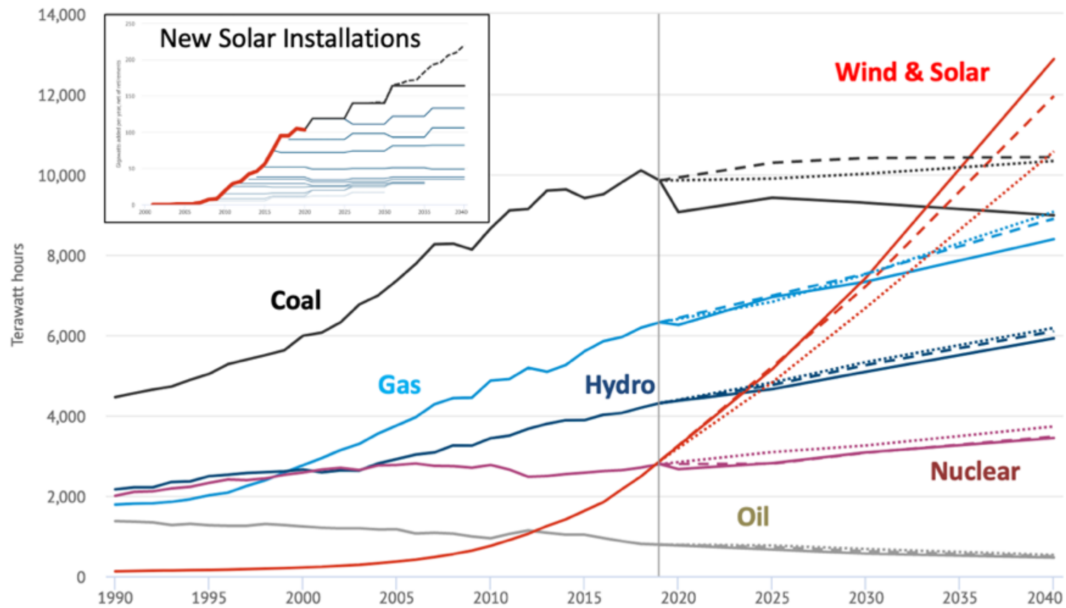


What remains to be determined is how to add unique value to solar and wind energy. Both are electric technologies; success in that business requires skill at managing electric markets or electric utilities that are, for the most part, alien to oil and gas companies. Five of the major oil and gas companies are, at present, making especially prominent pushes into electric power—BP, Equinor, Repsol, Shell and Total. The experience will be familiar (if forgotten by the generational expanse of time that has passed) because many oil and gas companies explored becoming electric companies in the 1990s when they had large volumes of gas that they wanted to monetize. For most, this did not end well, in part because the electric industry, which is highly regulated, is a very different type of industry from conventional oil and gas.

This time, the search for success in electricity is lot more diverse and, it appears, careful. The companies that are most poised to act on climate change—those shown in the upper right quadrant of Figure 7 and, not surprisingly, also those who have made the strongest renewable power pledges—have invested in a diverse array of options. Solar and wind supplies have dominated the investments, although compared with $311 billion in global investment in solar and wind, the $1.8 billion that large oil and gas companies put into these technologies in 2019 is still tiny.[67] (The 2020 data, when they come in, will be filled with pandemic noise and hard to parse.) Nonetheless, there may be room for big oil and gas companies because, with explosive growth, there is room for everyone.

Solar and wind power accounted for 10.6% of total global power generation in 2019; by 2040, as they travel steeply up the S-shaped curve of technology diffusion, mainstream projections see them accounting for 32% and still rising steeply (Figure 12). Moreover, those projections are plausibly underestimated because the same models that yield them have, historically, mostly missed the profound revolution in renewable power, notably solar power.

Figure 12: Solar explosion.



The main figure shows the takeoff of total electric power generation (terawatt hours) by solar energy, while coal flatlines. Projections are from the IEA's World Energy Outlook 2020 with insightful analysis and visualization by Carbon Brief. The inset shows the persistent lagging of these IEA models in estimating accurately the annual new installations of solar power (real capacity additions in heavy red line; the IEA estimates from "stated policies" scenarios 2009–2020 in jagged horizontal lines). This historical disconnect, which is being updated slowly, suggests that the surprises for solar deployment may still be large and upside. The expected exponential takeoff for non-hydro renewables (nearly all of which a wind and solar) may happen even faster than the IEA now projects.[68] Source: International Energy Agency (data); Carbon Brief (visualization).

This growth is being driven heavily by policy, along with technological advancements that are so profound and rapid that the same agency projecting big growth in the future has underestimated that growth every year for decades. It takes time for models to catch up to reality when the latter is changing so quickly.

Because they are small players in a huge, mature field, the incumbent oil and gas companies must be careful to identify what, if anything, they offer to the renewable electricity revolution that is valuable. The answer may lie with offshore wind. Equinor and BP, for example, have successfully repurposed skills in building offshore platforms in harsh environments into a winning strategy for building large offshore wind turbines.[69] Many companies are integrating renewables into field and refinery operations—places where electricity and heat are needed and where, often, grid service is nonexistent, unreliable or expensive—but this market will, at most, reduce scope 1 and 2 emissions. It will not address the much larger problem of scope 3 emissions. Other possible answers may lie with intelligent energy systems and smart grids. For example, Total is investing in this area using a venture capital arm that recognizes that key innovations will arise outside a large incumbent oil and gas firm. Most large oil and gas incumbents have similar venture arrangements, though they vary widely in the size and importance of the investment.

Integrating renewables with hydrogen may also prove promising as the places that are shifting to the highest levels of renewables—for example, Hawaii and California—are quickly learning about the high value of generators that are not as sensitive to exactly when the wind blows and the sun shines because they have built-in storage. Big oil and gas companies are experts in hydrogen, which they already use in refineries, but the hydrogen revolution for renewable electricity will probably require different skills that none of the majors currently possess. For example, it may require operations of large scale electrolyzers (where technology is advancing rapidly) along with the integration of hydrogen and other forms of electric storage into electric grid operations. Other formidable competitors are likely—among them, the green giants shown in Figure 1. Hydrogen integration with electricity is currently extremely costly and thus hinges on policy support—an area where the European firms are furthest along because the EU has included hydrogen in its European Green Deal and other infrastructure support. The UK and Norway are also among big policy supporters.

All four of these strategies, if they are to add value, will require a massive investment in R&D and searching outside the incumbent firms for solutions.

Fifth, if all these strategies seem daunting, firms can do the most familiar: just keep pumping. This strategy would involve shoring up investments in well-established oil fields that have low risk and low pumping costs—an area where integrated oil companies have, in fact, very little comparative advantage because many firms can do this. It would involve providing a shrinking market with the conventional oil and gas that it needs, although that market will be marked by many suppliers and huge state-owned oil companies that have exclusive access to most of the world's least costly oil to produce. It seems unlikely that Western oil and gas majors—who are fine-tuned to be seekers and managers of risky frontier production—have special skills in this world of a commodity death march to be the last man pumping. Firms that follow this strategy will plausibly find it more attractive to simply decapitalize before everyone in the markets recognizes what has changed.

All the major oil and gas companies, today, envision a continued role for oil and gas production. Where they differ is the size of that role and their outlook on what should be done about the remaining emissions associated with the continued combustion of hydrocarbons. All the firms that have set strict limits for their volume of total emissions—scope 1, 2 and 3—envision, to varying degrees, the need for offsets that would compensate for emissions from any remaining production of oil and gas. Indeed, the growing number of net zero emission goals set by firms has spurred rapidly, rising demand for these offsets. Also growing are calls for the standardization of offset protocols so that firms know the level of offset credit they can earn from different projects, such as protecting forests, planting trees or capturing CO_2 from the atmosphere and injecting it underground.[70]

It is easy to understand why so many firms now seek large volumes of offsets. However, it is also important to recognize that the prodigious use of offsets must soon confront growing evidence that a large fraction of offset credits reflect activities that do not actually cause the promised net reduction in emissions.[71] Firms that want to extract value as the last man pumping while still cutting total emissions must provide better answers to the problem of poor-quality offsets.

Part 3: What to Watch as the Industry Responds

With so much in flux, it is hard to take the pulse of change. It is even harder to manage a firm within an industry that has been optimized in a world that, quickly, will no longer exist. **Each firm that is taking the climate problem seriously is making strategic choices under conditions of huge uncertainty. Each response strategy is marked by upside and downside risks. Inaction—or tepid action—has no long-term upside and catastrophic long-term downsides.**

How can we distinguish firms that are preparing for and shaping the decarbonization transition from those that, by default, will try their luck to be the last man pumping?

One place to watch is learning and adjustment. If the best response strategies to the challenge of climate change were obvious, firms that are taking the problem seriously would all be doing the same thing and learning how to follow that single playbook better. That, more or less, describes the world that is now ending—a world in which all the major oil and gas companies, to varying degrees, sought supernormal returns from globally managed, risky upstream production plays. **Today, the firms that are taking this new challenge seriously are not all striving to perfect the same playbook because nobody—not firm managers nor sage analysts—reliably knows what is best.** In this context, success must be measured not simply by allocation of effort but by whether firms are designing their strategies to learn quickly.

Part of the learning is internal to the firms and is revealed by their diversity of response strategies—such as those documented above—and their mechanisms for rapid evaluation. In effect, these firms are running a series of experiments. Some are within domains that the firms control, such as businesses producing SAF or solar power that they acquire or build. Many of the experiments that seem likely to be most consequential are in domains that the firms share with other firms and with governments, such as the Equinor-led Northern lights project or a BP-led project at a longstanding industrial center in Teesside, a coastal community in northeastern England that used to be a center for steel and chemical production. The project aims to use hydrogen and CCS technologies to deliver clean gas fuel while storing CO_2 underground in the North Sea. That project involves four other companies and the UK government. The measure of these efforts is not just that they are occurring but also that they are designed for adjustment, namely enhancement where the experiments work and closure where they do not bear fruit.

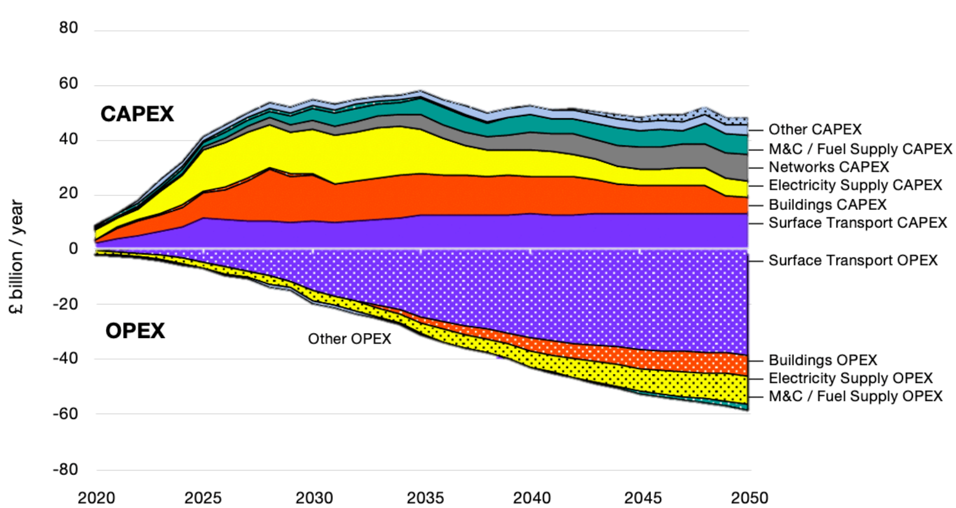
Part of the learning is collective. Of note is an industry-wide effort organized under the Oil and Gas Climate Initiative (OGCI) to invest in early-stage technologies and improved business practices that are likely central to any decarbonized future for the industry. In particular, OGCI pools capital and expertise to invest in CCS and strategies for cutting emissions of methane.[72] The former is essential if fossil fuels are to have any significant role in an economy that otherwise has near-zero overall emissions—OGCI helped organize the Teesside project, for example. The latter is vital if natural gas in particular is to have any role in a decarbonized future. OGCI members have made the strictest methane control pledges of the industry, essentially to eliminate leaks of the potent warming gas, and OGCI technologies have helped give the members the confidence to deliver. While OGCI members have collectively and individually set ambitious goals for cutting methane emissions, what ultimately matters is excellence in operations and independent verification. Here the experience with the new reporting framework under the Oil and Gas Methane Partnership (OGMP 2.0) is instructive, for it establishes rigorous standards (which are voluntary for now but are likely to inform binding European rules) for methane accounting and verification.[73] All the large European oil and gas firms adhere to OGMP 2.0; none of the U.S. firms do.

A central part of the learning process must be laser-like attention to the risks of stranded assets. Many of the potentially transformative experiments are organized as collectives that involve governments because this helps stabilize policy expectations and reduce the risks that shifts in policy will strand assets. The risks are extraordinary, even in a capital-intensive industry that is already highly sensitive to the dangers of stranded assets.

To reveal the risks, it is instructive to look at the plan from the UK government. This plan has been among the most aggressive in planning deep cuts in emissions and also the most transparent about how it intends this transformation to occur with the costs and disruptions that remain publicly acceptable and thus politically durable. The plan, as shown in Figure 13, is to reduce the long-term costs of energy services by shifting from energy systems with high operating costs to those with high capital costs and amortize those capital costs over long time periods.[74] This approach is consistent with many modeling studies, such as those examined by the IPCC, that show how decarbonization will move economies away from fuels, with their attending operating costs, to infrastructures such as electricity and hydrogen where most of the cost is fixed.[75] Put simply, economies that decarbonize are economies that electrify and capitalize.

That maxim of capitalization is the new reality for the energy industry. With that reality comes massive risks and the need for active strategies to learn quickly and manage the risks associated with dead ends and stranded capital. Those skills require learning through experimentation and, perhaps most crucially, the ability to work with other partners and governments that face the same challenges. The European firms are pioneering that approach, often at a near-term cost, because they see the realities of deep decarbonization looming. Globally, many others are doing the same. What is striking in this shift is that the biggest firm and the caboose is ExxonMobil; this is especially striking, perhaps, because for so long it was a leader of the industry.

Figure 13: The UK's climate change plan—shifting to capex to save, in time, opex.



The chart shows, by major segment of energy-related activity, the annual expenditure on capital costs (top) and savings in operating costs (bottom) to achieve net zero emissions by 2050.[76] Source: Committee on Climate Change, 2020. Visual adapted from original chart.

The transformation that is under way is laden with risks and will require a wide suite of new technologies. Nearly all of those technological options are so unfamiliar to the oil and gas industry of today that it seems likely that much of the creation of value in a deeply decarbonized world will come from new firms. Existing firms will need either to manage their own decline or to find strategies to integrate new ideas from outsiders and new entrants.

The challenges for successful management of incumbent oil and gas firms are immense. What is needed will be the identification of potentially wholly new lines of business, and reorientation of talent, culture and organization for excellence in those yet-unknown new purposes and directions. Success will require new organizational forms that can search broadly for new business models and engage with a wide variety of new partnerships. Success will also require highly active roles for boards—to support and steer executives who must take risks in reframing corporate missions and organizations. The board must also be equipped to aide in the evaluation of new lines of business that may be quite different from traditional oil and gas functions.[77]

This is a familiar problem in many industries that, over history, has mostly seen the death of the incumbents. Whether that happens here will hinge on a completely new set of technological and organizational skills, all acquired under conditions of extreme risk that uninformed large investments will strand capital.

About David G. Victor

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Engine No. 1 LLC, Engine No. 1 LP, Engine No. 1 NY LLC, Christopher James, Charles Penner (collectively, "Engine No. 1"), Gregory J. Goff, Kaisa Hietala, Alexander Karsner, and Anders Runevad (collectively and together with Engine No. 1, the "Participants") intend to file with the Securities and Exchange Commission (the "SEC") a definitive proxy statement and accompanying form of WHITE proxy to be used in connection with the solicitation of proxies from the shareholders of Exxon Mobil Corporation (the "Company"). All shareholders of the Company are advised to read the definitive proxy statement and other documents related to the solicitation of proxies by the Participants when they become available, as they will contain important information, including additional information related to the Participants. The definitive proxy statement and an accompanying WHITE proxy card will be furnished to some or all of the Company's shareholders and will be, along with other relevant documents, available at no charge on Engine No.1's website at https://reenergizexom.com/materials/ and on the SEC website at http://www.sec.gov/.

Information about the Participants and a description of their direct or indirect interests by security holdings is contained in the preliminary proxy statement filed by the Participants with the SEC on March 2, 2021. This document is available free of charge on the SEC website. The definitive proxy statement, when filed, will be available on Engine No. 1's website and the SEC website.

Notes

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[2] David Kirsch, 2000, The Electric Vehicle and the Burden of History (Rutgers University Press).

[3] For example, see the work of Vaclav Smil channeled into Michael Cemblast's annual energy letter. Tenth Annual Energy Letter (JP Morgan, 2020). Related, using data through 2015 managed by Resources for the Future shows long term decarbonization of the energy system has barely changed for decades. See www.rff.org/geo And for the long term trend starting in 1850 see: https://phe.rockefeller.edu/docs/HeresiesFinal.pdf

[4] http://www.climatefiles.com/lee-raymond-collection/1996-exxon-raymond-moving-forward-together-economic-club/

[5] Kingsmill Bond, 2020, Decline and Fall: The Size & Vulnerability of the Fossil Fuel System, Carbon Tracker (4 June). https://carbontracker.org/reports/decline-and-fall/; Katherine Blunt and Sarah McFarlane, 2020, "The New Green Energy Giants Challenging Exxon and BP," The Wall Street Journal, 11 Dec

[6] Brad Plumer, 2014. https://www.vox.com/2014/5/29/5761944/this-chart-shows-why-its-so-hard-to-make-predictions-about-energy

David G. Victor, 2020, "Forecasting energy futures amid the coronavirus outbreak," Brookings (3 April). https://www.brookings.edu/blog/order-from-chaos/2020/04/03/forecasting-energy-futures-amid-the-coronavirus-outbreak/

[7] Missing that reality helped explain why The Economist's cover on March 6th 1999 was "Drowning in Oil" and nine months later on December 16th the lead essay proclaimed "We woz wrong," and explored the perils of forecasting—in this case, forecasting that involved the behavior of Saudi Arabia and other oil rich exporters whose production behavior was hard to observe.

[8] Total liquids consumption, as reported by BP Statistical Review of World Energy (2020), the best and most convenient source of reliable energy information.

[9] Global Future Council on Energy, 2019. "The Speed of the Energy Transition: Gradual or Rapid Change?" World Economic Forum (September 2019).

[10] Data sources: Historical oil (liquids) data from BP Statistical Review; projections from Shell (2013 Mountains and Oceans scenarios plus 2018 Sky scenario and the 2021 Waves, Islands, and Sky 1.5 scenarios), BP (three scenarios released in 2020), the International Energy Agency (baseline projections since 2000 plus three scenarios in 2010 and three in 2020). And ExxonMobil sole Outlook for Energy scenario (2019). Online ExxonMobil has also "evaluated" the EMF27 two degree scenarios.

[11] The quote is so perfectly revealing that, it appears, it may never have been said by Yamani; certainly many others have said more or less the same thing. For example, see The Economist's 2003 vision for an end to oil—a vision that did not pass. https://www.economist.com/leaders/2003/10/23/the-end-of-the-oil-age

[12] This shift in mindset—from supply uncertainty as the key to oil security to demand uncertainty as the key to ecological security—is evident by looking at two of the iconic books from Dan Yergin, the most visible chronicler of the industry's past and future. His epic The Prize (Simon and Schuster, 1990) told the industry's history through the lens of corporate and political ventures that opened new fields for production and struggled to re-established production when, as in the Arab oil embargo, the spigots were shut. His latest book, The New Map (Penguin, 2020) explores how new priorities, climate centrally, will reshape the whole industry. As chairman of the world's leading energy conference—CERAWeek, held every March in Houston—this shift in wind direction identified by Yergin is a reflection that the industry, to some degree, now sees that same shift.

[13] Simon Evans, 2020, "The world has already passed 'peak oil' demand, BP figures reveal" CarbonBrief. https://www.carbonbrief.org/analysis-world-has-already-passed-peak-oil-bp-figures-reveal

[14] OPEC, 2020, World Oil Outlook 2045. (Vienna: OPEC). https://woo.opec.org/index.php

[15] Two out of BP's three scenarios see 2019 as the peak for total liquids consumption (at ~100 million barrels per day). One scenario ("Business as Usual", which is a concept increasingly fraught for energy modeling because little

is “usual” in the industry) sees tiny rises in oil demand before a long slow slide. BP Energy Outlook 2020. https://www.bp.com/en/global/corporate/energy-economics/energy-outlook.html

[16] See Shell, “Sky” scenario, which is designed as a plausible vision for a future, not a projection, and thus be design assigns no probability to that vision. https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/shell-scenario-sky.html

[17] See ExxonMobil “2020 Investor Day,” New York Stock Exchange (5 March 2020). https://corporate.exxonmobil.com/-/media/Global/Files/investor-relations/analyst-meetings/2020-ExxonMobil-Investor-Day.pdf

[18] For example, in BP’s “Net Zero” projection, which envisions the most aggressive decline in emissions, the company says, “implies that several trillions of US dollars of new oil investment is needed over the next 15 years or so to ensure adequate supplies”. See BP Energy Outlook 2020, p.137.

[19] https://www.woodmac.com/our-expertise/capabilities/electric-vehicles/2040-forecast/

[20] https://www.iea.org/reports/global-ev-outlook-2020

https://www2.deloitte.com/us/en/insights/focus/future-of-mobility/electric-vehicle-trends-2030.html

[21] BloombergNEF, 2020 “Battery Pack Prices Cited Below $100/kwh for the first time in 2020, While market average sits at $137/kWh” (December 16). https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/

[22] See figure 1.3a in: David G. Victor and Dadi Zhou et al., 2014, “Introductory Chapter,” in: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge: Cambridge University Press).

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[24] See figure 5 (mass-based global warming potentials by time horizon) in: [Balcombe et al (2018)]

[25] Inês Azevedo, Michael Davidson, Jesse D. Jenkins et al., 2020, “The Paths to Net Zero: How Technology can save the planet,” Foreign Affairs (May/June). https://www.foreignaffairs.com/articles/2020-04-13/paths-net-zero

[26] On the supply revolution see: Michael Shellenberger, Ted Nordhaus, Alex Trembath, and Jesse Jenkins, 2012, “Where the Shale Gas Revolution Came From,” Breakthrough. https://thebreakthrough.org/issues/energy/where-the-shale-gas-revolution-came-from On drilling activity, which I measure in footage, see data from US Energy Information Administration and IHS Markit at: EIA, 2018, “Monthly Crude oil and natural gas gas well drilling footage by type (2000-2016). The data here co-mingle gas and oil drilling; the story began with gas.

[27] Estimates are from table 8b in the biennial retrospective at the quality of forecasts by the Energy Information Administration, an informative if somewhat embarrassing exercise: EIA, 2020, Annual Energy Outlook Retrospective Review. (December 29, 2020). https://www.eia.gov/outlooks/aeo/retrospective/ The generally horrible performance of these “closed” energy systems models is now widely recognized, except by the purveyors of those models. See https://openenergyoutlook.org/ And see Adam Reed et al., 2019 “Interrogating uncertainty in energy forecasts: the case of the shale gas boom,” Energy Transitions, vol 3, pp. 1-11.

[28] See figure 9 in: Energy Information Administration, 2020, U.S. Energy-Related Carbon Dioxide Emissions, 2019. (Washington: EIA). https://www.eia.gov/environment/emissions/carbon/pdf/2019_co2analysis.pdf

[29] See Figure 27 (“The UK Electricity generation mix, 1998-2019”) in Peter Low, 2019, Oil Majors: Lost in Translation (London: Redburn).

[30] Alan J. Krupnick, Raymond J. Kopp, Kristin Hayes, and Skyler Roeshot, 2014, The Natural Gas Revolution: Critical Questions for a Sustainable Energy Future,” Resources for the Future. https://media.rff.org/documents/RFF-Rpt-NaturalGasRevolution.pdf

[31] Paul Balcombe et al., 2018, “Methane emissions: choosing the right climate metric and time horizon,” Environmental Science: Processes & Impacts, vol 20, pp. 1323-1339. https://doi.org/10.1039/C8EM00414E

[32] Data sources: see figure 2.

[33] On the policy front, notably the 45Q tax credits for CCS for which the Internal Revenue Service recently provided supportive guidance that will help unleash investment. On technology, see discussion below on CCS for gas, including: https://netpower.com/

[34] Mike Henchen, 2020, "Why States Need to Ban New Gas Hookups in Buildings (in 5 charts). Greentech Media (17 Feb). https://www.greentechmedia.com/articles/read/5-charts-that-show-why-states-need-to-eliminate-fossil-fuels-from-buildings

[35] See also Figure 28 in Kingsmill Bond, 2020, Decline and Fall: The Size & Vulnerability of the Fossil Fuel System, Carbon Tracker (4 June). https://carbontracker.org/reports/decline-and-fall/

[36] See the hyperbolic decline rates modeled here: https://www.eia.gov/analysis/drilling/curve_analysis/

[37] https://pubs.spe.org/en/jpt/jpt-article-detail/?art=6355

[38] https://financialpost.com/commodities/energy/saudi-arabias-biggest-oil-field-is-fading-faster-than-anyone-guessed

[39] International Energy Agency, 2020, World Energy Outlook (Paris: IEA)

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[41] The full experience is complex and generally more positive (at least until the pandemic) for shale oil than shale gas, where the latter has seen the supply industry suffer from long-term low prices and lots of entry from small drillers. For example: Ed Crooks, 2019, "The week in Energy : Big Oil Getting Bigger in Shale," Financial Times. (8 March). https://www.ft.com/content/4d4401f8-41ed-11e9-b896-fe36ec32aece

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[48] Data on scope 1, 2 and 3 emissions are for S&P500 members in "Energy" as estimated by Urgentum.

[49] https://corporate.exxonmobil.com/News/Newsroom/News-releases/2021/0201_ExxonMobil-Low-Carbon-Solutions-to-commercialize-emission-reduction-technology

[50] https://www.equinor.com/en/what-we-do/northern-lights.html

[51] David G. Victor, Frank Geels, Simon Sharpe, 2019, Accelerating the Low Carbon Transition. London: Energy Transitions Commission. https://www.energy-transitions.org/publications/accelerating-the-low-carbon-transition/

[52] https://netpower.com/

[53] A. Abdulla, R. Hanna et al., 2021, "Explaining successful and failed investments in U.S. carbon capture and storage using empirical and expert assessments," Environmental Research Letters, vol 16. Doi: https://doi.org/10.1088/1748-9326/abd19e

[54] Data on death rates of different projects are based on a global databased (anchored in the NETL dataset) as reported in Ahmed Abdulla, Ryan Hanna, et al., 2021,"Explaining successful and failed investments in U.S. carbon capture and storage using empirical and expert assessments," Environmental Research Letters vol 16. https://iopscience.iop.org/article/10.1088/1748-9326/abd19e

[55] See figure 25 in: Peter Low, 2019, Oil Majors: Lost in Translation (London: Redburn).

[56] The question of costs for natural gas replacements is very hard to pin down right now. Statements are based on current technology and pessimism about the ability of biomethane technologies to scale once the easy-to-tap sources (eg, landfills) in the United States are tapped. But the uncertainties must be recognized, and some visions for natural gas replacement see a huge role for innovation in biomethane alongside a roughly equal role for hydrogen blending while conventional natural gas shrinks by two-thirds. See a roadmap for Europe (where demand for decarbonization in gas is much more reliably seen by industry today): Daan Peters et al., 2020, Gas Decarbonisation Pathways 2020-2050. Gas for Climate and Guidehouse (April).

[57] Alex Dichter, Clemens Kienzler, and Daniel Riefer, 2020, Clean Skies for Tomorrow: Sustainable Aviation Fuels as a pathway to net-zero, McKinsey. https://www.mckinsey.com/industries/travel-logistics-and-transport-infrastructure/our-insights/scaling-sustainable-aviation-fuel-today-for-clean-skies-tomorrow . On emerging SAF blending mandate in Europe: https://www.euractiv.com/section/aviation/news/eight-eu-countries-call-for-green-fuel-to-be-mandatory-in-european-aircrafts/

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[59] https://www.neste.com/products/all-products/renewable-road-transport/neste-my-renewable-diesel

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[72] https://oilandgasclimateinitiative.com/

[73] https://www.ccacoalition.org/en/resources/oil-and-gas-methane-partnership-ogmp-20-framework

[74] Committee on Climate Change, 2020, The Sixth Carbon Budget: the UK's path to Net Zero. https://www.theccc.org.uk/publication/sixth-carbon-budget/

[75] Cite Leon Clarke et al., 2014, "Assessing Transformation Pathways" chapter 6 in: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge: Cambridge University Press).

[76] Source: figure 3 in Committee on Climate Change, 2020, The Sixth Carbon Budget: the UK's path to Net Zero. https://www.theccc.org.uk/publication/sixth-carbon-budget/

[77] A similar challenge is now arising for national oil companies, the main rivals to western oil and gas producers. They, too, face the risk of huge stranded assets and the need to understand how energy transitions could radically erode demand for conventional hydrocarbons. See in particular David Manley and Patrick Heller, 2021, Risky Bet: National Oil Companies in the Energy Transition" NRGI (February). https://resourcegovernance.org/analysis-tools/publications/risky-bet-national-oil-companies-energy-transition