The Pandemic and the End of Oil?

The Pandemic, Peak Oil Demand, and the Oil Industry

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ABOUT EPRINC

The Energy Policy Research Foundation, Inc. (EPRINC) was incorporated in 1944 as a not-for-profit organization that studies energy economics with special emphasis on the production, distribution, and processing of oil and gas resources. It is known internationally for providing objective analysis of energy issues.

The Foundation researches and publishes reports on all aspects of the petroleum industry which are made available free of charge to all interested organizations and individuals. It also provides analysis for quotation and background information to the media. EPRINC has been called on to testify before Congress on many occasions, and it briefs government officials and legislators, and provides written background materials on request. Additionally, EPRINC has been a source of expertise for numerous GAO energy-related studies and has provided its expertise to virtually every National Petroleum Council study of petroleum issues. EPRINC receives undirected research support from the private sector and foundations, and it has undertaken directed research from the U.S. government from both the U.S. Department of Energy and the U.S. Department of Defense.

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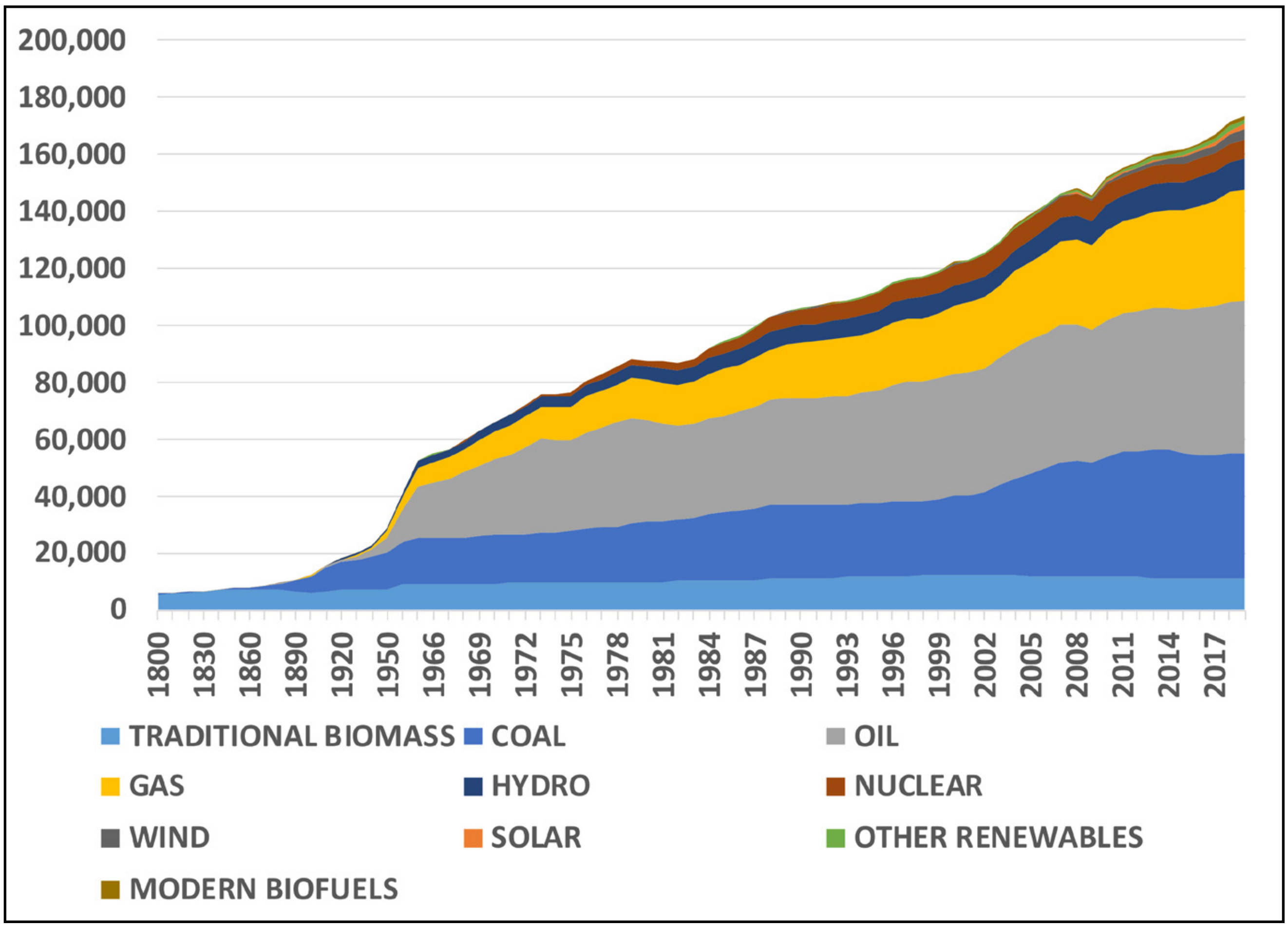
EXECUTIVE SUMMARY

The pandemic-related drop in oil demand in 2020 has led a number of analysts to argue that the peak in global oil demand is much more certain and imminent than previously anticipated. Here the thinking is that progress underway in the electric utility sector replacing coal with lower carbon emitting natural gas and renewable fuels (still quite low on a global scale) can be replicated in the transportation sector. Changes in public behavior, such as working from home, and a realization that gasoline and diesel fuels can be replaced by battery technology may offer a unique opportunity to dramatically cut carbon emissions. Some of these predictions are merely scenarios and others are aspirational, produced by advocates for robust climate change policies, while nearly all involve a variety of assumptions that are not well-supported by real-world behavior.

Vast sums have been committed to promote renewable fuels and low carbon energy alternatives. Press reports abound with breakthroughs and accomplishments that document that the energy transition is well underway. When we examine world energy use as recently as 2019, it is evident that the world remains reliant on fossil fuels and that any major transition will be costly and difficult (Figure 1). Fossil fuels, especially in the transportation sector, remain dominant as use is driven by cost, energy density, convenience, and reliability.

Figure 1
Global Direct Primary Energy Consumption (terawatt-hours)



Source: OurWorldinData.org; Vaclav Smil (2017), BP Statistical Review

So are we now on the precipice of the end of the oil? The oil industry has seen numerous similar predictions throughout its history, including such modern ones as the post-Iranian Oil Crisis arguments that oil was a declining industry and companies should use their cash flow to diversify into other sectors; an insistence in the 1990s that brick-and-mortar companies and industries were obsolete; and the post-2000 claims that world oil supply could not continue increasing. In every instance, the arguments achieved widespread publicity but ultimately proved to be erroneous.

Real-world experience demonstrates that consumption of a resource sometimes peaks but rarely declines, with stone and wood still comprising significant industries. The belief that battery electric vehicles will soon become competitive with internal combustion engine (ICE) vehicles is based on questionable assumptions on both the future costs and performance of batteries and the value consumers place on convenience. Gasoline has forty times the energy density of batteries, and refueling times of 3-4 minutes are far superior to the 20-40 minutes that even a fast charging station requires to provide a BEV with a partial charge.

Further, BEVs have a limited and uncertain range. Publicized ranges typically assume optimal driving conditions, such as mild temperatures and no use of heating, and drivers are warned to typically use no more than 60% of a battery's charge without recharging. Comparison with the rapid switch from horses to the Model T, the first mass-produced auto, are flawed, as the Model T, while more expensive than a horse, had far superior performance while BEVs are not only more expensive than ICE vehicles, but they also perform much more poorly.

Given that the primary trend in the automotive market has been an increased market share for SUVs, it is difficult to reconcile claims that consumers will sacrifice cost and comfort to help achieve the public good of better environmental performance, especially when BEVs require use of rare earth metals which can be difficult to dispose of, as well as produce only moderate reductions of greenhouse gas emissions. At present, use of BEVs represents one of the most expensive climate change policies and it appears unlikely that the trajectory of oil demand will be reduced in the near future, especially given current low prices.

The past few months have seen enormous change in global society, technological adaptations, health, and many industries. The petroleum industry has borne a significant part of the burden, with the pandemic crashing demand and prices, threatening bankruptcy for many companies, job losses, strategic shifts, and causing widespread production shutdowns. While it is clear that the pandemic will, at some point, recede, what the oil and gas industry will look like afterwards is less certain. This paper is intended to address these questions in light of similar predictions in the past and the realities of present energy technologies and fuels. Many opinions have been put forth, some predictive and others prescriptive.

The latter is illustrated by the many arguments for a post-pandemic stimulus package aimed at boosting carbon-free energy sources, primarily renewables. For example, Carbon Brief argues that "spending this money on climate-friendly 'green' policy initiatives could not only help shift the world closer to a net-zero emissions pathway, but could also offer the best economic returns for government spending."[1] Others have noted the seeming resilience of renewable energy and electric vehicle sales compared to coal and gasoline cars, respectively, while the pandemic is thought by some to be an investment opportunity to address problems like climate change.[2]

The combination has led some to predict an early peak in oil demand and a rapid move to net zero carbon emissions. The Guardian newspaper proclaimed that "Even the Oil Giants Can Now Foresee the End of the Oil Age,"[3] while Jennifer Morgan, executive director of Greenpeace International remarked, "It's just really important, particularly with the oil industry, to note that this type of volatility that we're seeing right now, it's a rehearsal for what climate chaos will bring to the oil market in the future."[4] [BP] added that the pandemic would probably "accelerate the pace of transition to a lower-carbon economy and energy system."[5]

Similarly, Russell Hardy, CEO of the world's biggest oil trader Vitol, believes "permanent demand erosion to be likely as humanity gets used to a different behaviour patterns."[6] Ben van Beurden, Shell's chief executive, said that the pandemic could bring the high-water mark of the oil market closer and may mean that the company shows preference to clean energy projects "which serve us better in the future."[7]

Many factors could lead to oil demand peaking and shrinking, but three primary causes are given:

- Lower long-term economic growth, higher unemployment, and more debt;
- Shifting consumer behavior, such as more virtual meetings and working from home, meaning less commuting and air travel; and
- Increased government support for non-fossil fuel sources of energy (or restrictions on fossil fuel use) to accelerate the transition to a net-zero carbon economy.

And one of the biggest factors in these projections is the rise of the electric vehicle as a mass market product, as batteries are expected to become much cheaper and more effective that they replace the internal combustion engine in large part or completely. Table 1 lists various recent projections of market share for new vehicles, ranging up to virtually 100% by 2050.

Table 1
Market Share of Electric Vehicles in Light Duty Vehicle Sales
(EV's as a % of total automobile sales)

	IEA 2019	IEA 2020					BP		Shell		
	SP	SP	SDS	NZE 2050	OPEC	Exxon	Rapid	Net Zero	Sky	Grantham	DNV
2018	2%										
2019		2%	2%	2%							
2020					1%						
2025											22%
2030	15%	20%	40%	60%					50%	19-21%	45%
2035					7%		30%	30%			
2040						30%				54-55%	76%
2050					16%		70%	80%	100%	69%	98%

BP is share of miles travelled. Some data read from graphs.
Sources: International Energy Agency, World Energy Outlook 2019, 2020 (SP for Stated Policies Scenario, SDS for Sustainable Development Scenario, and NZE2050 for Net Zero Energy 2050 Scenario; OPEC World Oil Outlook 2045, 2020; Exxon "Outlook for Energy: A Perspective to 2040"; BP "Energy Outlook 2020"; Shell "Scenarios Sky: Meeting the Goals of the Paris Agreement" 2018; Grantham Institute "Expect the Unexpected: The Disruptive Power of Low Carbon Technology," 2017; DNV-GL "Energy Transition Outlook 2020."

While some of these arguments are made by those advocating for stronger climate change policies, others simply reflect an attempt to understand the economic environment after the pandemic. For example, Mohammed El-Arian warns that with the increased partisanship in the U.S. "progress on laying the foundations for long-term growth — including in areas where there appeared to be bipartisan agreement, such as infrastructure and (to a lesser extent) worker retraining and retooling — seems a more distant prospect."[8]

HISTORY REPEATS

Throughout our careers (and earlier), there have been numerous warnings to the oil industry about changes that threatened the industry or just certain segments of it, including:

- Peak oil, or resource scarcity, wherein oil production would decline due to geological scarcity;
- Dominance by national oil companies, with access to cheap oil and cheap capital;
- Insufficient upstream investment, leading to future price shocks;
- A grey wave, as retirements lead to shortages of skilled personnel;
- Lack of access to resource rich areas (resource nationalism);
- Displacement of oil by new fuels or technologies, including electric vehicles, cellulosic ethanol, and hydrogen fuel cells.

The more serious of these were supposedly driven by physical factors, such as the superiority of other energy sources or geological scarcity of petroleum, but the actual pressures have had political origins, short-term disruptions of supply, and resource nationalism have raised prices, but have proved neither permanent nor insurmountable.

It is worth noting that while the supposedly permanent threats such as peak oil were largely touted by those outside the industry, such as the environmental community, nonetheless there have been prominent industry voices who supported them. In 1977, Mobil CEO Rawleigh Warner argued that the oil industry should diversify out of energy or "go the way of the buggy whip makers." In 1998, ARCO CEO Michael Bowlin proclaimed that the end of the oil age was at hand, and in 2007, Total CEO Christophe de Margerie insisted that world oil production would never surpass 85 mb/d.[9] (Pre-pandemic production was 100 mb/d.)

This serves to highlight the manner in which transient events such as the Iranian Revolution or the 1998 oil price war seem to influence long-term expectations about the industry. There were few dissenters in the early 1980s to the paradigm that oil would be ever more expensive, which led some companies to diversify away from oil and governments to encourage a variety of alternative energy programs, such as the Synthetic Fuels Corporation established by President Jimmy Carter. Those, like M. A. Adelman, who argued that prices were temporarily elevated were treated dismissively.

TECHNOLOGICAL PROMOTIONS

But just as some predict that the electric vehicle will mean an imminent peak in petroleum usage, numerous past predictions have been made and left unfulfilled. Amory Lovins is one of the leading proponents of energy efficiency and has for a quarter of a century argued that his very efficient "supercar" would shortly come to dominate the automobile industry. *Wired* magazine, in 1994, said, "Ecologist Amory Lovins's "supercar" concept may represent the biggest change since the microchip."[10] None are on the road as of yet.

The Clinton Administration's Partnership for a New Generation of Vehicles was modeled on that premise, intended to triple automobile efficiency by 2004 with "comparable or improved performance, safety, and cost."[11] (One of the co-authors of that article argued before the pandemic that peak oil demand was approaching, but similarly, in 2008, was a staunch believer in the immanence of peak oil supply.) Only minor features from that program, such as backup cameras, were adopted by the automotive industry.

Roughly the same time, Ballard Power announced that it had advanced fuel cell technologies and automakers rushed to embrace the technology. Daimler Benz not only invested $145 million with Ballard Power, but they also announced plans to produce 100,000 fuel cell vehicles a year by 2005.[12] A few years later, the Department of Energy said that fuel cell vehicles would be mass produced by 2010.[13] In fact, global sales of fuel cell cars were a mere 7,500 in 2019.[14]

Proponents of cellulosic ethanol (made from agriculture waste products as opposed to corn or sugar) have long argued that it was on the verge of commercial viability. In 1999, Richard Lugar and R. James Woolsey argued in *Foreign Affairs*, "Recent and prospective breakthroughs in genetic engineering and processing, however, are radically changing the viability of ethanol as a transportation fuel."[15] Despite Congressional mandates that the oil industry purchase cellulosic ethanol, production to date has been minimal and it remains prohibitively expensive.[16]

These historical failed predictions are not a guarantee that similar ones being made now are invalid, but that they deserve closer inspection, as below.

LOWER ECONOMIC GROWTH POST-PANDEMIC

The pandemic has seen debt levels soar around the world, for individuals, for corporations, but especially for governments, who have attempted to provide a fiscal safety net to prevent a downward economic spiral. The size and rapidity of the debt increases are unprecedented in the modern era, and the long-term economic impact remains uncertain.

On the one hand, individual and corporate debt could mean lower spending and investment respectively, while higher government debt could translate into higher taxes, depressing economic activity. Alternatively, stimulus packages such as infrastructure programs could boost economic growth and central banks could keep interest rates lower than otherwise in order to hold down borrowing costs and maintain spending levels.

So, while it is possible that economic growth will be depressed over the longer term, it seems equally likely that it will recover and perhaps prove robust, just as after the 2008 Financial Crisis.

BEHAVIORAL CHANGES DUE TO THE PANDEMIC

Jean Saldanha of the McKinsey Institute has said, "In *The Pandemic Is a Portal*, Indian author Arundhati Roy writes, 'Historically, pandemics have forced humans to break with the past and imagine their world anew. This one is no different. It is a portal, a gateway between one world and the next.'"[17]

The pandemic has forced a wide variety of changes in the way the public lives and works which had a dramatic impact on oil consumption. Specifically, jet fuel consumption dropped dramatically as people avoided air travel, and many began using the Internet to work remotely, cutting gasoline usage. Meetings and conferences have been taking place on Zoom and similar platforms, and daily travel has dropped sharply in many places, as witness pictures of deserted streets.

Could this translate into a post-pandemic world where increasing amounts of work are done virtually, that is, over the internet and not requiring transportation fuels? Some have suggested this, with a Bloomberg column opining, "Americans are driving less than before pandemic, and it's permanent."[18] Contrary evidence comes from China, where the success in controlling the pandemic seems to have led to a near-normal recovery.[19]

In particular, the loss of lengthy commuting times in some large cities is said to have increased worker productivity.

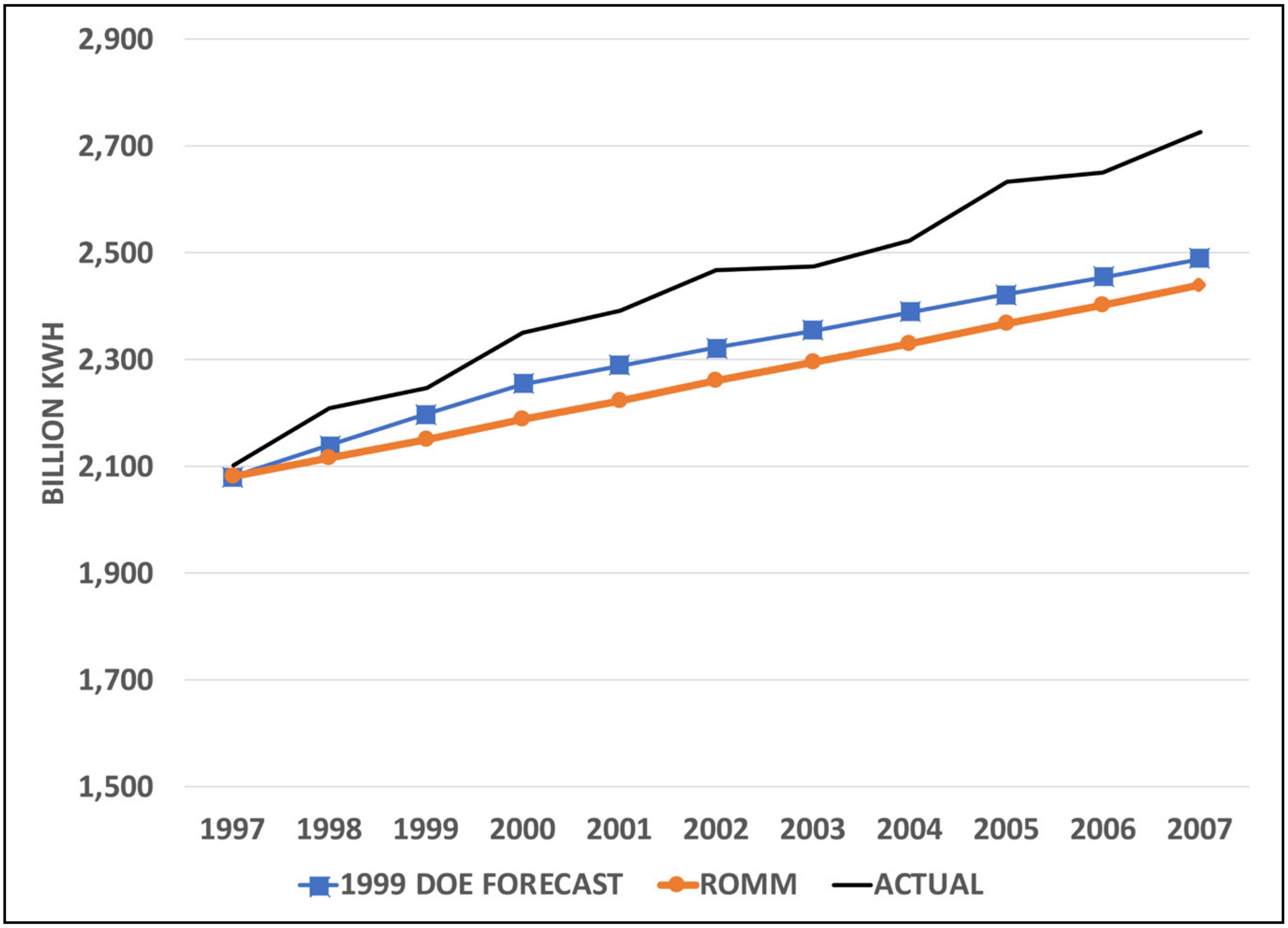
On the other hand, it has also been remarked that companies which attempted work-from-home experiments before the pandemic found them to have serious drawbacks. "…The history of telecommuting has been strewn with failure"[20] and indeed, industry clustering has for decades been recognized as valuable, where companies in the same business gather geographically because they cross-incubate. Silicon Valley has software, New York has finance, and Milan has fashion.

This explains why, despite the difficulty and expense of commuting in areas like Manhattan and Silicon Valley, it has been hard to convince industries to move to less crowded and much cheaper locations. The proposition that a few months of remote-working will suddenly negate the perceived benefits appears dubious.

Alternatively, it has been suggested that the increased use of bicycles seen in some large cities could, combined with climate change policies, mean less reliance on single-passenger vehicles for commuting. At the same time, though, this could easily be offset by a decline in ridership on mass transit due to fears of contagion.

Inasmuch as retail spending appears much less affected than travel, it seems likely that the manufacturing and shipping sectors will not be transformed by the pandemic, although the possibility that long-distance shopping will mean increased shipping cannot be ruled out. Still, the typical attitude of those optimistic that the internet would reduce energy consumption was expressed in a 1999 paper describing the "e-commercialization" of retailing, which, the authors argued, would reduce commercial floor space by 5%, with other savings by the substation of electronic files for paper documents and more efficiency, as in usage of large warehouses.[21] The authors believed that this might lower electricity use in the residential and commercial sectors by 50 billion kilowatt hours in 2007 compared to the U.S. EIA's forecast of an increase of a 400 billion kwh increase. In fact, as Figure 2 below shows, the increase proved even higher—600 billion kwh.

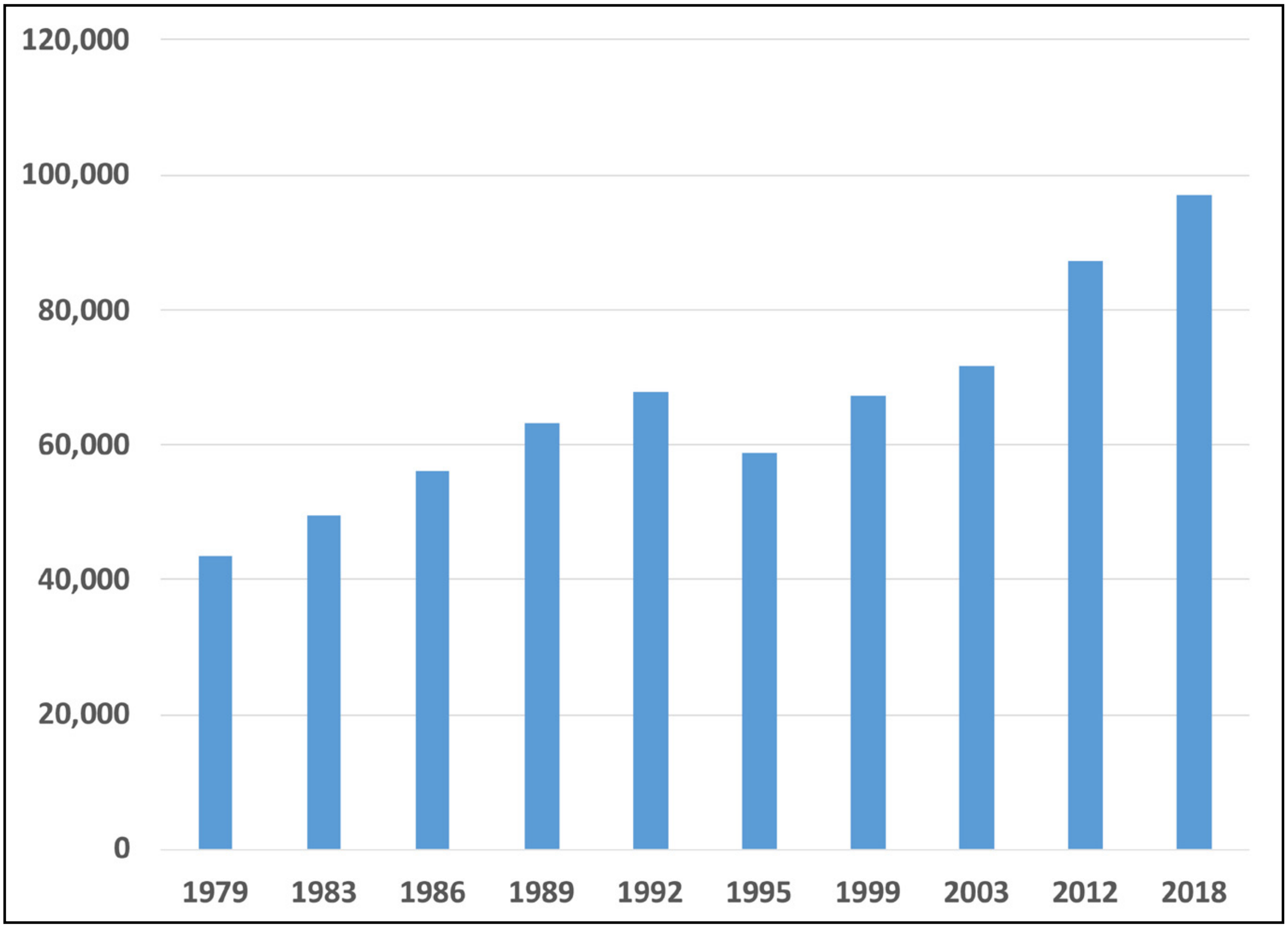
Figure 2
Impact of E-Commerce on Electricity Use (Residential and Commercial Sectors)



Source: EIA and Romm, et.al. 1999
Note: KWH is kilowatt hours

And although the data hasn't been updated recently, there was certainly no impact on the amount of commercial floor space as of 2012 (Figure 3). Aside from the pandemic, it does seem that internet shopping has reduced in-person shopping, but it is not clear if the pandemic is accelerating that trend. At any rate, commercial usage of electricity did decline in 2019, but after hitting a new record in 2018, so it is hard to say there has been a significant impact on energy usage as the result of the growth of the internet.

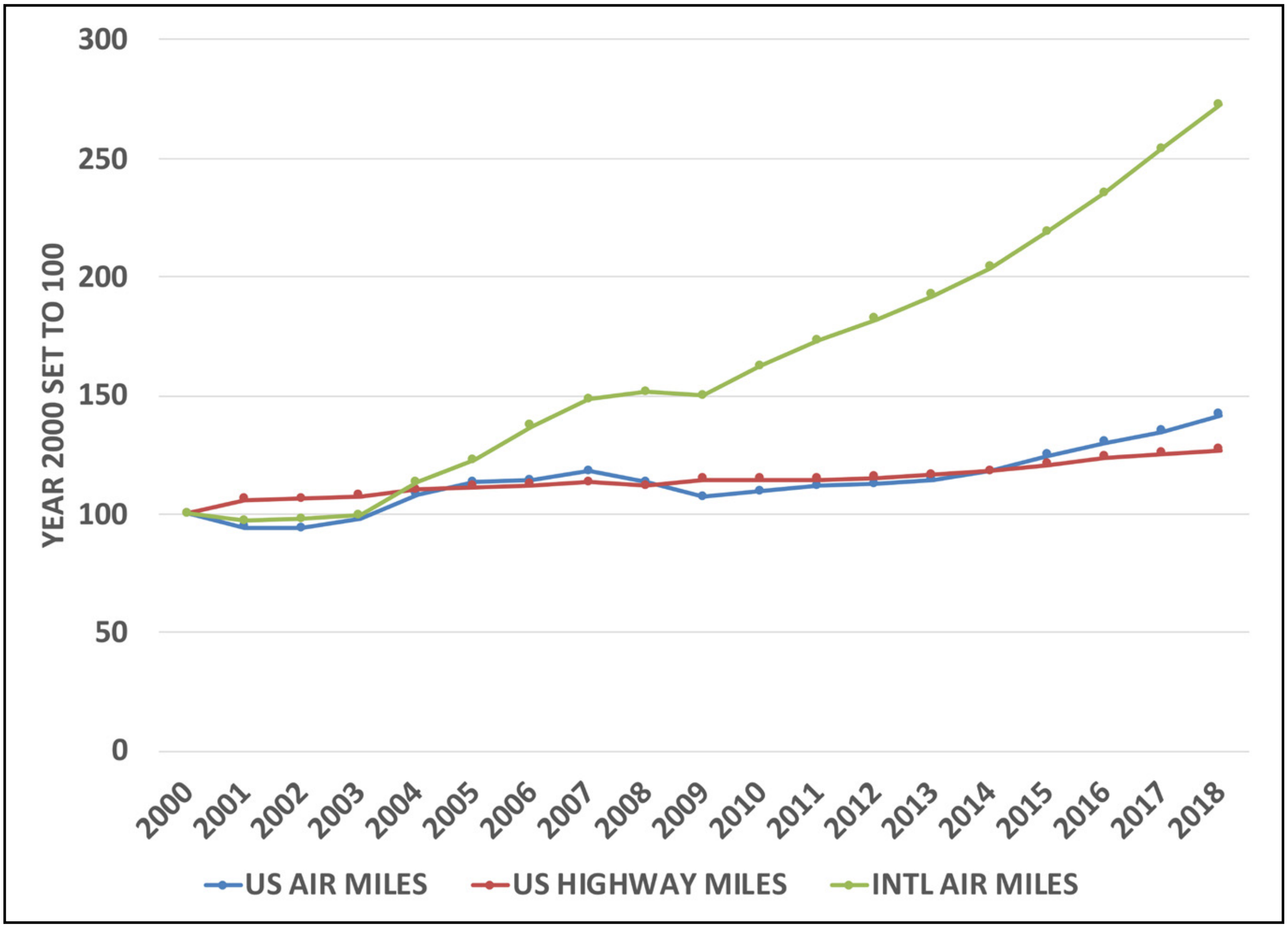
Figure 3
Commercial Floor Space in the U.S. (mln sq ft)



Source: Energy Information Administration[22]

Since the rise of the internet, it has been argued that both business and leisure travel would be reduced, as holding virtual meetings and conferences replaces in-person gatherings, and virtual tourism would reduce in-person visits, cutting costs and energy usage. This does not appear to have been the case, however, although brief interruptions in the trends can be seen after the September 11, 2001 terrorist attacks but especially the 2008 recession. Subsequently, the previous growth trends resumed and even accelerated.

Figure 4
U.S. Miles Traveled



Source: Energy Information Administratio Sources: U.S. data from Bureau of Transportation Statistics; International Air Miles from International Civil Aviation Organization

The recent reopening of some economies has seen a surge in demand for leisure and travel, although it is too early to quantify the longer-term impact. Almost no countries are completely open to tourism as of yet, and the early enthusiasm for beachgoing, for example, could reflect the satisfaction of pent-up demand more than a return to business-as-usual.

ATTITUDE CHANGES TOWARDS ENERGY CONSUMPTION

It has been suggested that the public will take a much stronger stance on pollution and climate change after the pandemic ends because first, areas that saw drops dramatic in air pollution such as Beijing or New Delhi will experience increased desire for that to persist. As the Sierra Club's Antonia Juhasz put it, "People delighted in the newly clean air as airplanes, trucks, trains and cars went idle."[23]

Second, the pandemic is thought to have highlighted the importance of taking drastic action to address problems such as climate change. Specialists at the World Economic Forum recently wrote, "The COVID-19 pandemic has made an even stronger case for a fundamental shift towards net-zero, nature-positive economies."[24]

Lord Browne, former CEO of BP, also made this link explicit, saying that "The Covid-19 threat feels all-pervading. It's vivid. Climate change remains a little bit distant from the human individual. But I don't think it will remain that way if we don't do something about it."[25]

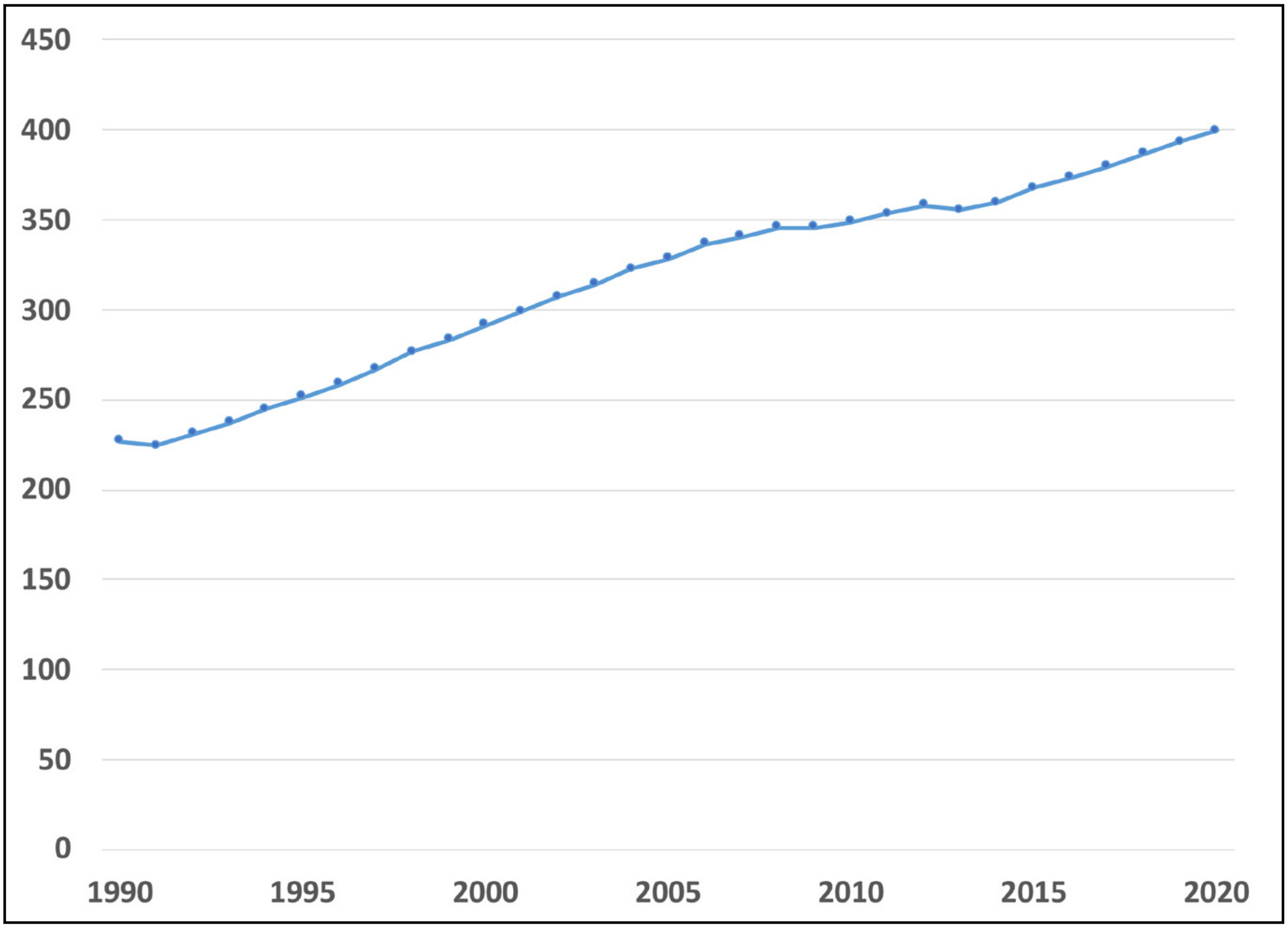
Still, it could just as easily be argued that crises like the pandemic will convince the public to focus more on near-term, obvious problems and worry less about more distant, less certain issues like climate change. Given that any number of disasters attributed—correctly or not—to climate change, such as hurricanes and forest fires, have not caused a significant increase in policy proposals related to climate suggests that the pandemic will not either. The International Energy Agency notes that the pandemic could either "cripple or catalyze energy innovation," adding "At a time when faster innovation is sorely needed, the covid-19 pandemic has delivered a major setback."[26]

One measure of this is the degree to which fossil fuel subsidies remain around the world. The latest *World Energy Outlook* estimates that global fossil fuel subsidies increased in 2018 by one-third, primarily due to higher oil prices, but the overall trend is not diminishing.[27] And Friends of the Earth Netherlands and Oil Change International actually noted that the Netherlands, considered one of the nations that are most aggressive about addressing climate change, retains approximately $10 billion a year in fossil fuel subsidies and financial support.[28]

Certainly, the enormous debts that governments are accumulating during the pandemic could see significant reductions in these subsidies and even increased carbon taxes, which would reduce global oil demand. However, the recent drop of $20/barrel in the price of oil is equivalent to approximately $700 billion in lower expenditures for oil, or nearly twice the current level of subsidies. The implication is that lower market prices will probably more than offset the demand reduction impact of higher carbon taxes or lower subsidies.

There are certainly reasons to doubt that consumer behavior will become more environmentally friendly without external stimuli. One example is that global air conditioner sales have not been affected by climate change concerns, as Figure 5 shows, although it could be argued that the rising temperatures should have meant faster sales growth. This, despite arguments from those like Stan Cox who believe air conditioning is an unnecessary luxury.[29]

Figure 5
Global Air Conditioner Stock (millions of units)



Source: International Energy Agency

Similarly, it has been noted since the 1970s that automobile energy efficiency drops at higher speeds, yet there have been few efforts to reduce highway speeds.[30] As Weinberg noted back in 1979, “When Western man has a choice, he usually chooses technologies that save time.”[31] Indeed, even in the supposedly environmentally progressive country of Germany, public resistance has left the autobahns with no speed limit.

A similar case of environmental politics failing to sway consumers can be seen in automotive sales. In 1999, a number of activists began to target the American purchasers of Sports Utility Vehicles (SUVs), as “un-Christian, destroyers of the environment, aids to terrorists, road hogs, and just plain ugly and rude.”[32] By the early 2000s, the campaign against SUVs was supported by a variety of groups, including the Union of Concerned Scientists, the Friends of the Earth, and the Natural Resources Defense Council. There was significant media attention, a few cases of arson aimed at car dealers, and even a bumper sticker for activists to put on offending vehicles that said, “I’m Changing the Climate! Ask me how.”[33]

Yet despite all this, the SUV is not just surviving, but reigns supreme. As the *New York Times* recently put it, “Rise of SUVs: Leaving Cars in their Dust, with no Signs of Slowing.”[34] The IEA, in their latest World Energy Outlook, noted a near-continuous rise in SUV market share around the world in recent years, with trends from 2010 to 2018 for the U.S. of 30% to 50%, China from 12% to 42% and the world from 18% to 40%.[35]

PAST ENERGY TRANSITIONS

Many of those arguing that the pandemic will accelerate the transition to renewables and electric vehicles often point to the increased speed of market penetration of new technologies. Oddly, this is an inversion of the peak oil arguments about the difficulties in undertaking a rapid transition from oil: "Previous energy transitions (wood to coal and coal to oil) were gradual and evolutionary; oil peaking will be abrupt and discontinuous."[36] For context, eight of the eleven experts or institutions surveyed in the article predicted a production peak at a date since passed.

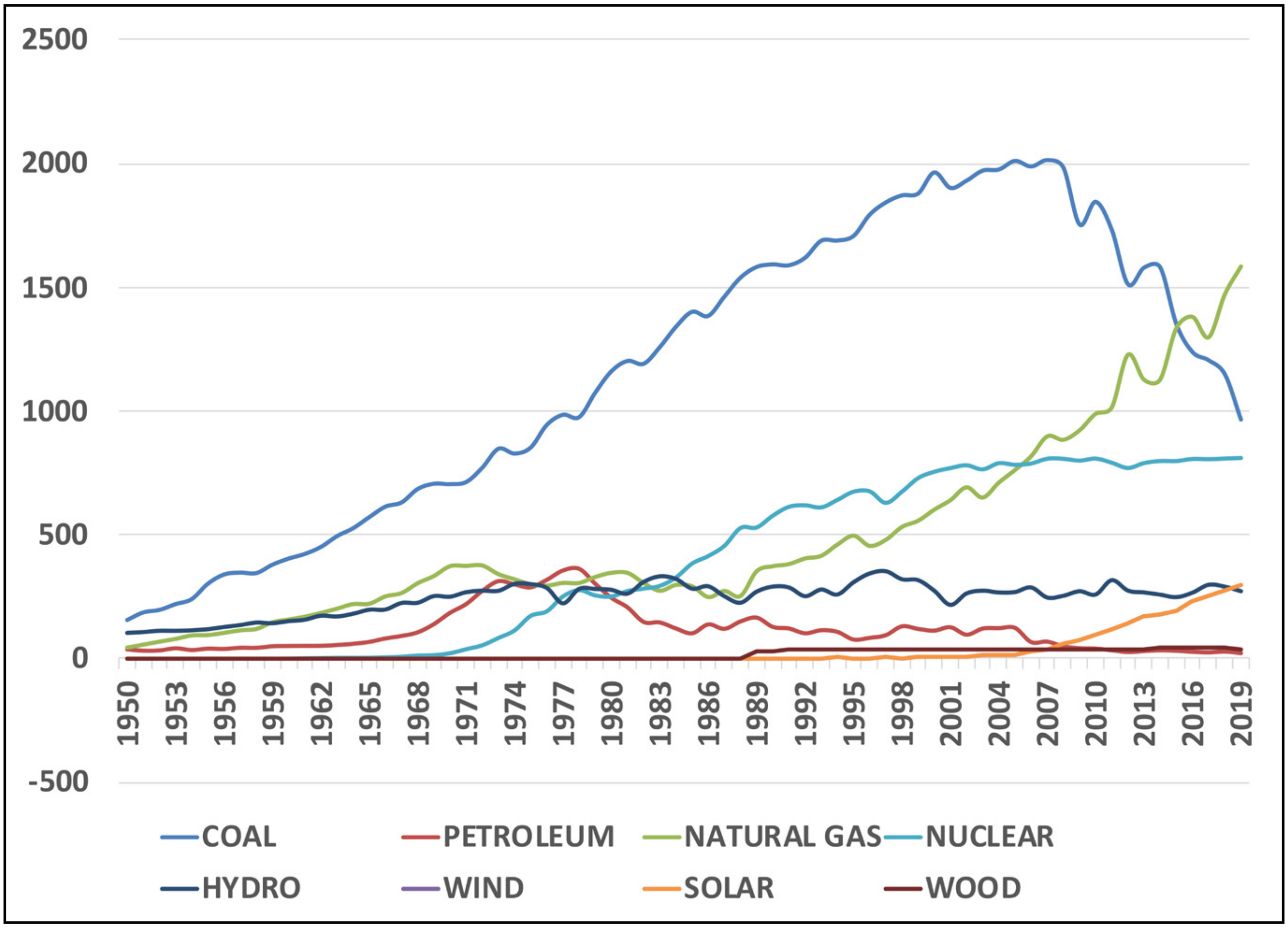
Instead, it is now argued that the sharp cost declines for renewable energy and lithium-ion batteries have caused their adoption to be accelerated. Jeff Desjardin makes this point, adding that earlier products such as landlines and running water required massive infrastructure investments, while new ones, such as smartphones and social media do not.[37] Michael Liebreich of Bloomberg New Energy Finance touted the huge orders for Tesla's Model 3: $12 billion in 3 days, compared to $3.5 billion for iPhone6 and $0.5 billion for "Star Wars: The Force Awakens."[38]

These comparisons are imperfect, however. Social media access is relatively cheap, and smartphones, while expensive, are not on the order of major household appliances and certainly well below the thousands of dollars needed to buy solar panels or an electric vehicle. The introduction of the Tesla Model 3 was a one-off event, not reproduced since.

Further, the need for infrastructure does exist for Cleantech, at least where wind and solar power often require transmission lines to be constructed, and electric vehicles need charging stations. Both have progressed, but are far from complete, with public opposition in many places blocking power lines especially (as well as pipelines for oil and gas). Some have objected to the construction of utility-scale solar power farms, and even Michael Moore has criticized the land-hungry nature of renewables.[39]

Probably the closest comparison to the suggested switch to renewables for power generation would be the surge in natural gas use in the American power sector, shown in Figure 6. This was driven primarily by price, as in the case of oil-to-coal conversion in the 1970s/80s, and the development of natural gas turbines for power generation, with their higher efficiency. Wind and solar have lagged in comparison.

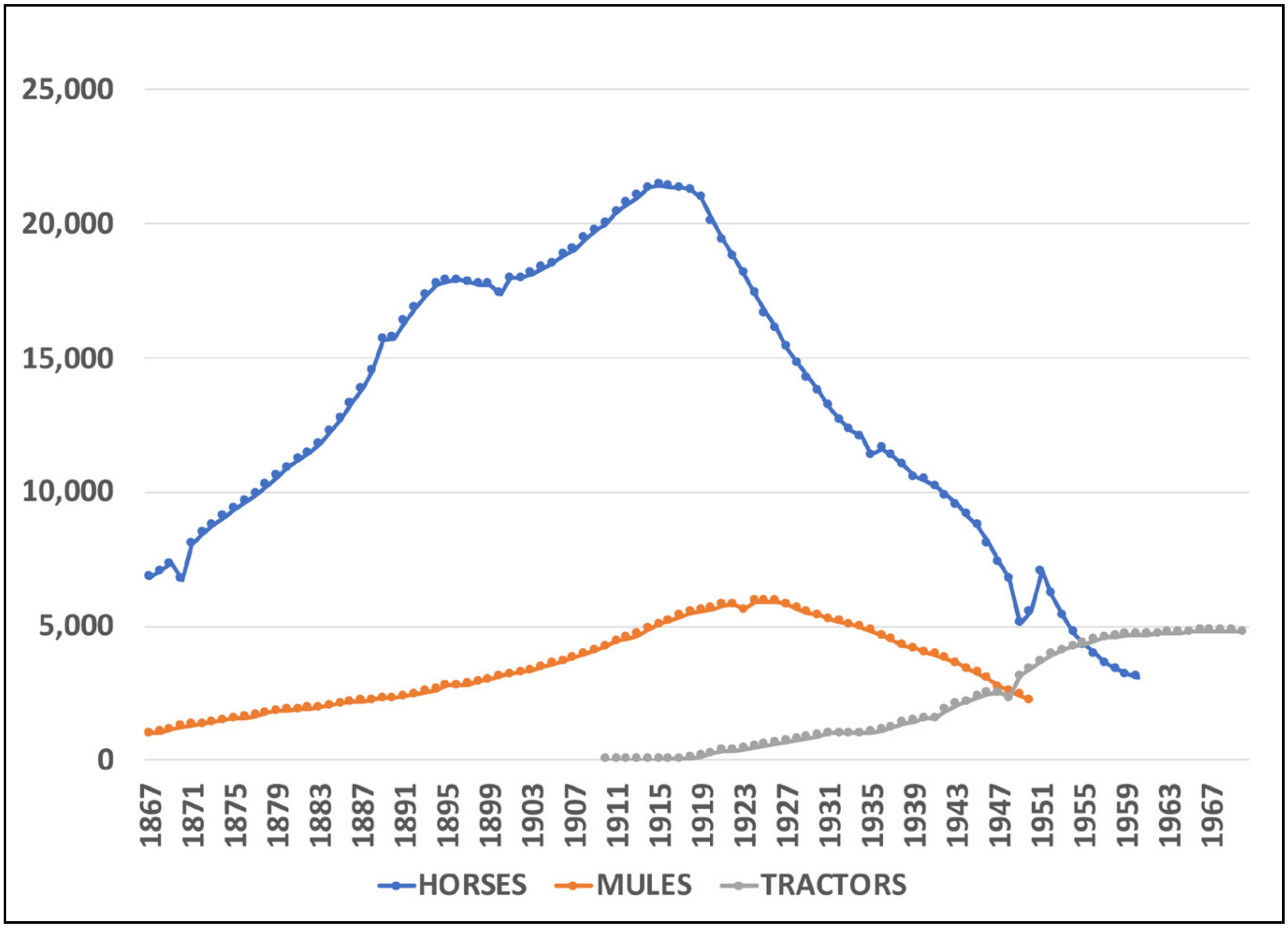
Figure 6
Electric Power Sector Energy Consumption (gigawatt hours)



Source: Energy Information Administration

There has been no major substitution in transportation comparable to replacing the internal combustion engine with electric vehicles in decades, but a couple of examples might be illustrative. First, figure 7 shows how tractors for farm use did not achieve their full market penetration until the mid-1950s, approximately four decades after introduction.[40]

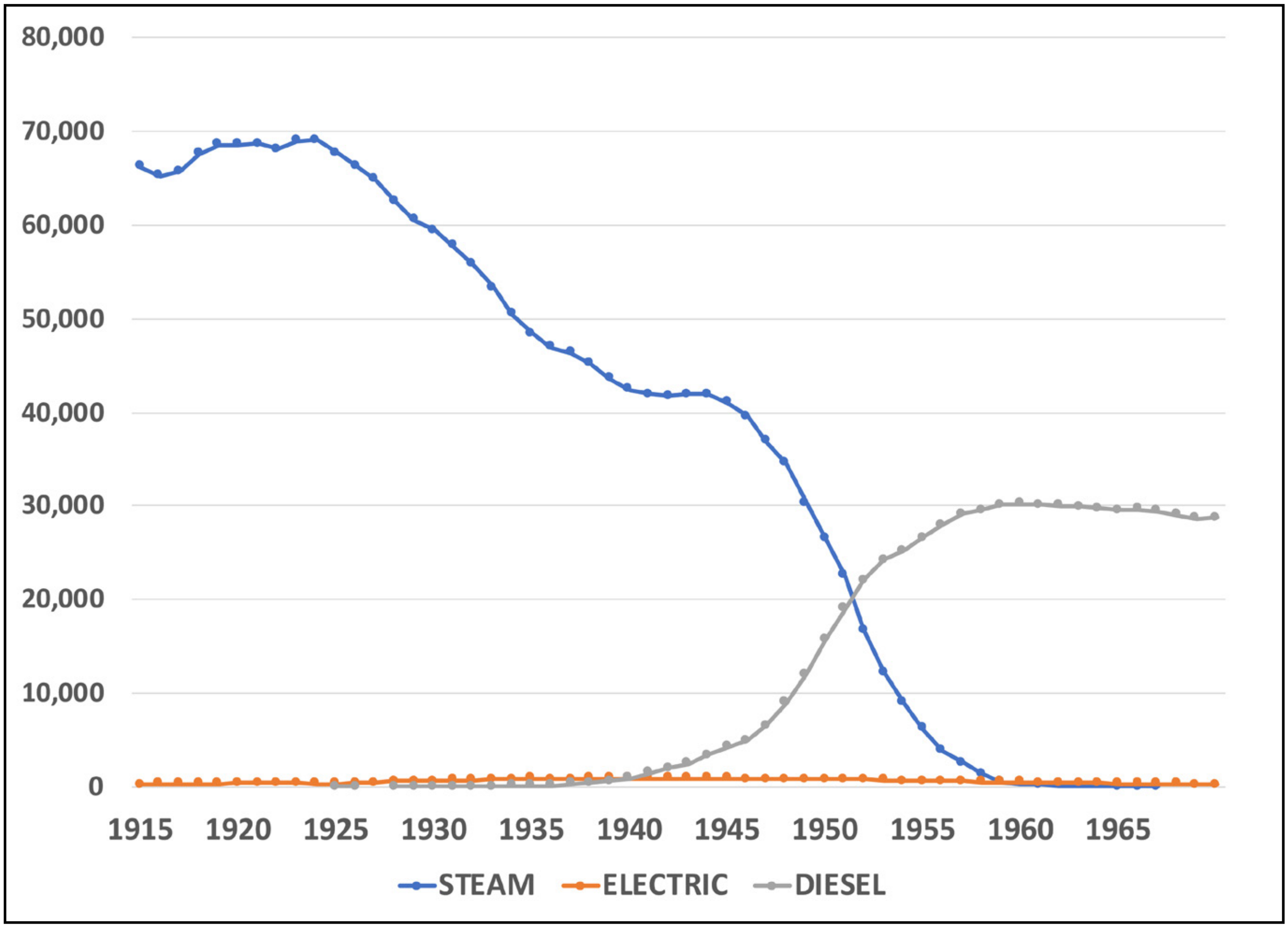
Figure 7
Farm Equipment (units in thousands)



Source: *Historical Statistics of the United States: Colonial Times to 1970*, U.S. Census Bureau

Perhaps a more appropriate example is the conversion of the locomotive fleet from steam engines to diesel power. The first diesel engines became available in the 1920s, but only achieved market dominance in the late 1950s, as seen in Figure 8, despite the fact that their use was much more convenient: water tanks that required constant refilling became a thing of the past.

Figure 8
Locomotive Engine Type (number of locomotives)



Source: *Historical Statistics of the United States: Colonial Times to 1970*, U.S. Census Bureau

SYSTEM INERTIA: STRANDED ASSETS

The Carbon Tracker Initiative believes that they "introduced the concept of stranded assets to get people thinking about the implications of not adjusting investment in line with the emissions trajectories required to limit global warming."[41] In actuality, the phrase was widely used during the deregulation of the U.S. electricity industry, where older generators would become idle as they were replaced with newer, more efficient power plants.

This highlights the problem of capital inertia in a system, and especially when it is suggested that existing capacity be left idle by the proposed energy transition, which will happen if the adoption of renewable energy technologies is accelerated. Of course, many coal plants are already being shut down, but if zero-carbon goals are adopted, many natural gas turbines now in operation and under construction would presumably need to be shut down at a relatively early age.

More relevant to the oil industry and consumers would be the possibility of closing pipelines, refineries, distribution networks and service stations, although the last could become charging stations and convenience stores. Still, given the IEA Sustainable Development Scenario projection that oil consumption would drop to 85 mb/d by 2030 and 65 by 2040, the implication is that $20 billion of refinery assets would be lost each year.[42] Other losses, such as pipeline abandonment (or underutilization) would depend heavily on where oil production declined.

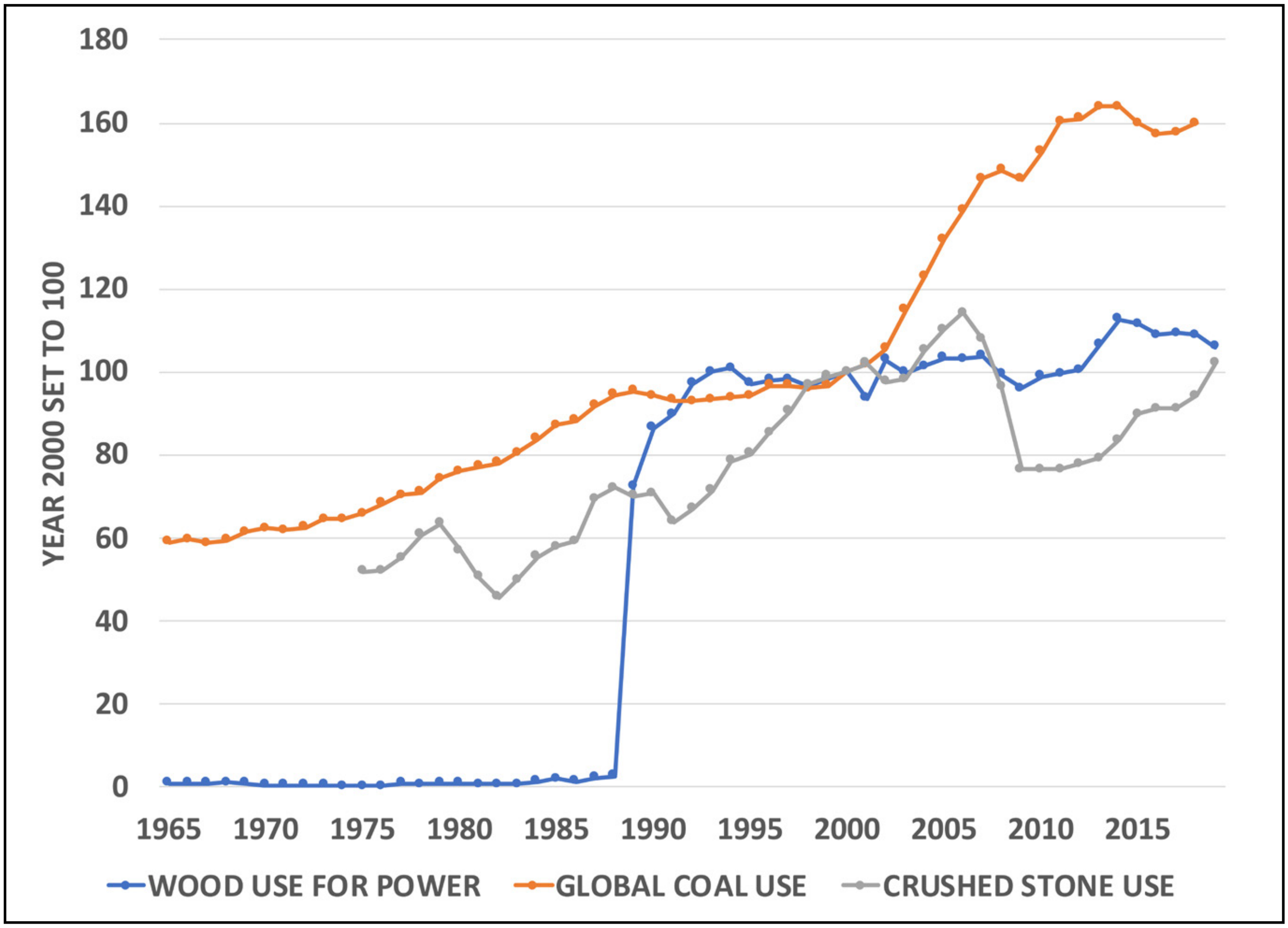
Under the IEA's Sustainable Development Scenario, global natural gas use would drop only slightly over the long-term, but some areas such as North America would see a significant decline, up to 25% by 2040, and the power sector's gas use down by 33%. (Non-OECD countries would see flat or rising gas use.) The implications for natural gas pipelines depend on where gas is produced and consumed in the future, but it seems clear that this scenario would mean billions of dollars of abandoned assets.

At the same time, the marginal cost of supply from these assets will be very low, given that their capital costs will, in many cases, be paid off. A similar problem happened in the U.S. utility sector when new, more efficient plants sometimes found themselves competing with existing plants. Thus, while oil sands in Canada might be too expensive for new investment, existing facilities would continue to be viable.

PERSISTENCE OF "OBSOLETE" ENERGY

The notion of oil use peaking and declining certainly describes a possible scenario, but it is important to realize that few if any resources have disappeared from common usage. Many have noted that coal use remains stubbornly high around the world, but few seem to realize that the use of wood for power generation even in the advanced U.S. power system remains roughly constant (although most is in industrial plants or independent power producers).

Figure 9
U.S. Wood and Crushed Stone Use, World Coal Use

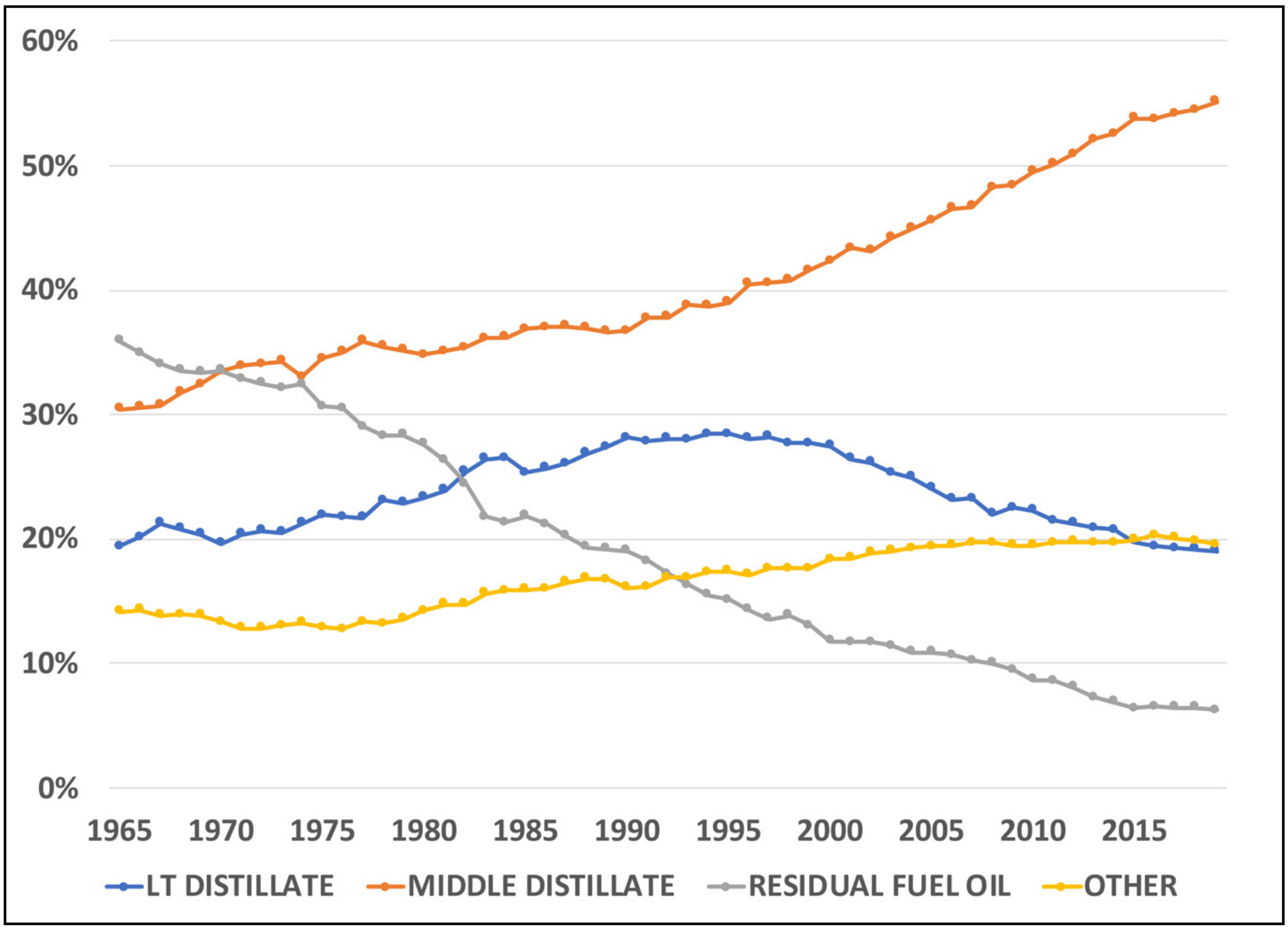


Sources: Wood use for Power (U.S.) from EIA *Annual Energy Review*; Coal from BP Statistical Review of World Energy 2019; Crushed Stone Use (U.S.) from Mineral Yearbooks, U.S. Geological Survey.
*Note: Pre-1989, wood use includes only electric utilities.

Of course, in none of these cases has there been a political push for cessation of consumption or production, but the clear implication is that history suggests usage of a commodity persists long after newer, often superior substances appear.

One of the major past transitions was the movement from the use of oil for power generation in the 1960s and early 1970s, to the use of coal and, later, natural gas. This occurred primarily as the result of the surge in oil prices during the 1970s which encouraged the switch to cheaper fuels and the upgrading of residual fuel oil to light products. Global consumption of residual fuel oil peaked in 1979 and has declined since by 9 mb/d through 2018, even while total oil consumption rose by 35 mb/d. Figure 10 shows how the residual fuel oil's share of oil consumed in the European Union declined from 37% in 1965 to 20% in 1985.

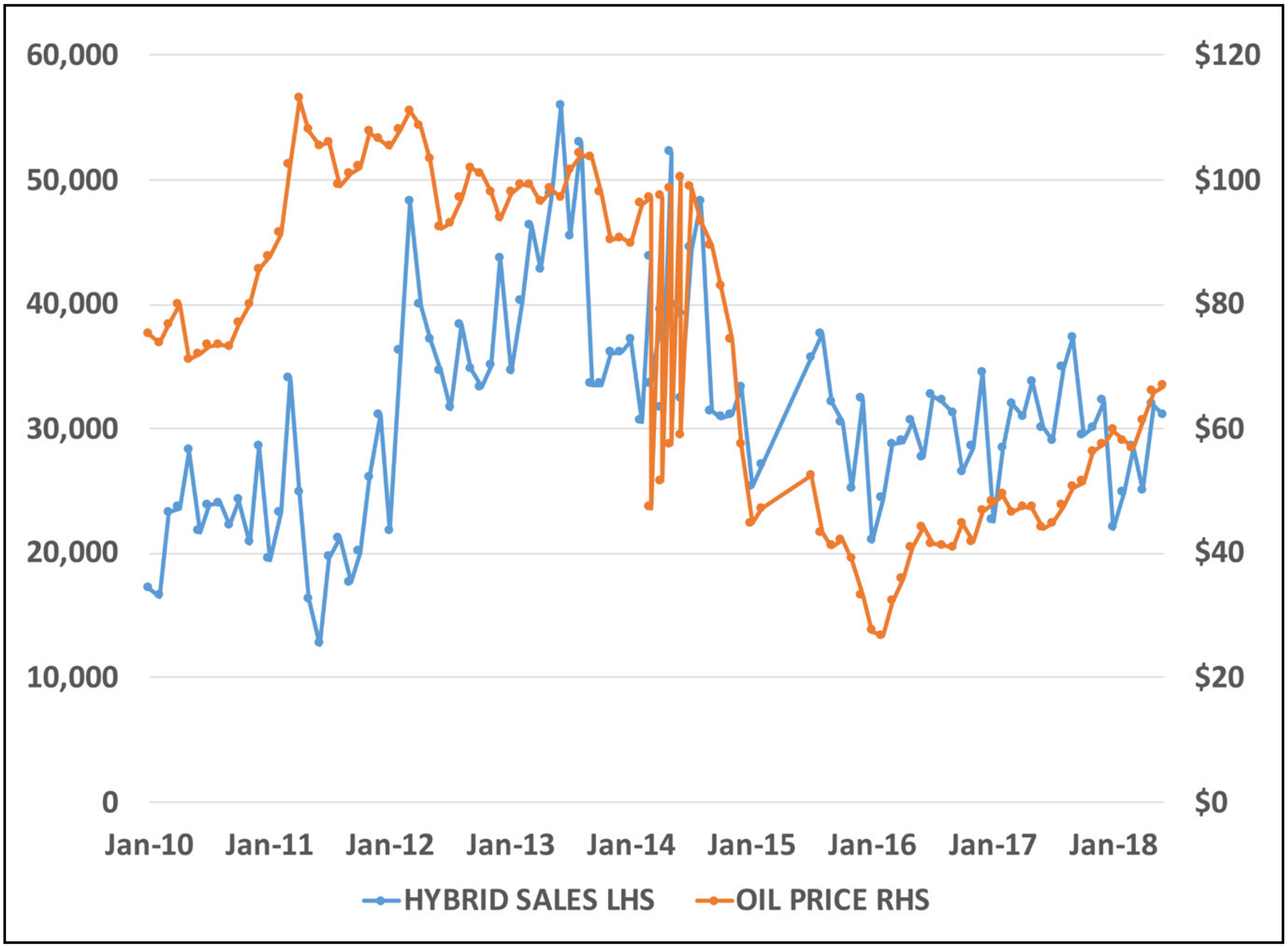
Figure 10
Oil Consumption by Product Type, European Union
(distribution by percent)



Source: BP Statistical Review of World Energy, 2019

The market for hybrid electric vehicles, using batteries as complementary to their internal combustion engines, demonstrates that economics remains important in the evolution of the automotive market. When oil prices dropped in 2015, hybrid electric vehicle sales in the U.S. fell by 60%. (Figure 11, the source does not have updated data for 2020.) The pandemic-related oil price drop thus does not augur well for sales of battery electric vehicles although, again, it is too early to be certain of the precise long-term impact.

Figure 11
Hybrid Electric Vehicle Sales and the Oil Price



Data from Electric Drive Transportation Association.[43]
Oil price is refiner's acquisition cost for imported oil from Energy Information Association.

> "If you think about it, the parallels between Ford's legendary car and Tesla's products are stronger than anyone would have suspected. The Model T was a revolutionary vehicle during its time, and that's precisely the status Tesla hopes to achieve with its upcoming Model 3." Mitracha (2017)

> "As Keith Crain, publisher of Automotive News, put it: 'When I arrived on the automotive scene more than a couple of decades ago, people told me that the electric car was about five years away from production and sale….Today, the electric car is about five years away from production and sale….When I die, the electric car may be five years away from production and sale.'" Winton 1996[44]

As the two above quotes show, electric cars have long had both supporters and detractors, those who think the electric vehicle is ready for take-off and their opponents who have seen many such predictions in the past. Crain's comment puts a vague timeline on the enthusiasm for electric vehicles, written as it was when the California government had an electric vehicle sales mandate and GM's EV1 was being touted in environmental circles and amongst the Hollywood elite, as shown in the film "Who Killed the Electric Car?"

So, it makes sense to be skeptical about claims for the electric vehicle as a mass market technology, but at the same, the progress seen in recent years has made it much more viable than before. Table 2 shows a comparison of the specifications for the GM EV1 and the Tesla Model 3 and the improvements in range and power stand out, primarily as a result of the switch from nickel metal hydride (NIMH) batteries to lithium-ion ones. Unfortunately, no sales price was ever given for the EV1 (which was leased to customers), so it is hard to compare the economics, but it's worth noting that the Tesla is fairly pricey, at $46,000.

Table 2
Progress in Electric Vehicle Technology

	Gen II	Long-Range
	EV-1	Tesla Model 3
Horsepower	137	283
Range	105	322
Weight	3086	4072
Passengers	2	4
Doors	2	4
Battery	NIMH	Li-ion
Wheelbase	99	113
Price '000k		46

Sources:
https://www.caranddriver.com/tesla/model-3/specs
https://www.carfolio.com/gm-ev1-gen-ii-nimh-107844

To put this in historical context, the difference between the Model T and its primary competitor, the horse, can be seen in Table 3. While the Model T is twice as expensive as a horse, it has five times the range, seven to ten times the carrying capacity, two to three times the passenger capacity, and the top speed is twice as much and sustainable for much longer than a horse's. The intangible benefit of not having to clean up over 20 pounds of manure each day is hard to quantify, but especially for urban dwellers, significant. Further, Collins (2020) makes an excellent case that Telsas are much more comparable to high-end sports cars like Porches than to mass market vehicles like the Model T.[45]

Table 3
Comparison of a 1920 Model T Ford and a Horse

	Model T	Horse
Horsepower	20	1
Speed	35-40	10-17
Passengers	2-7	1 to 2
Cargo Capacity (lbs)	2000	200-300
Exhaust (Daily)	N/A	22 lb manure
Range (mi)	200	40
Price $	4740	2280
Fuel Cost/year $	1752	840

Sources: Model T data from
http://www.barefootsworld.net/ford-t-specs.html
Horse data from:
http://www.mtfca.com/discus/messages/506218/597388.html?1451265136
https://www.cartographersguild.com/showthread.php?t=19730
and
https://babel.hathitrust.org/cgi/pt?id=mdp.39015069877382;view=1up;seq=359

The electric vehicle does not have the same advantage over the internal combustion engine. It is very true that some electric cars have outstanding performance, but they are typically much more expensive than petroleum-fueled cars. Unfortunately, the many technical differences between models makes it hard to provide a precise comparison, as there are few models made that are available in both electric and internal combustion versions. The Ford Focus was one such electric vehicle, and as Table 4 shows, it was initially significantly more expensive than the conventional ICE Focus and much less capable.

Unfortunately, the price for EVs does not always correlate to the cost of production. At first, the price difference was about $12,000, but when the Nissan Leaf appeared at a much lower price, Ford cut the Focus's price.[46] Since sales peaked at only 150 per month before the EV version was cancelled, it is possible the manufacturer was taking a loss on sales, motivated in part by needing to minimize penalties accrued for not meeting its CAFÉ standard goals.

Table 4
Ford Focus 2018 Model Year

	ICE	Electric
MRSP	25,145	29,995
Range	298-422	143
Horsepower	160	143
Weight	3055	3640
Wheelbase	104	103
Passenger	5	5
Pass. Volume	91	91
Trunk	13.2	14

Sources:
https://www.caranddriver.com/ford/focus/specs
https://www.caranddriver.com/ford/focus-electric/specs

One of the few vehicles now available in with both conventional and battery electric power is the Hyundai Kona, which have similar characteristics but the electric version costs roughly $15,000 more. It's not clear if there are any significant differences other than the engine.

The Tesla Model 3 is the best-selling electric vehicle in the U.S. at present, but its unique model makes it difficult to compare with existing conventional cars. It does roughly resemble the Ford Edge in terms of size and costs $8,000 more. The Edge has more room and a much greater range (see above).

INTANGIBLES: CONVENIENCE

Advocates of electric vehicles tend to wave off criticism about lengthy charging times, pointing out that the cars can be charged over night at home or that the driver can get lunch while the car is being charged. As one put it, "Recharging isn't a lengthy process, even with a normal house plug—the Fusion took just over 6 hours to acquire 19 miles of electric range."[47] This translates into 1000 times slower than refueling a gasoline powered car.

These are rationalizations that are difficult to quantify, at least in terms of monetary value. There are relatively few (if any) consumer goods that cannot be used for lengthy periods of time: a stove or washing machine doesn't have to sit idle for hours after use. The most prominent exception is the cellphone, and the myriad accessories to recharge them implies that this represents a significant inconvenience to consumers. (And its recharging time is many times faster than for an electric vehicle using a home outlet.)

Electric vehicles, having been driven for three hours, can take six to ten hours to recharge on a standard outlet. Fast charging is available in some places, and can cut the time to recharge a vehicle from hours to approximately 40 minutes, depending on weather, how depleted the battery is, and other factors.[48] Unfortunately, there are only 4,000 fast charging stations in the U.S. at present, out of 27,000 charging stations nationwide[49] and compared to 168,000 gasoline stations, and 2,000 of the fast chargers are only compatible with Tesla cars.[50] Level 2 charging stations, the majority, will charge at a rate of 15-40 miles per hour,[51] which can mean 1-3 hours of charging for trips of any length. Inasmuch as refilling the tank on a petroleum powered car takes 3-5 minutes and provides a traveling range of 300 miles or more, the refueling convenience for ICEs is far superior to even the best battery electric vehicle.

There is more to the market for BEV's than just battery cost, including a number of intangible aspects of consumer preference, such as range anxiety and inconvenience of refueling. Advocates of BEVs tend to be dismissive of these factors but they are clearly a concern for most consumers. They insist that range anxiety isn't real, it clearly is, as evidenced by the way advocates describe the supposed ease of coping with it: planning the route by researching charging stations in advance, taking a lunch or bathroom break while charging, minimizing use of the heater by wearing heavy clothes, and so forth.

It is also the case that the published range given for the battery packs needs to be discounted for normal usage. Manufacturers recommend normally only charging to 80% of capacity, and cold weather can reduce capacity by another fifth, meaning a 200 mile range will sometimes translate into a 140 mile range. And while the electronics in some vehicles provide an estimate of remaining charge and the distance it translates into, this apparently fluctuates heavily according to driving behavior and conditions, meaning the estimate is not very reliable.

Tesla itself has a range calculator that shows the fluctuations based on speed and temperature. A Model 7 running at 45 mph in 70 degree weather has a range of 393 miles; at 70 mph in 90 degree weather with the air conditioning on, the range drops to 230 miles.[52] Table 5 shows estimates for range under a variety of conditions. And of course, rechargeable batteries degrade faster if they are fully charged or discharged, so that you should normally lose 20-30% of your range if you avoid the extremes.[53]

Table 5
Variations in Range for Tesla Model S

Speed (mph)	Temperature (Fahrenheit)	Range (miles)
45	70	393
60	70	292
70	70	241
45	32	309
45	0	271
45	90	347
70	90	230
70	32	208

Source: Lynch, Michael C., "Possible Determinants of Peak Oil Demand," March 2018[54]

Aside from long charging times and poor and uncertain range, there are some serious concerns about the environmental impact of BEVs and the reliance on imported materials such as rare earths. The cost of greenhouse gas abatement is addressed in the next section, but here, data on the environmental impact of BEVs are examined.

The reduced emissions have been estimated in many places. While the TTW (tank to wheel) emissions for battery electric vehicles are non-existent, the WTT (well to tank) is significant, given the high energy needs in battery manufacturing. The IEA estimates that an internal combustion engine vehicle emits 35 tCO_2 equivalent, a hybrid electric vehicle 28 tCO_2e, while a Battery Electric Vehicle emits 22 tCO_2e (midsize cars).

The numbers are based on average power plant emissions, meaning they are higher than for Norway, where electricity comes primarily from hydropower, but lower than for China, where much of the power is still based on coal. But the point is that a BEV saves roughly 10 tCO_2e, at a cost of \$5,000 or more (see above), or about \$500/tCO_2e, far off charts describing cost curves from GHG abatement, as described above. Even adjusting the cost for lower fuel and maintenance costs does not offset this discrepancy significantly.

The Argonne National Laboratory has done a more intensive study of emissions from various vehicles and fuels, in its "Greenhouse gases, Regulated Emissions, and Energy use in Technologies," or GREET model, which allows the user to input different assumptions about fuels and vehicles to generate either 'Well-to-Pump' or 'Well-to-Wheel' emissions, meaning including emissions resulting from battery construction. Table 6 shows the ratio of emissions for BEVs vs ICEs using 10% ethanol blend of gasoline (E10), where figures below 1 represent lower emissions for BEVs. Clearly, the BEV has an advantage over the ICE's in most reas, but it only represents an improvement, not a solution.

Table 6
Well-to-Wheel Emissions, Ratio BEV to E10 ICE

Name	WTW	Battery Only	Total
Total Energy (J/mi)	0.42	45.12	0.52
VOC (kg/mi)	0.06	21.31	0.63
CO (kg/mi)	(ICE=0)	37.75	(ICE=0)
NOx (kg/mi)	0.40	64.09	0.57
PM10 (kg/mi)	0.90	32.12	1.30
PM2.5 (kg/mi)	0.55	20.68	0.90
SOx (kg/mi)	3.66	50.29	2.90
CH4 (kg/mi)	0.50	23.80	0.64
CO2 (kg/mi)	0.35	50.00	0.43
N2O (kg/mi)	0.12	65.06	0.18
BC (kg/mi)	0.28	101.65	0.44
POC (kg/mi)	0.35	89.14	0.48
CO2_Biogenic (kg/mi)	0.00	122.58	0.00
GHG-100 (kg/mi)	0.37	43.29	0.47

Source: Argonne National Laboratory GREET model.
Note: POC is particulate organic carbon, BC is black carbon. Energy used is approximately 70% fossil fuel, 20% nuclear, hydro and renewables.
kg/m is kilograms per mile.

THE EXPENSIVE CLEAN SOLUTION

One of the major past transitions was the Many have noted that the greater expense of electric vehicles translates into subsidies for them going to the wealthier population, but far fewer note that the cost of reducing GHG through switching conventional engines to battery electric power is one of the most expensive forms of reducing GHG emissions. In part, this is because few bother to make the estimate, but also, reducing GHG emissions through use of battery electric vehicles is so much more expensive than other policies that it is often ignored by broader analysis.

The most famous of these was the McKinsey abatement cost curve which lists 43 separate approaches to reducing GHG emissions, where 1.4 GtCO2e/yr reduction would cost nothing (the savings would be more than the expense), and another 1.6 GtCO2e/yr would cost less than 2019$/75 ton CO2e.[55]

It is noteworthy that battery electric vehicles do not appear on this curve, although car hybridization is the most expensive option measured. Of course, costs have come down since this work was published a decade ago, but more recent work described above shows estimates for current vehicles.

BATTERY PRICES AND CONSUMER ACCEPTANCE

Advocates such as Bloomberg New Energy Finance have argued that BEVs will reach price parity when battery prices, at $156/kwh in 2019, reach $100/kwh, projected to occur in 2023.[56] Unfortunately, this appears to be as much an assumption and is at odds with actual market experience, including the above-noted disparity in prices for BEVs and ICE vehicles of similar profiles. As one of us noted in 2018, the plunging price of batteries had not translated into lower prices for BEVs, possibly because early sales were subsidized by producers. Additionally, reductions in government subsidies always resulted in a sharp drop in sales, although the number of cases is not very large.[57]

Perhaps the most detailed analysis of the competitiveness of BEVs comes from Clinton et.al. (2020), who have developed an on-line tool that allows the user to enter different values for oil and electricity prices, vehicle miles travelled, BEV range, and so forth. For an oil price of $50 and the default settings, BEVs are competitive at a battery price of $60/kwh.[58]

MATERIALS

At present, a large portion of conventional lead-acid car batteries are recycled but less than 5% of li-ion batteries are and there are significant challenges to increasing that proportion. As Harper et. Al. note, the million BEVs sold in 2017 would mean approximately "250,000 tonnes and half a million cubic metres of unprocessed pack waste."[59] They note that the battery packs are not designed for ease of disassembly, and that a number of technical challenges remain, including fire hazards and the potential for hydrogen fluoride outgassing. And while the cobalt in lithium-ion batteries is valuable, making recycling the batteries more attractive, manufacturers are trying to substitute cheaper materials for them.

Additionally, there have been growing concerns about reliance on rare earth minerals in electronics, including BEVs, as much of the world's production takes place in China. The danger was highlighted in 2010, when following a dispute with Japan, China halted rare earth exports to that country. This has led many governments to seek to diversify supplies, with some success, but the U.S. is heavily dependent on imports and China continues to dominate production. Alongside more mundane requirements such as iron, tin, and aluminum, minerals like neodymium and dysprosium (used for permanent magnets) will be necessary in growing quantities.

Further, some minerals such as cobalt are sourced from unstable countries, often using unethical production methods. As Harper et.al. noted, "Of greater immediate concern are cobalt reserves, which are geographically concentrated (mainly in the politically unstable Democratic Republic of the Congo). These have experienced wild short-term price fluctuations and raise multifarious social, ethical and environmental concerns around their extraction, including artisanal mines employing child labour." Harper et.al. op. cit.

CONCLUSIONS

Past energy transitions have featured new sources of energy that were cheaper and better, where better typically means easier to use. While battery electric vehicles have some benefits compared to petroleum-fueled vehicles, they are much more expensive and significantly less convenient. Petroleum has approximately forty times the energy density of batteries, and recharging even with a fast recharger takes five times refilling a gasoline tank. BEV range remains both shorter and less certain than for conventional cars. To date, success for BEVs has required substantial government subsidies implying limited consumer acceptance.

Governments have generally failed when attempting to mandate consumer choice as experiences with bans on alcohol and narcotics have shown, to say nothing of efforts to improve the fuel efficiency of conventional vehicles. It is possible that heavy spending to subsidize BEV purchases will give them a meaningful market share, but given the current financial difficulties resulting from the pandemic, such spending seems unlikely. Carbon or petroleum taxes could change consumer behavior but have met strong resistance in the past in the United States, at least. While it is possible that the energy industry will be transformed by the pandemic, in reality there are good counter-arguments to suggest that, if anything, the evolution to an all-electric, zero-carbon energy system will be slowed. The irrational exuberance of promoters of cleaner fuels and technologies is dominating the discussion at the expense of more solid analysis, and the inferior performance and economics of solar power and electric vehicles remain a major obstacle to any significant increase in their market share, especially in a post-pandemic world of constrained budgets and lower oil prices.

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