The Aspirations and Economics of the New Jersey Energy Master Plan

A REPORT FOR THE GARDEN STATE INITIATIVE
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Executive Summary

The New Jersey Energy Master Plan (EMP) in its previous and anticipated forms proposes that the state can soon produce all the electricity needed using mainly wind and solar technologies and achieve near-universal electrification of vehicles as well as the heating/cooling of homes and buildings. Today, New Jersey obtains over 90 percent of all the state's energy from hydrocarbons and 98 percent of vehicles on the roads use petroleum.

The goals of the EMP are entirely driven by the objective of reducing the state's contribution to *global* CO_2 emissions. While mandates and subsidies can move the state towards those goals, both recent history and the underlying technology realities make it clear that the goals aren't achievable, and even if they could be achieved would lead to a miniscule reduction in *global* CO_2 emissions which are, in the meantime increasing. Emissions *increases* that will come solely from only the *new* coal-fired power plants under construction in China will be vastly greater than eliminating the entirety of NJ's emissions.

But the pursuit of the New Jersey's EMP goals will be extraordinarily expensive, have enormous economic and social consequences, disadvantaging those least able to afford higher energy costs, and create disincentives for industries and businesses to locate or remain in the state. Furthermore, planners underestimate the potential for new energy demands from economic growth. Meanwhile, policies that constrain supply and increase the cost of energy will be self-fulfilling in ensuring that the growth does not occur in New Jersey.

The EMP contains seven strategies directed at an "energy transition" away from hydrocarbons. In this paper we provide some perspectives on some, though far from all, of the key challenges with each of the seven strategies.

1. *Reducing Energy Consumption and Emissions in Transportation*
   Key perspective: Total lifecycle analyses point to small, possibly non-existent reductions in CO_2 emissions associated with mass deployment of EVs.
2. *Accelerating Deployment of Renewable Energy and Distributed Energy Resources*
   Key perspective: Greater deployment of wind and solar correlates, everywhere, with increased cost of electricity.
3. *Energy Efficiency and Conservation to Reduce Peak Demand*
   Key perspective: In an unrestricted economy, in nearly all applications, increased energy efficiency is associated with an overall net increase in energy demand.

4. *Reduce Building Energy Use*
   Key perspective: The future potential for energy savings is now far less, and will take more time and cost more than in the past.
5. *Decarbonizing and Modernizing New Jersey's Energy System*
   Key perspective: The track record for "decarbonizing" energy systems shows very small changes in overall societal carbon-intensity, and far higher consumer costs.
6. *Community Energy Planning and Action in Underserved Communities*
   Key perspective: Policymakers should keep in mind a basic tenet for low-income citizens and communities, i.e., high energy costs are destructive.
7. *Expand the Clean Energy Innovation Economy*
   Key perspective: Many proposed "clean energy" innovation policies are antithetical to other innovation policies and objectives.

There are far better options, more economical and provable means to meet the goal of minimizing or reducing hydrocarbon use. The two clearest and achievable examples include promoting and accelerating the deployment of new nuclear power plants, and a redirection of subsidies away from EVs (enjoyed mainly by the wealthy) towards incentives for consumers (especially low-income citizens) to buy more efficient conventional vehicles.

Introduction & Context

New Jersey is amongst the 23 states that are each pursuing energy policies with the intention of achieving an "energy transition" away from the status quo wherein, today, hydrocarbons—petroleum, natural gas, and coal—supply over 80 percent of society's energy and over 90 percent of energy in New Jersey. The stated goal for New Jersey is *"to achieve 100 percent clean energy by 2035"* wherein "clean" is defined as "carbon free." For policymakers, and the citizens they serve, the critical issue is whether there is full transparency and understanding of the consequences of that pursuit.

It is an important stipulation to note that while the stated motivation for the New Jersey Energy Master Plan is for climate action, the science and economics of issues, claims and forecasts relating to climate science are entirely independent of the scientific and economic realities of energy production. The purpose of this analysis is to illuminate some of the underlying physics, engineering, economics, and necessary infrastructure of energy-producing and energy-using machines. In addition, as a practical matter, given the nature of the two domains, it is a simple fact that far more is known, with much greater certainty, about energy technology than about atmospheric sciences. Thus, regardless of the "climate action" sought, policymakers and citizens should be considering the consequences of pursuing an "energy transition" away from hydrocarbons in the timeframes proposed.

Understanding how energy demands arise in the first place is critical to gauging the consequences of modifying or constraining the means for supplying energy. Energy demands begin with the invention and production of products and services that are needed not only for basic survival and safety but also, in a modern economy, for the far more numerous products and services that make possible everything including healthcare, education, entertainment, improved conveniences in every domain, as well as the modern luxury of environmental protections. Thus, it is relevant to understand the impacts of energy policies with regard to more than, say, food costs, which depend on energy inputs not least because natural gas is the dominant factor in fertilizer production and a major agricultural expense, but also because the transportation of food, and the "cold chain" infrastructure to move and store food are also energy-intensive.[1]

In addition, given national policy trends directed at not only maintaining but expanding manufacturing industries, especially now with "re-shoring" initiatives, the other critical factor in energy planning arises from the reality of the energy-intensity of manufacturing in general, and especially regarding the fabrication of modern products. As a point of perspective, manufacturing 21st century

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[1] Kathryn McNutt, "Fertilizer Costs Triple from Year Ago," *The Journal Record* (Oklahoma City, Oklahoma), Nov. 22, 2021.

digital devices and hardware requires, on average, about 1,000 times more energy per pound than do the products that dominated the early 20th century.[2] Historically, the energy costs of manufacturing a product roughly tracked the weight of the thing produced. A refrigerator weighs about 200 times more than a hairdryer and takes nearly 100 times more energy to fabricate. But it takes nearly as much energy to manufacture one smartphone (or similar digital device) as it does one refrigerator, even though the latter weighs 1,000 times more.[3] Thus, for example, even though a car weighs 10,000 times more than a smartphone, the energy used globally to fabricate automobiles is only 20-fold more than all energy used to fabricate smartphones.[4] Thus, efforts to reshore supply chains for either of those sectors will have non-trivial energy demand implications. And, critically, in the calculus of accounting for *global* CO_2 emissions, all this has relevance for products purchased locally by consumers, but produced elsewhere.

Thus, state or federal policies that have the effect of continuing or expanding the off-shoring or outsourcing of manufacture of products locally purchased are, by definition, exporting energy use—and all the associated CO_2 emissions, not to mention other environmental features—to remotely located factories and related facilities that produce the products and the needed input materials. This reality has particular relevance for energy policies directed at reducing or eliminating CO_2 emissions since the locally purchased products necessarily entail remotely caused emissions entering the "same atmosphere." This reality has come to be framed as "scope three" emissions, an inherently complex and generally opaque feature for all products.

One of the few comprehensive analyses of this reality was commissioned recently by the government of France which found its national CO_2 emissions were some 70 percent higher than domestically reported data because of the energy/emissions associated with imported goods.[5] The subsequent European imposition of a "carbon border adjustment mechanism," i.e., a carbon tax on imports, raises the price of the goods imported on the theory that it will eventually make more competitive the (more expensive) local production of goods presumably using less carbon-intensive energy sources. Whether the theory will yield the predicted onshoring results is debatable and necessarily takes time and is in the meantime both inherently inflationary and a regressive tax.

Without regard to goals for future CO_2 emissions, if "transition" policies lead to increased energy costs it will create impediments to private sector decisions relating to expanding energy-intensive manufacturing operations. Indeed, policies leading to higher energy costs will lead to, and have led to manufacturing operations shrinking or closing, as is currently seen, for example, in Germany where industrial energy costs have been steadily rising in large measure from "climate action" energy policies. The self-evident result of off-shoring of manufacturing puts the sought-after goals regarding energy choices beyond the jurisdiction of the local authorities.

Finally, one of the key uncertainties for energy policy planners is found in guessing the magnitude of future demand, something that is inherently unknowable at the granular level but that is inher-

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[2] Timothy G. Gutowski, et al, , "The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand," *Phil. Trans. R. Soc. A,* 28 January 2013,

[3] N. Duque Ciceri, T. G. Gutowski, and M. Garetti, "A Tool to Estimate Materials and Manufacturing Energy for a Product," Conference Paper, MIT, June 2010.

[4] Vaclav Smil, "Your Phone Costs Energy—Even Before You Turn It On," IEEE Spectrum, Apr. 26, 2016.

[5] Moscovenko, Louise Rozès, "France's 'imported emissions' are 70 percent higher than domestic CO2 output, report finds," Euractiv France, October 7, 2020.

ently predictable at the macro level. In general, there is a tendency these days to underestimate how much more energy society will demand—whether it is supplied or not is a separate issue—at the local, national, and especially global level.

How much *more* energy the world will *demand* first depends on achieving the economic growth sought by most citizens—though not necessarily by environmentalist planners, hence the "de-growth" movement or the related claims that "new metrics" are needed to measure prosperity instead of GDP growth. Since the target CO_2 emissions are a global not local factor, it is, by definition, relevant to consider global trends.

Greater wealth for more people invariable leads to more demand for the kinds of things billions of people do not have that are taken for granted by the minority of the (wealthy) global population, from better medical care to vacations and owning a home, or a car. In the U.S., there are nearly as many vehicles as people, while in most of the world fewer than one in 20 people have a car.[6] More than 80 percent of the world's population has yet to take a single airline flight.[7] It is thus obvious that even radical changes to energy-use patterns in the U.S. transportation sector, never mind in one U.S. state for example, will be overwhelmed by global growth. The same is true for health-related technologies: drug manufacturing is far more energy-intensive than fabricating cars or aircraft, and hospitals use 250 percent more energy per square foot than do commercial buildings.[8]

It is thus relevant to note for context a fact regarding global CO_2 emissions trends. Even if the theoretical claims are achieved for a reduction of 2 gigaton/year in total U.S. emissions arising from the implementation of the Inflation Reduction Act's energy goals—i.e., goals that will require not only New Jersey but all of other states to collaborate—it is a fact that the *new* coal plants that China added to its grids last year *alone* will add over 2 gigatons/year in emissions to the same atmosphere.[9] China, along with India and Indonesia, and other major emerging markets, have made clear that plans will continue for expanding conventional hydrocarbon energy systems to fuel economic growth in those regions. In China, again alone, the number of *additional* coal plants under construction or planned is more than four-fold greater than the quantity that came on-line there in 2023.[10] Since, again, CO_2 emissions are relevant globally, policymakers and citizens may want to calibrate the value of implementing policies that entail local economic or social costs against the global effectiveness of the actions taken within a state (or a country).

Additional context relevant to the time-frames inherent in these energy debates should also include an understanding of the potential energy demand implications arising from the emergence of entirely new energy-using technologies within the wealthy economies themselves. There is an implicit, deeply flawed presumption that there are no new yet-to-be-commercialized inventions that will create net new energy demands. To state the relevant principle simply, there was no demand for electricity to power computers, or the cloud, before the invention and proliferation of both; the

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[6] Our World in Data, "Motor Vehicle Ownership per 1,000 Inhabitants."

[7] Stefan Gössling and Andreas Humpe, "The Global Scale, Distribution and Growth of Aviation: Implications for Climate Change," *Global Environmental Change* 65, article 102194, November 2020.

[8] U.S. Energy Information Administration (EIA), "Energy Characteristics and Energy Consumed in Large Hospital Buildings in the United States in 2007," Aug. 17, 2012.

[9] Global Energy Monitor, "Boom and Bust: Coal 2024," April 2024.

[10] Center for Research on Energy and Clean Air, "China's new coal power spree continues as more provinces jump on the bandwagon,' August 29, 2023.

same is true for all products from air conditioners to refrigerators, and from cars to aircraft. Two recent examples illustrate the potential for myopic demand forecasts: few policymakers, pundits, or analysts anticipated just a few years ago that cryptocurrencies and artificial intelligence would lead to significant new demand for electricity. That reality is now clear and widely acknowledged; in fact, those uses of energy are on track to become comparable to, likely more significant than the electricity demands expected from greater use of electric cars.

In general, history shows that innovators have been far more productive at inventing new ways to use energy, than to produce it. History also shows that only a handful of new means to deliver energy to civilization have emerged and, further, that when new means of producing energy do emerge it has never resulted in transitions eliminating the use of previous means. Wood, for example, society's oldest energy source, still supplies three-fold more global energy than does the combined output from all wind and solar hardware. Even in the U.S., wood-for-fuel today is at roughly the same level of consumption as in 1824. The transition that has occurred has been the huge decline in wood's *share* of supply for a far bigger economy. New means of energy production have served as *additions* to society's options necessary to meet expansion of both populations and wealth.

But the central conceit of the "energy transition," one that is novel and unprecedented in history, is the idea that state and federal policies can now create a wholesale replacement of most of society's primary energy sources and do so without economic or social consequence.

New Jersey's Energy Policy Goals

It appears that a new iteration of New Jersey's Energy Master Plan (EMP) is imminent. The new plan will likely be in line with the ambitions made clear in previous plans and statements. Previous plans and policies have focused on two core areas: (i) increasing the supply of electricity from renewable electricity, in particular offshore wind power and solar photovoltaics; and (ii) forcing greater electrification of end-uses, notably electric vehicles and space and water heating. The EMP would pursue these goals through combinations of subsidies, or taxes, and mandates or standards, the latter which also necessarily entail costs to the end-users.

Increasing Renewable Electricity

In September 2022, Governor Murphy signed Executive Order #307, which increased the state's offshore wind goal to 11,000 MW by 2040.[11] In 2021, the Governor signed the "Solar Act of 2021," which mandated a minimum of 3,750 megawatts (MW) of solar photovoltaic generation by 2026, much of which will be met with "behind-the-meter" rooftop solar installation on residential and commercial buildings.[12] In 2023, legislation was introduced (S-2978) that would mandate 100 percent zero-emissions electricity supply in the state. Although that legislation was not passed in 2023, it is expected to be reintroduced.

Offshore wind has been especially challenging for New Jersey. In 2023, Orsted cancelled its Ocean Wind I and II projects which totaled 2,200 MW of capacity, despite being offered an additional $1 billion in subsidies that were originally intended for state electricity ratepayers. Thus far, the 1,500 MW Atlantic Shores Wind project has not been cancelled, nor have the developers requested upward revisions to the prices in the long-term power sales contract signed with the state in 2021. Most recently, the BPU awarded contracts for two new offshore wind projects – the 2,400 MW Leading Light Wind project and the 1,300 MW Attentive Energy Wind project. The new power purchase contracts have prices that are far higher than those for Ocean Wind and Atlantic Shores Wind. They also include escalators for inflation, which will allow the developers to charge prices that are up to 15 percent more than the contract prices.

Building & Vehicle Electrification

In February 2023, the Governor signed Executive Order #316, which calls for 400,000 residential

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[11] State of New Jersey, Office of the Governor, "Governor Murphy Signs Executive Order Increasing Offshore Wind Goal to 11,000 MW by 2040," September 21, 2022.

[12] P.L. 2021, c.169 (A4554 ACS).

buildings to be electrified, along with 20,000 commercial buildings and public facilities.[13] On July 26, 2023, the state Board of Public Utilities issued an order requiring utilities to file building electrification plans for the years 2024 – 2027.[14]

In 2021, the state adopted the California Advanced Clean Truck (ACT) rule. That rule requires increasing shares of new heavy trucks (i.e., those whose weight in greater than 8,500 pounds) sold in the state to be electric.[15]

In 2020, Senate Bill 2252 was signed into law. It mandates a total of 300,000 electric vehicles on New Jersey roads by 2025 and two million by 2035. And, in November 2023, the state adopted the California Advanced Clean Car (ACC) II standards. Under ACC II, 43 percent of all model year 2027 vehicles sold in the state (which usually begin sales in the middle of the prior year) must be zero-emission vehicles: either battery-electric vehicles (BEVs), plug-in hybrids (PHEVs), or fuel cell vehicles (FCVs). The percentage increases each year until 2035, when 100 percent of new cars and light trucks sold in the state must be zero-emission.[16]

Over the past decade the sales of BEVs and PHEVs have steadily, and by some standards, dramatically risen. Through the first half of 2023, sales of BEVs and PHEVs accounted for almost 10 percent of all new vehicle registrations in the state.[17] However, it bears noting that consumers primarily buy used cars (which are lower cost), roughly three time as many as compared to new ones. Thus, it is likely the ratios for New Jersey are similar to the U.S. overall, wherein EVs comprised about 8 percent of all new cars bought in 2023, but only 2 percent of all vehicles purchased.[18]

EVs currently account for less than two percent of the 6.5 million cars and light trucks registered in NJ, and less than a half of a percent of all purchased vehicle registrations.[19] Although sales of BEVs and PHEVs have increased, the rate of growth has slowed recently, leading automakers to cut production.[20] To meet the 330,000 EV goal mandated for 2025 by SB 2252, sales will need to rise by some 500 percent over the current rate.

The December 2019 EMP, which was mandated under Governor Murphy's 2018 Executive Order 28, included a wide range of longer-term energy policy goals.[21] These included 100 percent zero-emissions energy (not just electricity), which would entail eliminating all end-use natural gas and petroleum in residential and commercial buildings. There are approximately 1.9 million single family residences, 350,000 townhomes, and 1.3 million multi-family units in NJ.[22] Of these, approximately 75 percent are heated with natural gas, while another 10 percent are heated with propane or fuel oil. ***There were no estimates of the costs associated with those mandates.***

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[13] Executive Order #316, February 15, 2022.

[14] New Jersey Board of Public Utilities, "NJBPU Approves Second Energy Efficiency Framework," July 26, 2022.

[15] New Jersey Dept. of Environmental Protection, "DEP Commissioner Latourette Announces Adoption of Clean Truck Rules, Setting New Jersey on Path for Zero-Emission Vehicle Future," December 20, 2021.

[16] State of New Jersey, Office of the Governor, "Murphy Administration Adopts Zero-Emission Vehicle Standards to Improve Air Quality, Fight Climate Change, and Promote Clean Vehicle Choice," November 21, 2023.

[17] NJDEP| Drive Green NJ | NJ EV Data

[18] Statista

[19] Atlas Public Policy, EValuateNJ, updated December 2023.

[20] Nick Carey and Joseph White, "Industry pain abounds as electric car demand hits slowdown," Reuters, January 20, 2024.

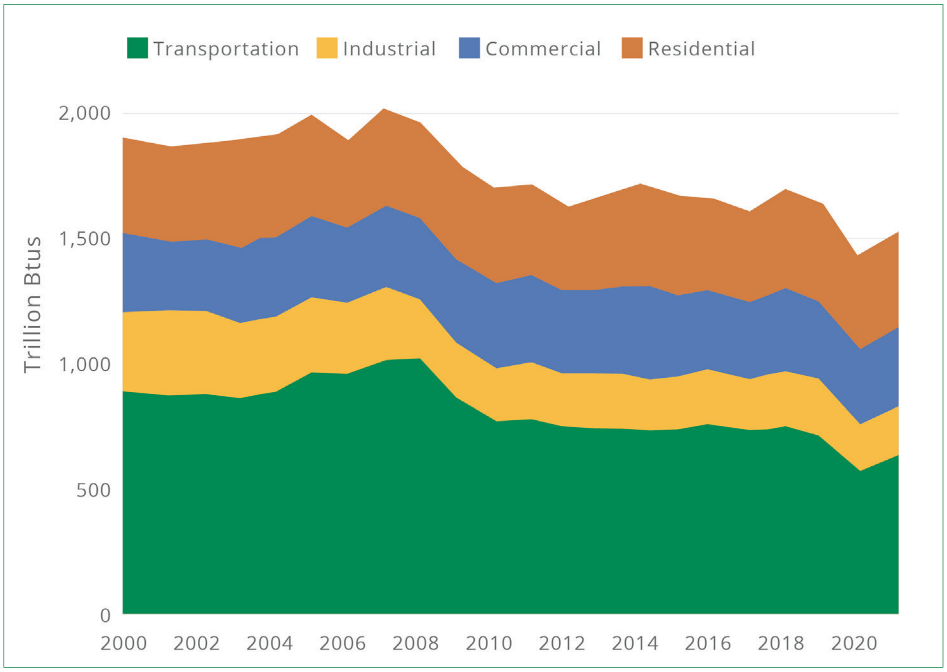
[21] Executive Order 28, May 23, 2018.

[22] U.S. Census Bureau, Selected Housing Statistics, Table DP04. A townhome is known as an "attached" structure.

New Jersey Energy State-of-Play

Developing a realistic state energy plan and assessing the impacts of proposed plans, necessarily begins with an analysis of recent energy in transportation, commercial, residential, industrial, and electric sectors. Since 2000, total N.J. end-use energy consumption has decreased by almost 25 percent, from just over 1,915 trillion Btus (TBtus) to just over 1,500 TBtus.[23] (**Figure 1**) While residential and commercial energy consumption has remained relatively steady, energy consumption in the industrial and, especially, transportation sectors have decreased.

FIGURE 1: NEW JERSEY'S END-USE ENERGY CONSUMPTION, BY SECTOR, 2000–2021



Source: U.S. Energy Information Administration

The transportation sector accounts for the largest share of energy consumption in New Jersey, a factor that's been true for years. In 2000, transportation accounted for almost half of the total. Although transportation-related energy consumption decreased by almost one-third between 2000 and 2021, primarily the result of improvements in overall vehicle fuel efficiency, the sector still accounted for 41 percent of total energy use. The decrease in industrial energy use began with the 2008 financial crisis and accompanying recession, essentially marking the beginning of a de-indus-

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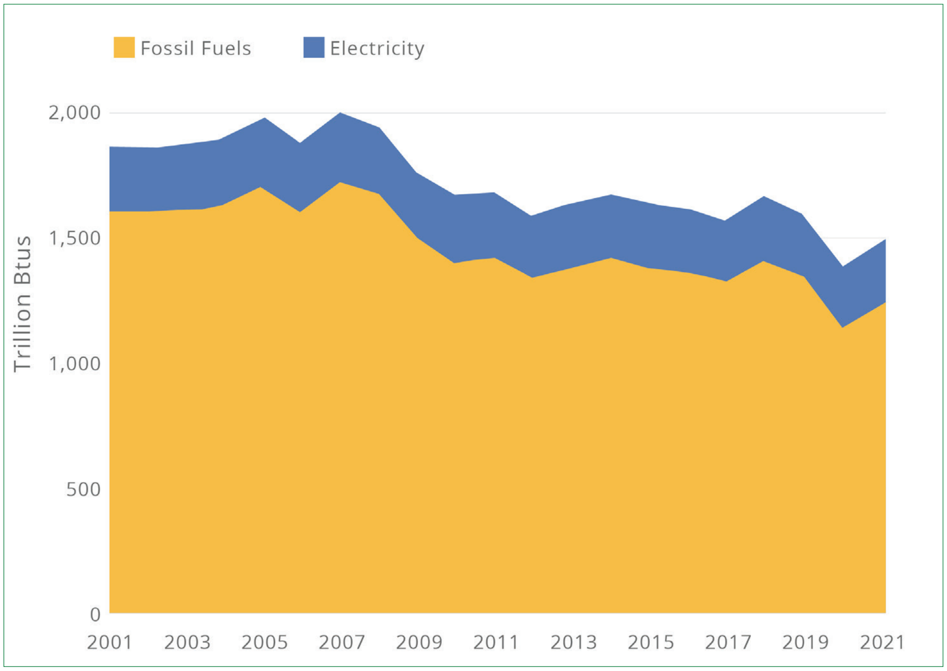
[23] End-use energy consumption excludes the energy used to generate electricity for use by consumers and businesses.

trialization of the state's economy.[24] Manufacturing output, as measured by real (inflation-adjusted) gross state product, fell by over one-third between 2008 and 2012. There has been some recovery since then, but output has yet to reach pre-2008 levels.[25]

Because the state's energy policy, as reflected in the 2019 EMP, calls for an increase in the use of electricity, in particular for transportation (electric vehicles) and space and water heating, it is useful to examine the share of end-use energy consumption met with hydrocarbons and electricity (**Figure 2**). As this figure shows, electricity accounts for less than 20 percent of total end-use energy consumption.

FIGURE 2: TOTAL NEW JERSEY END USE ENERGY CONSUMPTION, HYDROCARBONS AND ELECTRICITY



Source: U.S. Energy Information Administration

The 2019 EMP and state energy policy envision meeting the increased demand for electricity that will result from end-use electrification primarily with renewable energy, especially offshore wind and solar photovoltaics. Hence, it is instructive to examine the historical contribution of all renewable energy sources to the state's end-use consumption (**Figure 3**).

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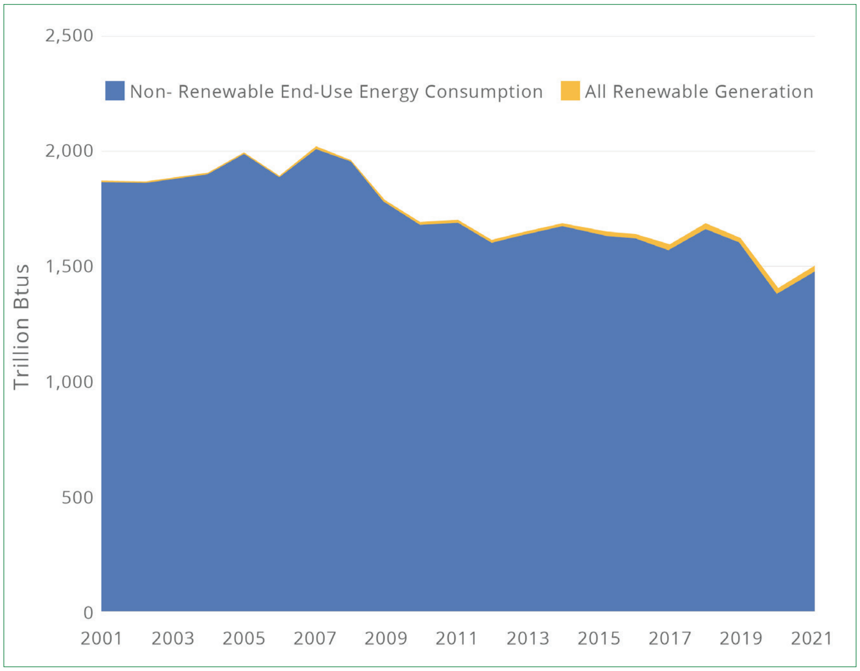
[24] New Jersey Manufacturing Extension Program, Industry Report 2022. The largest single manufacturing segment in NJ is the chemicals industry. In 2000, it accounted for almost half (~$30 billion) of total manufacturing gross state product. By 2020, it was ~$16 billion.

[25] New Jersey Economic Development Agency, "Economist's Corner: Manufacturing Trends in New Jersey," December 3, 2021.

FIGURE 3: RENEWABLE CONTRIBUTION TO NEW JERSEY END-USE ENERGY CONSUMPTION



Source: U.S. Energy Information Administration

As Figure 3 shows, the contribution of all renewable energy resources to meeting end-use energy consumption is negligible. In 2021, renewable energy accounted for just over 16 TBtus of the 1,500 TBtus of end use energy use, or just one-tenth of one percent.

It is also important for context to consider the share of each sector's energy consumption by fuel source. Energy consumption in the transportation sector, not surprisingly, is virtually all from petroleum. In the residential sector, natural gas used for space and water heating accounts for over 40 percent of total final consumption (**Figure 4**), with a similar share in the commercial sector (**Figure 5**).

In the commercial sector, however, the arrival of enterprise scale datacenters is not only a new feature of the modern economy but also a new vector for electric power demand. Since 2000, if the (economically desirable) datacenters had not been built in New Jersey, the state's commercial electricity use would have ***declined by 10 percent***, instead seeing overall demand grow.[26]

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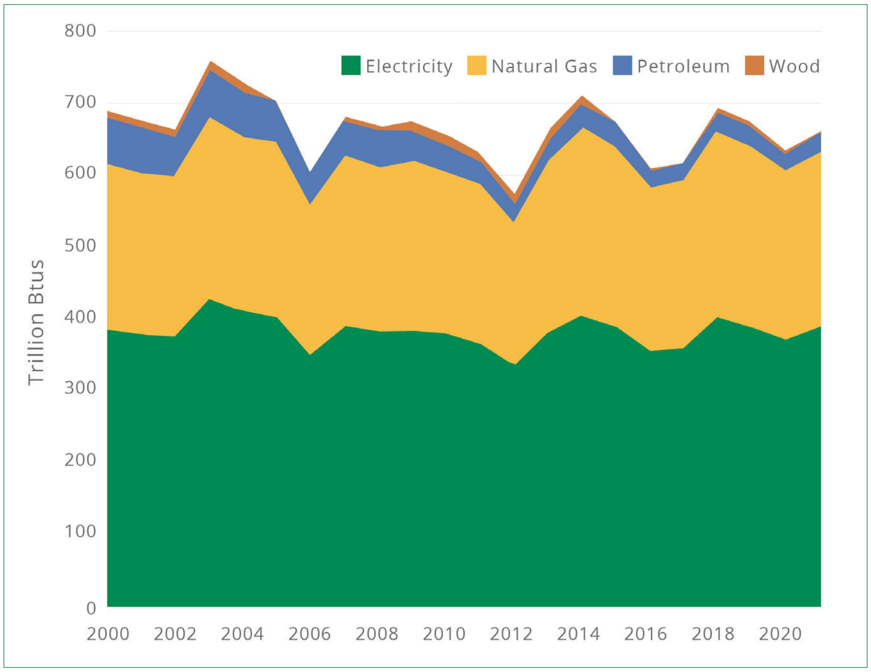
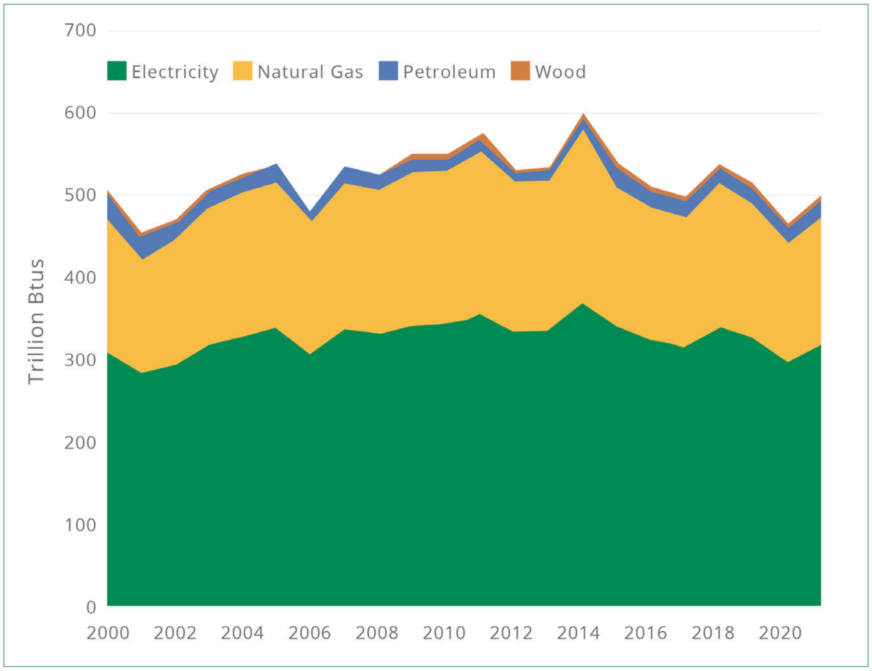
[26] Modor Intelligence, "New Jersey Data Center Market": calculated from 300MW NJ datacenter installations.

FIGURE 4: NEW JERSEY RESIDENTIAL END USE ENERGY CONSUMPTION BY FUEL



Source: U.S. Energy Information Administration

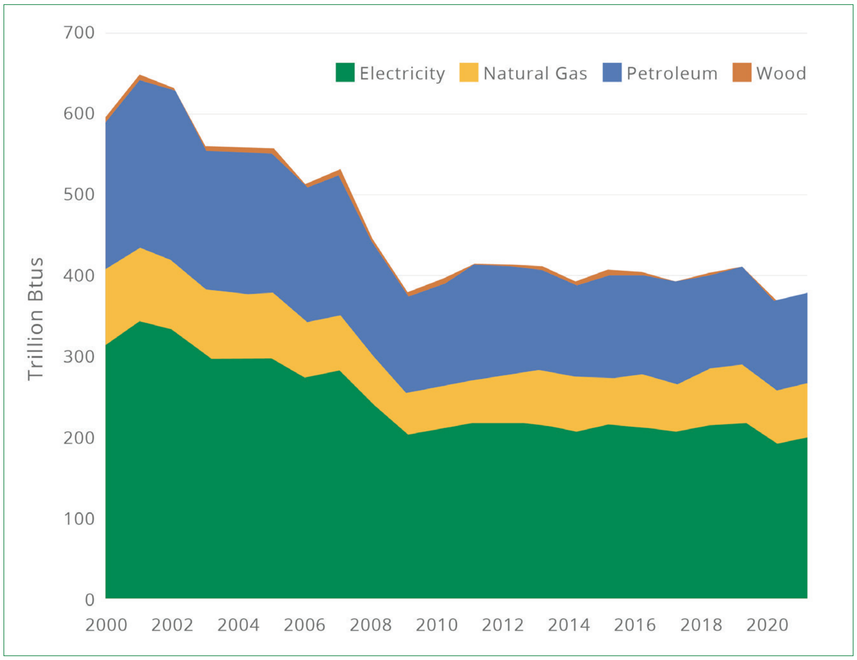
FIGURE 5: NEW JERSEY COMMERCIAL END USE ENERGY CONSUMPTION BY FUEL



Source: U.S. Energy Information Administration

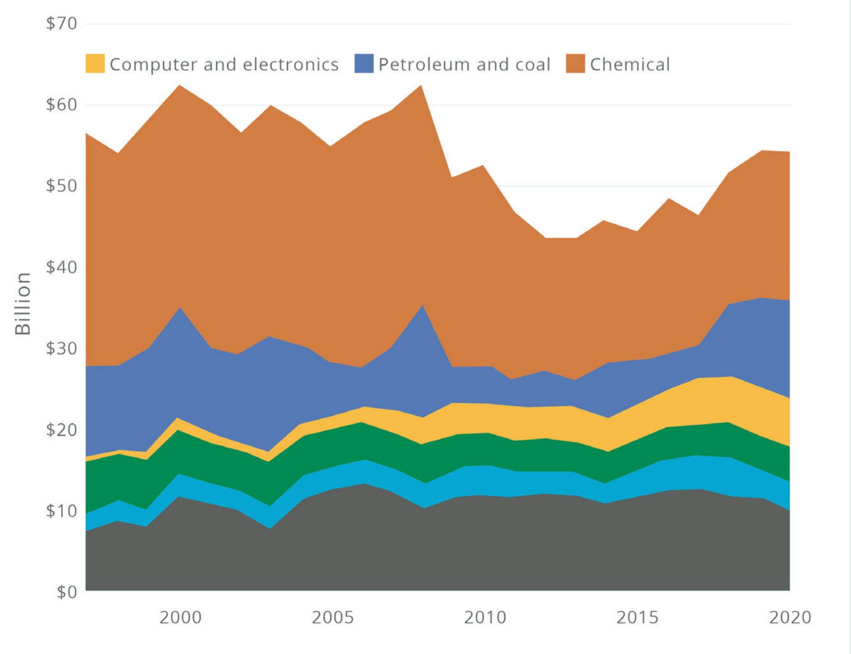
The industrial sector relies far more heavily on petroleum or natural gas than the residential and commercial sectors, primarily because of the need for high-temperature process heat (e.g., furnaces, kilns) that cannot be met using electricity. (**Figure 6**) The decline in energy use tracks the decline in manufacturing output (**Figure 7**) and in particular the decline in energy-intensive chemical industries. Thus manufacturing employment (**Figure 8**) has also declined, dramatically, the class of work with the greatest economic multiplier. Consequently, it should not be surprising to see that, since 2000, the overall ***state's economy has grown half as much*** (in real terms) as has the national overall, 15 percent and 30 percent respectively.[27]

FIGURE 6: NEW JERSEY INDUSTRIAL END USE ENERGY CONSUMPTION BY FUEL



Source: U.S. Energy Information Administration

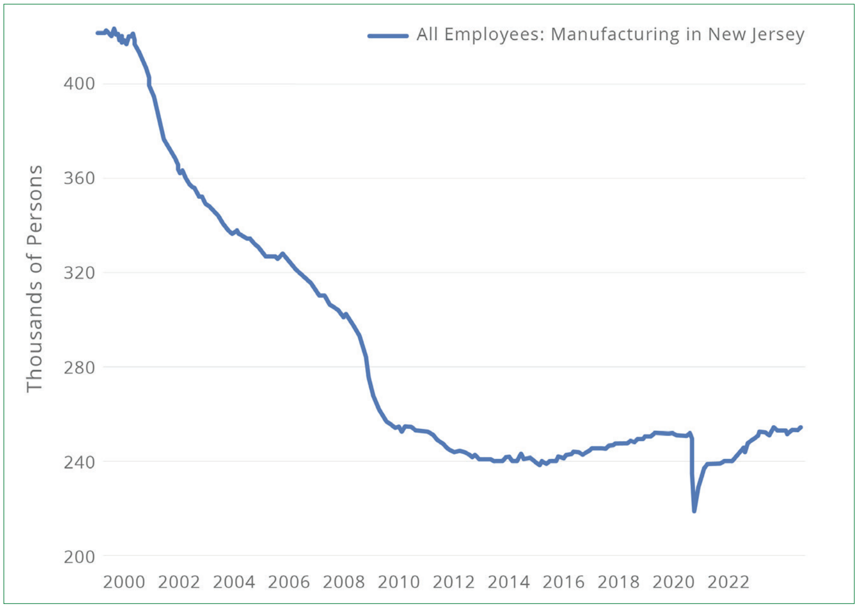
FIGURE 7: NEW JERSEY MANUFACTURING OUTPUT ($BILLION GDP) BY SECTOR



Source: State of New Jersey Manufacturing Industry Report 2023

[27] Statista

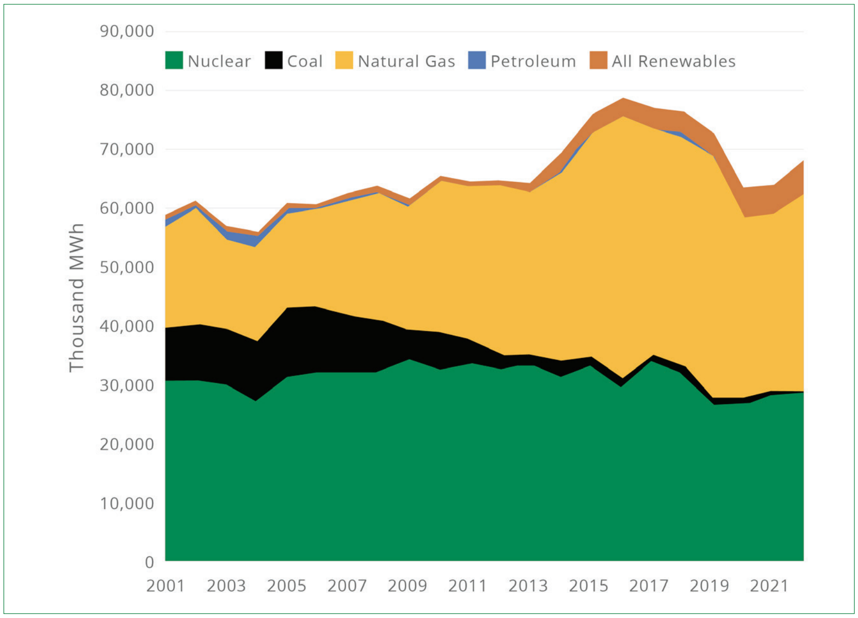
FIGURE 8: NEW JERSEY MANUFACTURING EMPLOYMENT[28]



Source: St. Louis Federal Reserve

The state's electric generation is derived almost entirely from the combination of two sources, natural gas (51 percent) and nuclear power (44 percent), the latter from the state's two remaining nuclear power plants (**Figure 9**).

FIGURE 9: NEW JERSEY ELECTRIC GENERATION BY SOURCE



Source: U.S. Energy Information Administration

As the data show, about 90 percent of New Jersey's energy currently comes from hydrocarbons. And the extent to which there has been any decline in the state's energy use, it has come mainly from the

[28] St. Louis Federal Reserve

de-industrialization of the local economy, and (normal) technological progress with combustion engines in automobiles. Total vehicle-miles traveled in New Jersey have increased by less than 15 percent since 2000, while the average fuel efficiency of new cars has improved by over 30 percent.[29]

A central question for policymakers going forward is the extent to which the state puts into place policies that will allow participation in the wealth-creation of reshoring energy-intensive manufacturing (whether steel, silicon, or pharmaceuticals), and also to serve as a home to the electricity-intensive datacenter sector, or whether to see continued shrinkage in high-value employment in those energy-using industries. Those who propose to focus instead one more employment from alternative energy-producing industries should note this entails not only lower-values jobs but also cannot be sufficient to offset the aforementioned employment losses.

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29 NJDOT and Lending Tree, August 2023.

New Jersey's Seven Energy Goals: Perspective & Flaws

The 2019 EMP contains seven energy transition strategies which were repeated, unchanged, in a March 2024 Board of Public Utilities Notice.[30] The seven strategies are similar to if not identical to those enumerated by many of the other states and many federal proposals directed at an "energy transition" strategy, all intended to pursue a significant reduction in, or elimination of the use of hydrocarbons.

1. Reducing Energy Consumption and Emissions in Transportation
2. Accelerating Deployment of Renewable Energy and Distributed Energy Resources
3. Energy Efficiency and Conservation to Reduce Peak Demand
4. Reduce Building Energy Use
5. Decarbonizing and Modernizing New Jersey's Energy System
6. Community Energy Planning and Action in Underserved Communities
7. Expand the Clean Energy Innovation Economy

Given that today, as noted above, hydrocarbons are essential to the state's economy, planners should be aware of the entirety of the consequences arising from the "energy transition" ideas proposed, as well as context for the prospects for achieving the goals.[31]

While there are myriad and often complex issues associated with each of these seven pillars of NJ's strategy, in order to provide perspective on and highlight cautionary implications, **we focus herein on providing perspective on only some of the core challenges or flaws regarding each of the seven strategic objectives**. We devote a somewhat more extensive focus on EVs, both below regarding goal #1, and in an Appendix, because of the magnitude of misinformation in that domain

1. Reducing Energy Consumption and Emissions in Transportation

Key perspective: total lifecycle analyses point to small, possibly non-existent reductions in CO_2 emissions associated with mass deployment of EVs

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[30] NJ Board of Public Utilities, March 11, 2024.

[31] 2019 New Jersey Energy Master Plan

It is entirely reasonable to imagine that one could see a reduction in the energy used in the transportation sector, measured in energy per vehicle-mile or ton-mile. It is far from clear that there are economically, or socially viable means for an absolute, or significant reduction in transportation energy use. And it bears noting that the emissions in question are not the so-called criteria pollutants -- e.g., SOx, PM, NOx, CO, O3, Pb – all of which have seen radical reductions in the past two decades.[32] Rather, the proposed emissions reductions sought are exclusively with CO_2 which is, itself, an inherent feature of hydrocarbon engines, and are essentially the same regardless of when or where a car is refueled, or when it is driven.[33]

Tailpipe scrubbing of CO_2 is technically feasible, though not commercially viable or deployed, and until there are chemistry breakthroughs, still very expensive.[34] Thus reducing overall CO_2 emissions requires either superior combustion efficiency, less driving, or non-combustion primary energy in the transportation supply chains. The assumption in mandating EVs is that the result will be a radical reduction in the state's contribution to global CO_2 emissions since, by definition, battery-electric vehicles have no engine or tailpipe. It is clear, however, that upstream, real-world upstream emissions from EVs are more significant than commonly understood.

An EV's CO_2 emissions are not directly measurable, and instead are necessarily estimated. While, self-evidently, there are no emissions while *driving* an EV, emissions occur upstream, before the vehicle is driven and obviously when the vehicle is being recharged.

For EVs, setting aside the significant temperature variabilities in efficiency (kWh per mile rising, as much as 50% in cold periods), the specific emissions depend on the specific time of day that the vehicle is recharged because of the very wide variabilities in sources of electricity at the time of recharge itself. These variabilities can be modeled, but such models are rarely employed. Instead, most analysts assume an average EPA-rated average kWh per mile, and the average annualized grid kWh of CO_2 emissions. The former number has been found recently to be questionable, and the latter average does not reflect the actual as-used kWh.

All the aforementioned issues aside, the most important variables for EV CO_2 emissions are associated with upstream industrial emissions from building batteries. Claims made for reducing emissions through EV use are anchored in *assumptions* about the quantities and varieties of materials mined, processed, and refined to make the battery. Unlike criteria pollutants which are local, the issue here, again, is global since the remote and upstream CO_2 emissions are as relevant as local. And while conventional cars also have associated upstream emissions—the energy used to obtain materials and fabricate the vehicle and to create gasoline—these comprise only 10 to 20 percent of these vehicles' total lifecycle emissions. The picture is inverted for EVs wherein upstream CO_2 emissions dominate.

The scale of EV upstream emissions emerges from the fact that a typical EV battery—those that are typical for the majority of EVs that consumers purchase—weighs about 1,000 pounds to re-

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[32] Langworthy, Kurth, "Air Quality in the United States has Improved Dramatically since Enactment of the Clean Air Act," National Law Review, June 26, 2020.

[33] For precision, it's notable that altitude and ambient temperature create very small variations in fuel efficiency and therefore emissions.

[34] Sharma, Maréchal, "Carbon Dioxide Capture From Internal Combustion Engine Exhaust Using Temperature Swing Adsorption," Energy Res., 16 December 2019.

place a fuel tank holding about 80 pounds of gasoline.[35] The half-ton battery is made from a wide range of minerals including copper, nickel, aluminum, graphite, cobalt, manganese, and of course, lithium, the specific mix of which depends on battery chemistry choices. The quantity of these so-called "energy minerals" is roughly ten-fold greater to build an EV compared to an ICE car.[36] The upstream energy, and emissions, arise from that fact that hundreds of thousands of pounds of rock and materials are mined, moved, and processed to create the intermediate and final refined minerals to fabricate a single thousand-pound battery.

The fact is all emissions claims about EV are estimates based on where in a very wide range of outcomes a specific vehicle may reside. The technical literature shows estimated emissions from fabricating an EV battery vary by as much as three-fold.[37] Accurately assessing the actual quantities of specific fuels used for specific vehicle supply chains is complicated by the labyrinth of global suppliers and the lack of transparency with many of the companies. A useful starting point can be found with the IEA's seminal report on "energy minerals" which includes both upstream factors and grid fueling,

The IEA concluded that, compared with an ICE car, there is still about a 50 percent reduction in life-cycle emissions for EVs.[38] (**FIgure 10**) However, that IEA claim is, essentially a 'cherry-pick' from the range of possibilities, and not a statement of fact, nor a relevant factor for planning purposes. As the IEA document itself illustrates the possible EV emissions vary widely depending on variables, shown as "error bars" in the figure.[39] In addition, a key variable in the IEA estimate is the assumption of battery size. The IEA calculation assumes a small car with a small 40 kWh battery pack which is one-half the size of the batteries in most popular EVs.[40] As the IEA itself notes, SUVs with batteries roughly twice as big account for 60 percent of EV purchases.[41] The quantity of upstream emissions directly tracks increases in battery size.

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[35] Small EVs can have smaller batteries, an issue addressed later in this report; nevertheless, nearly two-thirds of EVs purchased use large batteries in the 1,000-pound range.

[36] IEA, "The Role of Critical Minerals in Clean Energy Transitions," May 2021.

[37] Jens F. Peters et al., "The Environmental Impact of Li-Ion Batteries and Role of Key Parameters—A Review," *Renewable and Sustainable Energy Reviews* 67 (January 2017): 491–506.

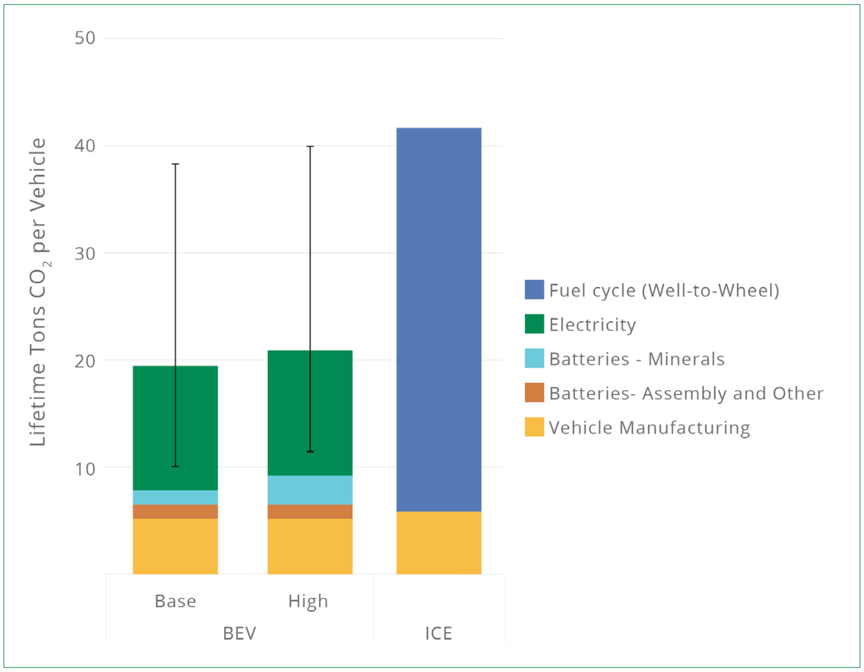
[38] IEA, "The Role of Critical Minerals in Clean Energy Transitions."

[39] IEA, "Well-to-wheels greenhouse gas emissions for cars by powertrains," Feb. 25, 2021.

[40] Ibid: 40 kWh battery pack, p 194.

[41] IEA, "Global EV Outlook," April 2023.

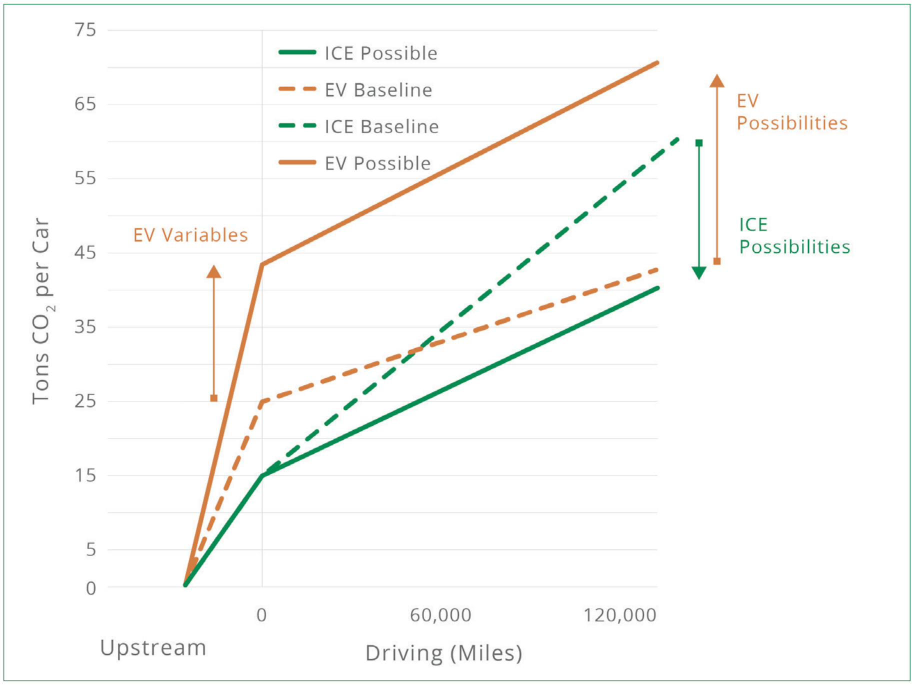
FIGURE 10: ESTIMATED LIFE-CYCLE CO_2 EMISSIONS FOR EVS VS ICE-CARS PER IEA



Source: IEA, "The Role of Critical Minerals in Clean Energy Transitions."

If one undertakes an analysis of the range of possibilities for lifecycle emissions, taking into account the known variables within known ranges of values, and also *realistic* scenarios for EVs driven on grids that will exist for the next decade, one finds that EVs could lead to *greater lifetime emissions* than using a more efficient conventional internal combustion engine (ICE) car. (**FIgure 11**) Additional details on these variables are provided in the Appendix.

FIGURE 11: EV VS ICE CO$_2$ LIFECYCLE EMISSIONS: SCENARIOS WITH KNOWN VARIABLES



Source: Mark P. Mills, "Electric Vehicles for Everyone? The Impossible Dream, *Manhattan Institute* Policy Paper, July 2023.

2. Deployment of Renewable Energy and Distributed Energy Resources

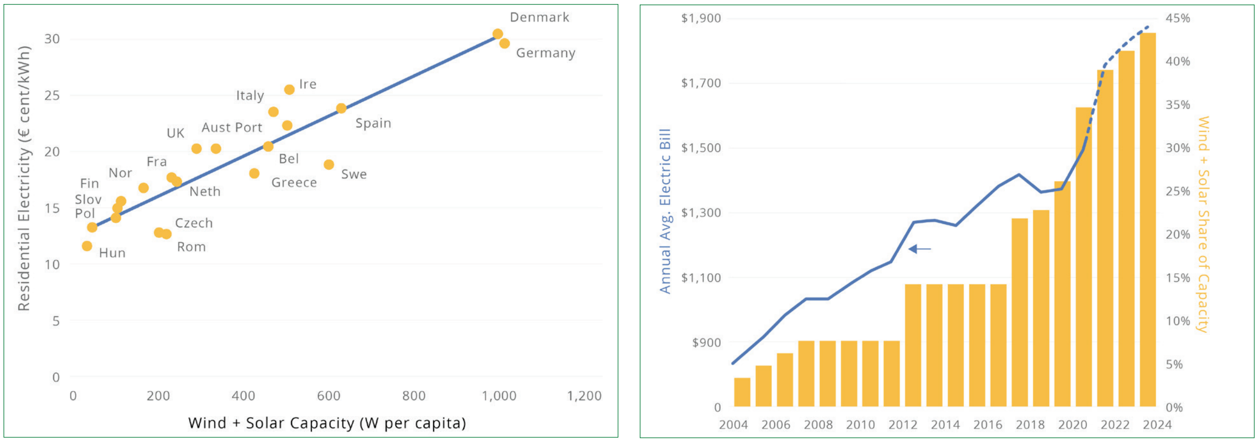
Key perspective: Greater deployment of wind and solar correlates, everywhere, with increased cost of electricity.

While it is true, as often noted, that there has been a significant decline over the past decade in the cost of building wind and solar electricity generation, the effect of adding more such episodic capacity to grids has been on increased cost of electricity to consumers. This has occurred, in large measure, because of the operational cost trends to manage reliability as the share of non-dispatchable power rises on a system. The same trend is visible across Europe where there is a longer, and more extensive, history of increased installation of episodic power sources. (**FIgure 12**).

The trends are clearly visible in data over the last two decades in the service territory for Xcel Energy in the U.S. Midwest. (**FIgure 12**) And as recent EIA data show, the average residential cost of electricity has soared, up nearly 20 percent in the past several years.[42] The cost increase cannot be attributed to conventional generation since 75 percent of the nation's electricity is produced by natural gas and coal, both of which are at record low costs. Something else has led to radical price hikes despite the contemporaneous decline in fuel costs for the majority of electricity supply. The only new variable on grids has been the addition of far more wind and solar which cause overall systems costs to rise, due to practical reasons relating to operating reliable grids while using unreliable and episodic wind and solar sources.

[42] EIA

FIGURE 12:AVERAGE COST OF ELECTRICITY VS INCREASED INSTALLATION OF WIND + SOLAR



Europe

Xcel Service Territory

Sources: Eurostat, *American Experiment* November 2021

3. Energy Efficiency and Conservation to Reduce Peak Demand

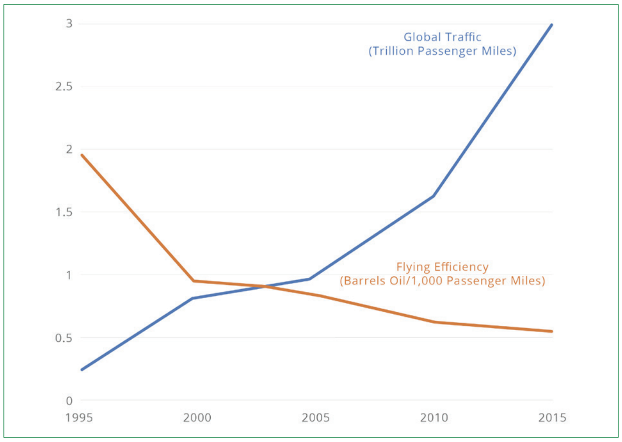
Key perspective: In an unrestricted economy, in nearly all applications, increased energy efficiency is associated with overall net increase in energy demand.

While efficiency and conservation are often used either simultaneously or interchangeably, these are two different features. Improving efficiency, which is fundamentally achieved with technological progress, reduces inputs to achieve the same or greater output. Conservation is typically a choice, or behavior, intended to reduce the use of the output. Put simplistically, a more efficient car engine and driving less can yield the same energy savings. However, history shows that people typically conserve when forced to, or for economic reasons, while the efficiency, at the societal or macro-economic level, is typically associated with inducing or allowing greater use of the machine, product, or service.

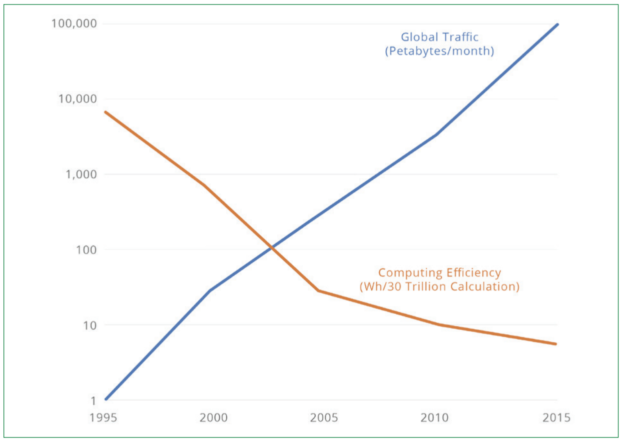
The evidence for this reality is clear across technologies, markets, and time. It is possible in isolated, constrained domains (a single building, or narrow class of products, etc.) to see improved efficiency yield declining net energy use, but the issue—again keeping in mind that the CO_2 objectives are inherently global—is that the technologies used in those isolated cases are not necessarily available globally. Thus, the effect of promoting/using efficient technologies cannot be examined without a macro, or global context. And the global effects of efficiency are clear (**FIgure 13**) wherein global net energy demands have increased even as efficiency has radically improved in, for example, the major domains of data traffic and air travel.

FIGURE 13: LONG-RUN IMPACT OF EFFICIENCY

Air Travel



Data Traffic



Sources: Author calculations

4. Reduce Building Energy Use

Key perspective: The future potential for energy savings is now far less, and will take time, and cost more, than in the past.

Commercial (and residential) buildings are capital assets well-known to have long lifespans which necessarily impacts the velocity of turn-over (or rebuilding) that allows incorporating new technologies not suitable for retrofit; commercial buildings have average lifespans around a half-century or more.[43] The HVAC systems used in commercial buildings themselves have 15 year working life.[44] However, the challenge for forward-looking policies is not just the long time periods for significant adoption but resides with two fundamental features of relevant building-related technologies.

First, the costs of commercial HVAC equipment have more than doubled over the past two decades, radically changing the cost-benefit analyses, a feature absent from most reports and forecasts.[45] (**FIgure 14**) Recent data shows that 2023 and 2024 price increases continue in all categories of commercial HVAC equipment and parts.[46]

Second, at least half of the energy use in commercial building is associated with HVAC and lighting (**FIgure 15**) wherein the rate of technology improvement -- in terms of inherent energy efficiency – has slowed. This latter is an inevitable phenomenon for all technologies wherein, as efficiency gains approach physics limits, the future gains become limited and incremental. One indicator of that reality is visible in the state-based commercial site-energy efficiency standards wherein early on big gains are possible, but the rate of gains slows as limits are approached. (**FIgure 16**) The combination of smaller potential gains in efficiency along with rising equipment costs arithmetically results in rapidly rising costs per unit of energy saved.

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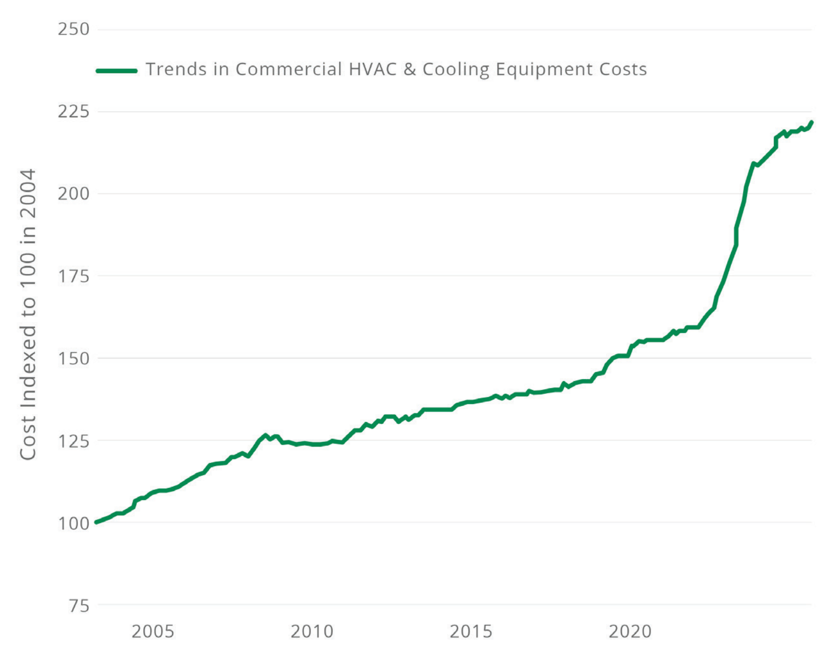
[43] Shingobee, 2021

[44] Trend Statistics, 2019

[45] Bureau of Labor Statistics

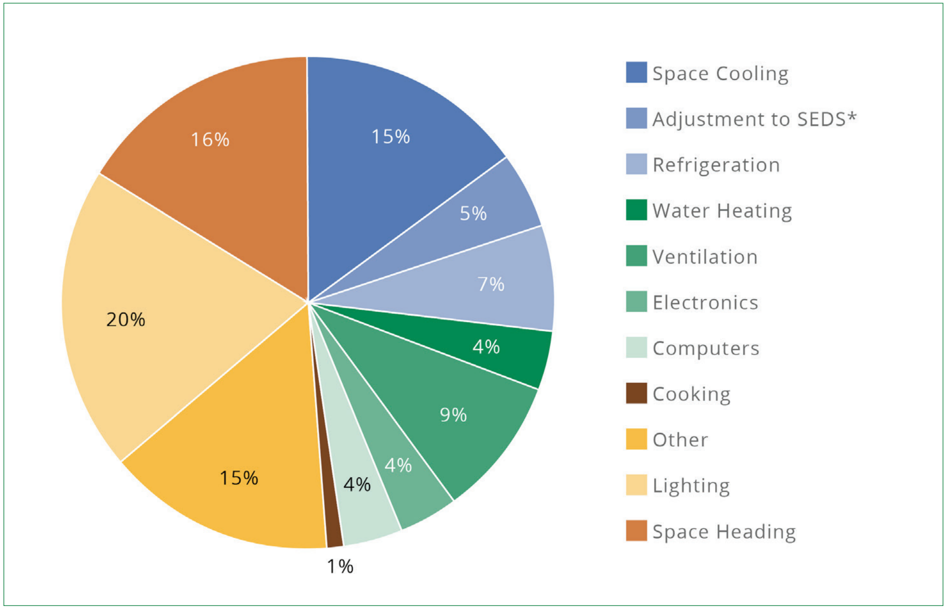
[46] ABR Wholesalers, Terry's AC& Heating

FIGURE 14: TRENDS IN COMMERCIAL HVAC & COOLING EQUIPMENT COSTS



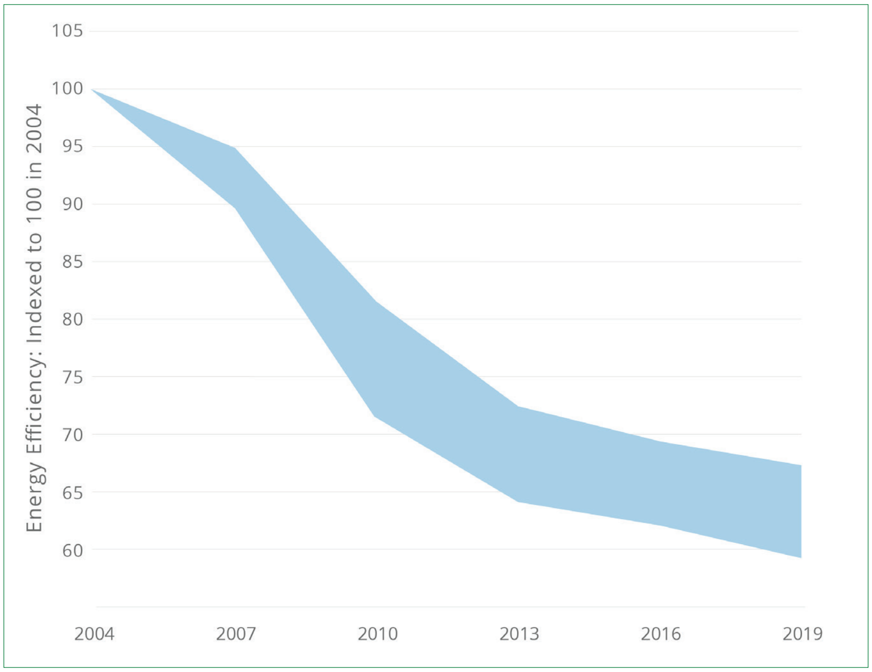
Source: Bureau of Labor Statistics

FIGURE 15: U.S. COMMERCIAL SECTOR ENERGY END-USES



Source: US DOE, Energy Efficiency and Renewable Energy (EERE) (2012) 2011 Buildings Energy Data Book

FIGURE 16: COMMERCIAL SITE ENERGY INDEX: THE EFFICIENCY ASYMPTOTE



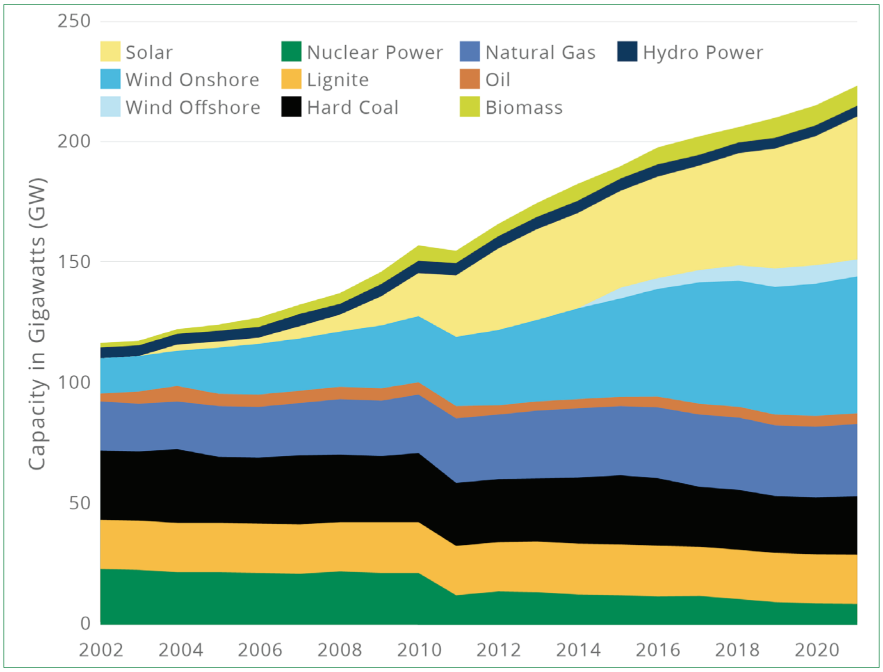
Source: DOE Building Energy Codes Program Infographics

5. Decarbonizing and Modernizing New Jersey's Energy System: The Case Study of Germany

Key perspective: The track record for "decarbonizing" energy systems shows very small changes in overall societal carbon-intensity, and far higher consumer costs.

Germany provides an instructive example of the challenges in the pursuit of a "decarbonized energy system" wherein the primary focus has been and will continue to be on the electric sector. This is in large measure because there are few alternative energy technologies available for industrial systems, especially those requiring high temperatures (for reasons anchored in the physics of energy). Germany has engaged in the most aggressive decarbonization effort of any large, modern economy; it has roughly doubled the size (GW capacity) of its electric grid almost entirely from the addition of (heavily subsidized) wind and solar hardware. The capacity of the existing conventional grid is roughly unchanged over the past two decades (smaller by ~15% due to nuclear plant shutdowns) to maintain grid stability and manage the obvious features of episodic and non-dispatchable wind/solar power generation. (**FIgure 17**) Over the past two decades Germany's absolute demand for electricity increased under 5 percent. Thus it is unsurprising that a doubling of the capital asset to supply marginal demand increase resulted in a nearly tripling of the average cost of electricity delivered – and last year wind and solar combined in Germany supplied nearly half of the grid-delivered kilowatt-hours. It has been successful in the sense of increasing non-combustion electricity supply, at a very high cost, but largely unsuccessful in significantly decarbonizing Germany.

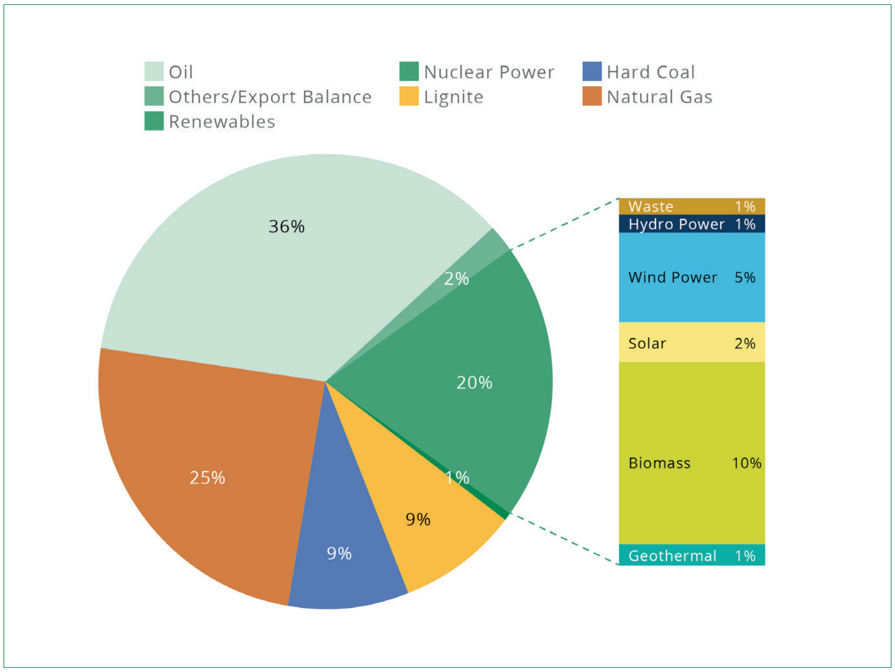
FIGURE 17: GERMAN EXAMPLE FOR DECARBONIZING THE GRID



Source: Clean Energy Wire, August 2022.

Last year in Germany, renewables (i.e., non-hydrocarbons) supplied 20 percent of all German primary energy, but half that renewable share came from burning another carbon-based fuel, wood. Solar and wind combined delivered 7 percent of Germany's primary energy; hydrocarbons supplied 77 percent. If we include the carbohydrate (wood) the carbon share was 87 percent. (**FIgure 18**)

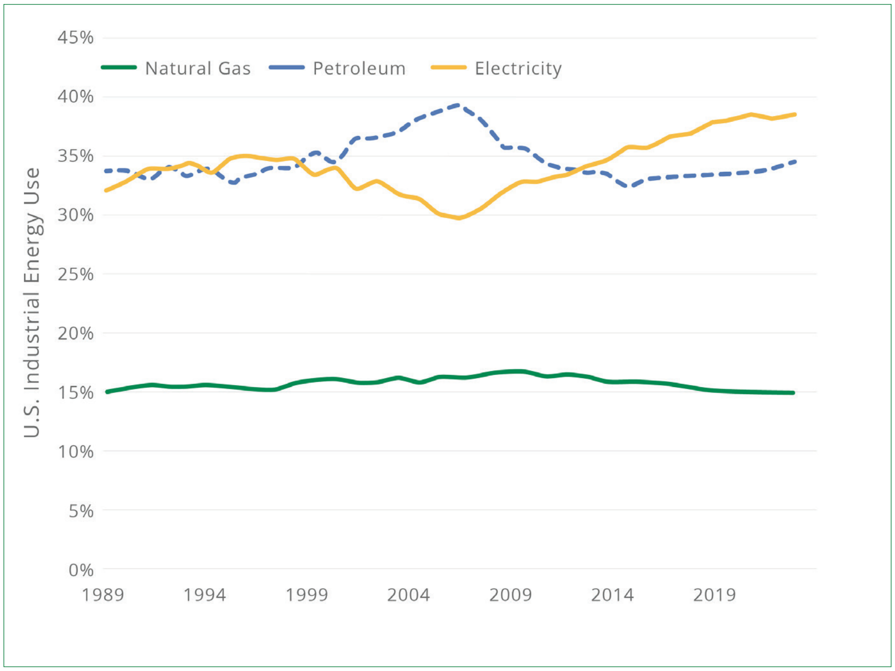
FIGURE 18: GERMAN EXAMPLE FOR DECARBONIZING THE COUNTRY



Source: CleanEnergyWire

There are manifold challenges with decarbonizing the industrial sector in general, not just in Germany. If there were fundamentally superior electricity-based technologies or phenomenologies available for industrial applications, the trends seen over the past three decades in the U.S. would have shown rapid electrification; there's been none. (**FIgure 19**) To expect that to rapidly change at all, at any price, is naïve.

FIGURE 19: U.S. SHARE OF INDUSTRIAL ENERGY USE



Source: Michael Cembalest, "Electravision," JPMorgan, 2024.

And, to expect that there will be a technology-driven decline in the costs of wind and solar is similarly naïve considering that those technologies are now on the asymptote of incremental technology gains (similar to the efficiency gains noted earlier) while other costs associated with deploying the technologies are rising. Over the past decade the average cost of power, via power purchase agreements, has doubled.[47] (**FIgure 20**) The trends arithmetically point to increasing, not decreasing costs for the pursuit of "decarbonization" by deploying wind and solar on grids.

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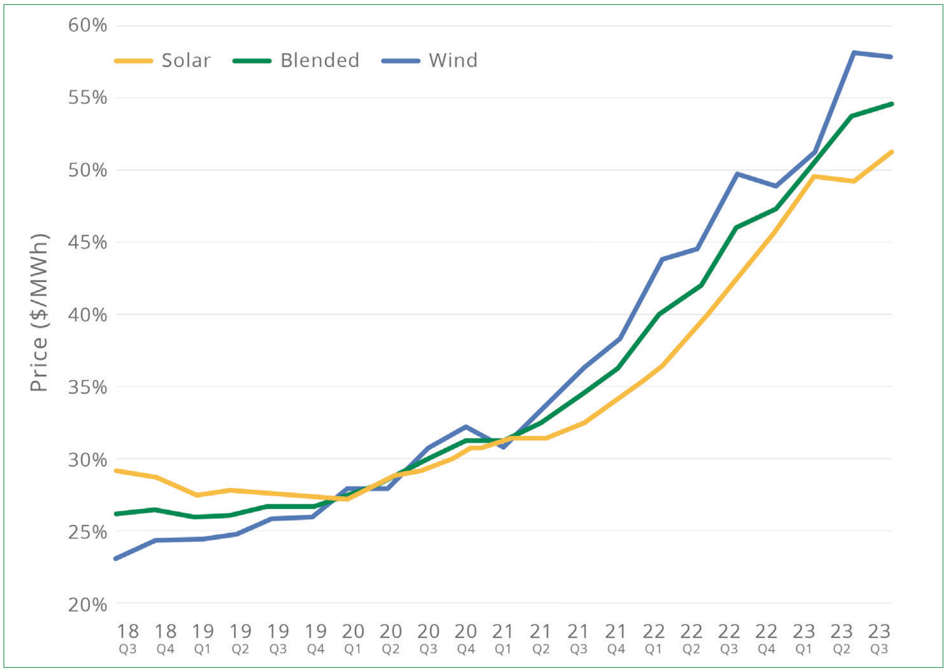
[47] PV Magazine, October 2023.

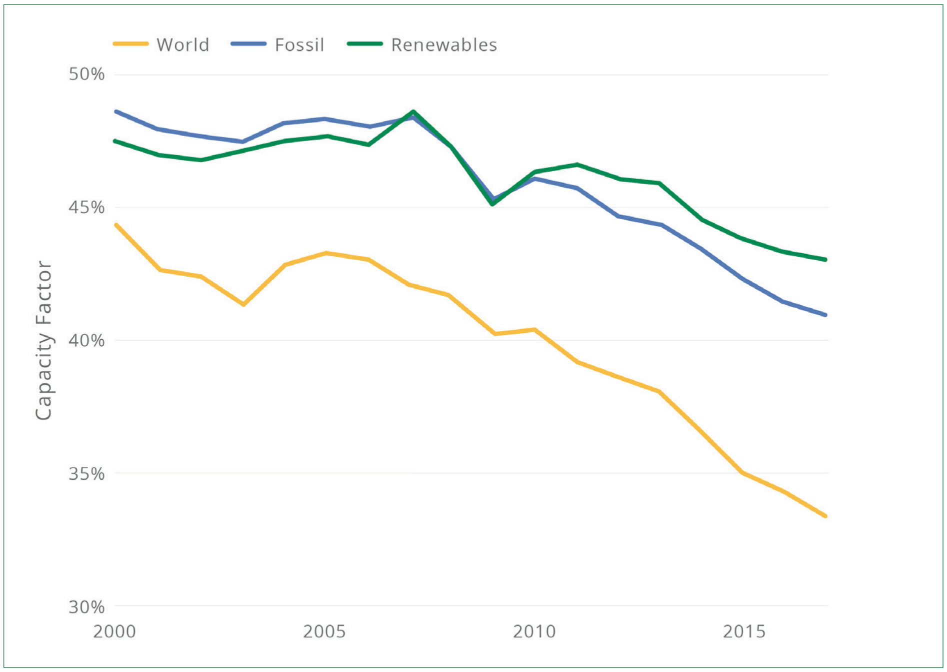
FIGURE 20: RISING REAL-WORLD SOLAR-WIND COSTS: AVERAGE U.S. PPAS



Source: PV Magazine

The episodic nature of wind and solar, or in utility terms, their lower capacity factors, is now having an additional macroeconomic impact on electric grid costs. The fact that Germany continues to operate conventional grid resources, but at lower capacity levels (essentially as back-up to offset solar/wind unavailability) means that overall grid capacity factors necessarily fall. The effect of this is quite clear in global trends, as it would be in similar trends for countries, or states. **(FIgure 21)** Thus, policy planners at the state or country grid level should be aware of the lower output per dollar of infrastructure capital deployed; or inversely, the increased costs of capital to deliver the same energy to society, something that is inherently, structurally, inflationary.

FIGURE 21: GLOBAL TREND IN ELECTRIC GRID CAPACITY FACTORS



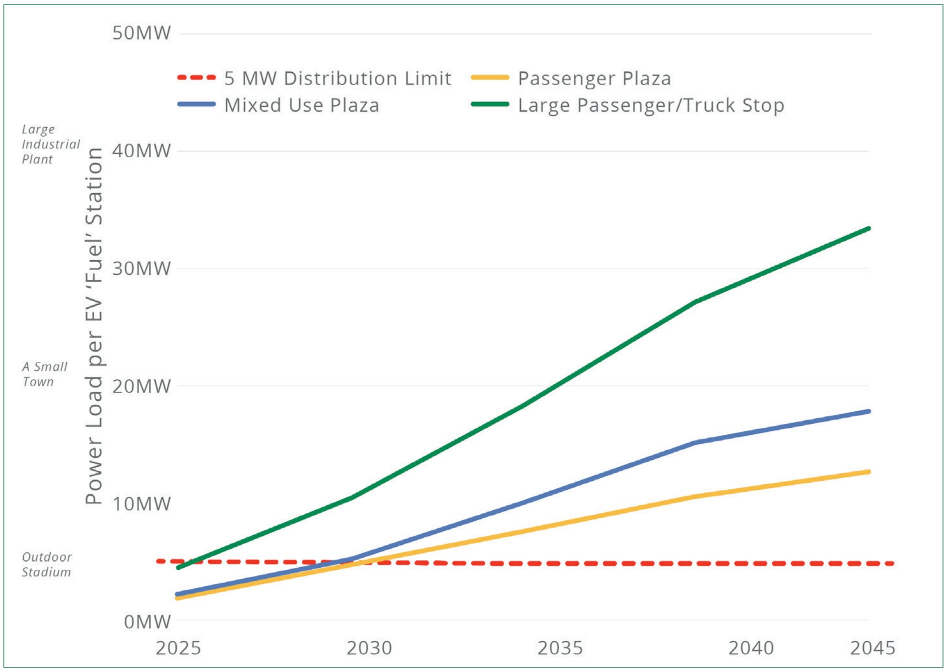
Source: Bolson et al, "Capacity factors for electrical power generation from renewable and nonrenewable sources," PNAS, December 20, 2022.

While there are numerous other features impacting future costs that are either different than past assumptions, or often ignored, we note one additional feature that is poorly analyzed and comes with significant capital costs, this relating to infrastructure for on-road EV charging. Since it is the case, as noted for goal #1 above, that electrification of vehicles is technically feasible (unlike many industrial processes), the central issues for such policies often distill the costs of the necessary infrastructure. And regardless of legislative legerdemain for attaching those costs to different entities, it is indisputable that the consumer ultimately pays. The plans to install on-road and on-highway fast-chargers for EVs and electric trucks will require upgrading local and sub-transmission level distribution, especially the associated grid-scale transformers.

Even if one assumes significant at-home charging (which also requires local distribution upgrades), there remains the need for on-road refueling both for those without garages, or the equivalent, and for road trip refueling. The magnitude of the requirements for the upgrades for multiple fast-chargers per fueling station, because on-road superchargers are each 150kW to 400kW vs at-home overnight 3 to 5 kW, means that each fuel station's grid power requirements will be equal to the grid power infrastructure needed for a stadium or a small town. (**FIgure 22**)

The NJ Turnpike alone would require grid upgrades totaling 23 stadiums even if there were only a couple of dozen fueling points at each station (numerically the same as the number of gasoline nozzles, but operationally inferior since the "fast" recharge time is 20 to 40 minutes versus 5 minutes for gasoline). There are some 2,500 fuel stations in NJ. Even if one assumed half as many would be needed in a future with increased at-home charging/fueling, most of the other 1,000 will require stadium-class grid infrastructure if a majority of vehicles being serviced are battery-powered. The aggregate costs for such run into the tens of billions of dollars.

FIGURE 22: GRID-SCALE POWER REQUIREMENTS FOR ON-ROAD EV CHARGING



Source: National Grid et al., "Electric Highways: Accelerating and Optimizing Fast-Charging Deployment for Carbon-Free Transportation," November 2022.

And without regard to on-road charging, and the associated sub-transmission level grid upgrades, at-home charging of EVs will require substantial costs for local distribution system upgrade.[48] Most estimates put that at between $1,700 and $5,800 in distribution system upgrade per EV. (The upgrade challenge will be amplified by contemporaneous electrification of space/water heat.) PSEG has 22,000 miles of distribution circuits and an estimated statewide system totaling 50,000 – 75,000 miles. If it is all upgraded to handle a doubling in electricity demand, using EEI estimates of an average of $200,000/mile for overhead and $560,000/mile for underground, the total cost for New Jersey comes in at $40 billion.[49]

6. Community Energy Planning and Action in Underserved Communities

Key perspective: Policymakers should keep in mind a basic tenet for underserved citizens and communities, i.e., high energy costs are destructive.

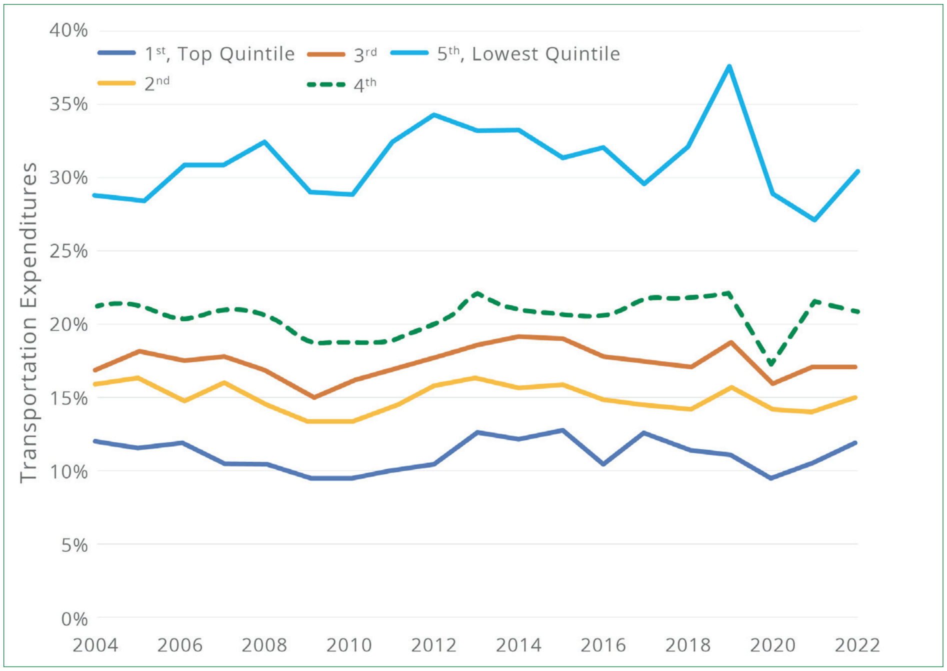
Energy policies, regardless of motivations, can have the unintended—or intended, see for example carbon taxes, etc.—effect of increasing energy costs, not least associated with many of the issues noted above. It is well-established that there is a direct correlation between economic growth and greater energy consumption. And similarly well-established, there is an inverse correlation that is unchanged over time across different countries and societies, i.e., higher energy costs constrain consumption. These iron-clad economic features of society are specifically visible with regard to the share of low-income household incomes consumed by home energy costs and by the costs of transportation.

[48] Anshuman Sahoo, et al., "The Costs of Revving Up the Grid for Electric Vehicles," Boston Consulting Group, December 20, 2019.

[49] Warwick, "Electricity Distribution System Baseline Report for DOE Quadrennial Energy Review," 2016.

A household is considered "energy impoverished" when the cost of home energy purchases exceeds 10 percent of income.[50] Nationally, roughly one in seven families nationally live in "energy poverty," and in New Jersey the share is roughly 12 percent.[51] Policies that lead to higher energy costs, self-evidently, will push more low-income households into energy poverty. The same features attend to transportation costs, wherein low-income families are again the most impacted by policies that lead to higher costs to purchase and to fuel vehicles. Nationally, after the cost of the mortgage or rent, transportation constitutes the second largest household expenditure.[52] For the lowest income quintile transportation consumes 36 percent of income. (**FIgure 23**) There is no evidence to support the expectation that EV will soon be available at prices close to competitive with low-cost new cars, much less low-cost used cars that are primary choices for low-income households. Similarly, there is no evidence that on-road operating costs are lower for EVs.

FIGURE 23: SHARE OF INCOME DEVOTED TO TRANSPORTATION



Source: Bureau of Transportation Statistics, "The Household Cost of Transportation: Is it Affordable?" September 19, 2023.

While it is conceptually obvious that high-cost energy can cause broad negative impacts—so-called "energy poverty" is now rampant in many European nations—it is interesting to note a study undertaken last year by the *Economist* examining the health impacts of high-cost energy. Policies implemented—both tax and "climate" polices—over the past two decades have led directly to higher energy costs in Europe. Then the war in Ukraine not only exposed geopolitical vulnerabilities of energy policies, but also led to European energy price spikes. The study by the *Economist* concluded: "Expensive energy may have killed more Europeans than Covid-19 last winter." (**FIgure 24**)

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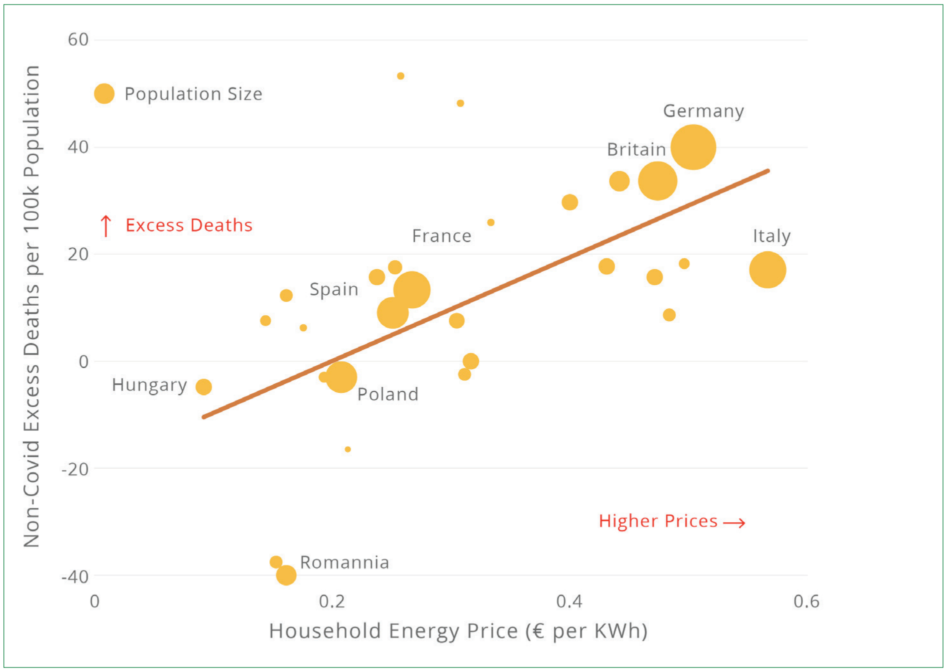
50 Brown et al, "High energy burden and low-income energy affordability: conclusions from a literature review," Prog. Energy 2, April 2003, 29 October 2020.

51 Rubin et al, "1 in 7 Families Live in Energy Poverty. States Can Ease That Burden," RMI, December 18, 2023,

52 Bureau of Transportation Statistics, "The Household Cost of Transportation: Is it Affordable?" Tuesday, September 19, 2023

FIGURE 24: EXCESS DEATHS CORRELATE WITH HIGH-COST ENERGY



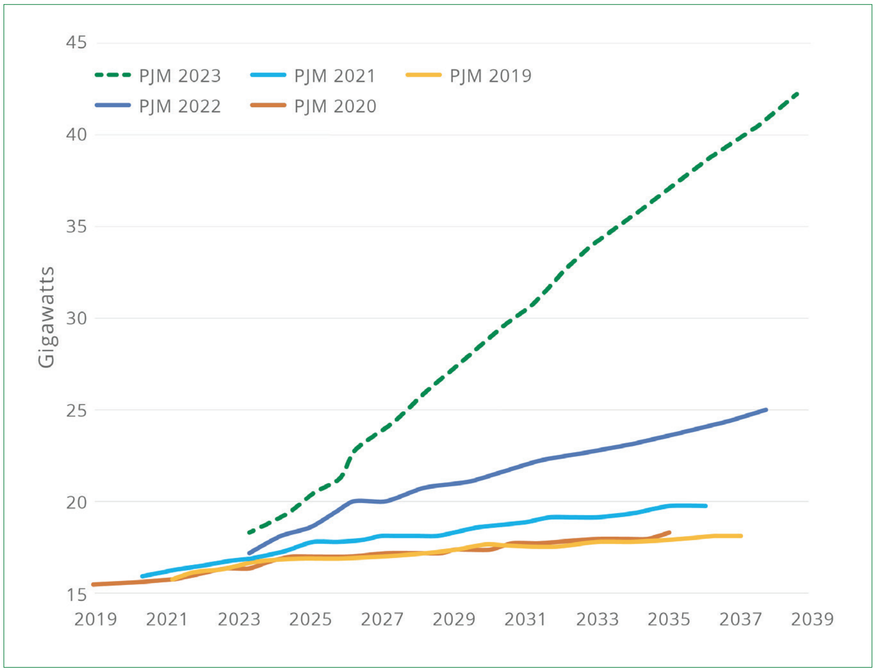
Source: Economist, "*Expensive energy may have killed more Europeans than covid-19 last winter*," May 13, 2023.

7. Expand the Clean Energy Innovation Economy

Key perspective: Many proposed "clean energy" innovation policies are antithetical to other innovation policies and objectives.

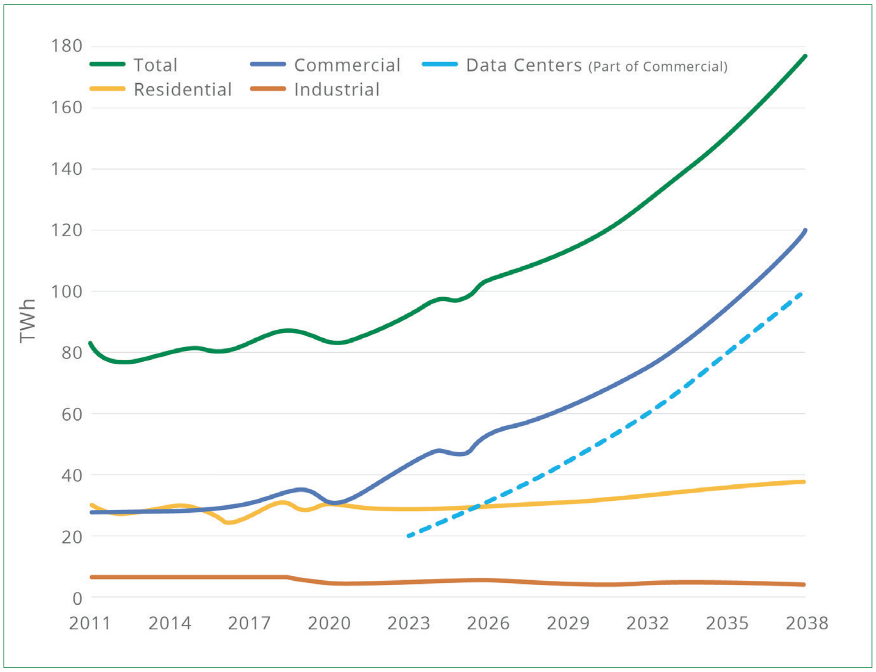
Since policy is forward-looking, we note some recent predictive changes in the state-of-play for innovation and the energy future, and specifically electric demand. The PJM Interconnection—the regional transmission organization that moves wholesale electricity in the mid-Atlantic—within which New Jersey is one of the 13 member states, recently and radically increased forecasts for growth in near-term electric demand. More than twice as much new generating capacity will be needed by 2035 as compared to the forecast expectations over the past half dozen years. (**FIgure 25**) Unbundling the sectoral forecasts, one sees that the information economy, specifically datacenters, are the primary driver of that future rise in power demand. (**FIgure 26**) The issue for policymakers will be whether those facilities are built within the states of the PJM or whether, if the owners/operators of such facilities determine power there will be insufficient or too expensive, those facilities are built in other states, or even other countries.

FIGURE 25: PJM FORECAST FOR *ADDITIONAL* ELECTRIC CAPACITY REQUIREMENTS



Source: Michael Cembalest, “Electravision,” JPMorgan, 2024.

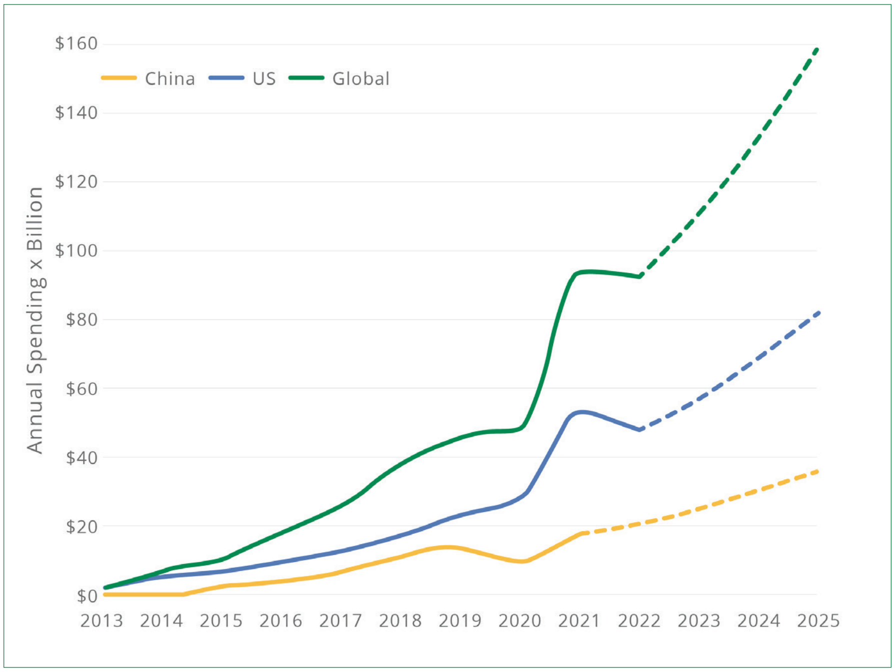
FIGURE 26: PJM: SECTORAL ELECTRIC DEMAND FORECASTS



Source: Michael Cembalest, “Electravision,” JPMorgan, 2024.

The expectation of rising demand arising from expanding the information infrastructure, the cloud, has been amplified by the collateral recognition that the maturation and commercialization of artificial intelligence portents an acceleration in datacenter, and societal, electricity use.[53] For context, every $1 billion of datacenters built leads to some $300 million a year in electricity purchases, a figure that can rise to roughly $800 million annually when artificial intelligence engines are used in those buildings. By comparison, every $1 billion of cars purchased leads to the need for about $100 million in energy purchases each year. Total U.S. spending on AI alone is now roughly $60 billion a year and rising rapidly, much of which is directed at datacenters. (**FIgure 27**) The extent to which New Jersey participates in the infrastructures of AI "innovation" will be significantly impacted by both the available and cost of electricity.

FIGURE 27: SPENDING ON AI



Source: WSJ: Goldman & Stanford Institute for Human-Centered AI, Azure, AWS, NVIDA, Google Cloud

And, contemporaneous with the above, to the extent that NJ policymakers are interested in joining vigorous efforts across the nation for re-shoring manufacturing to capture the attendant economic benefits, such goals will necessarily require increased supply of energy. Industrial activities are inherently more energy-intensive, and more reactive to both prices and plans that signal high prices—or low reliability/availability. Historically, overall U.S. utility sector investment has tracked over manufacturing construction investment The necessary correlation ended and diverged dramatically starting in 2020. (**FIgure 28**) It is notable that if New Jersey's industrial sector had not shrunk, but were the same size as two decades ago, the state's overall energy and electricity consumption would be 10 percent and 20 percent higher today (respectively).

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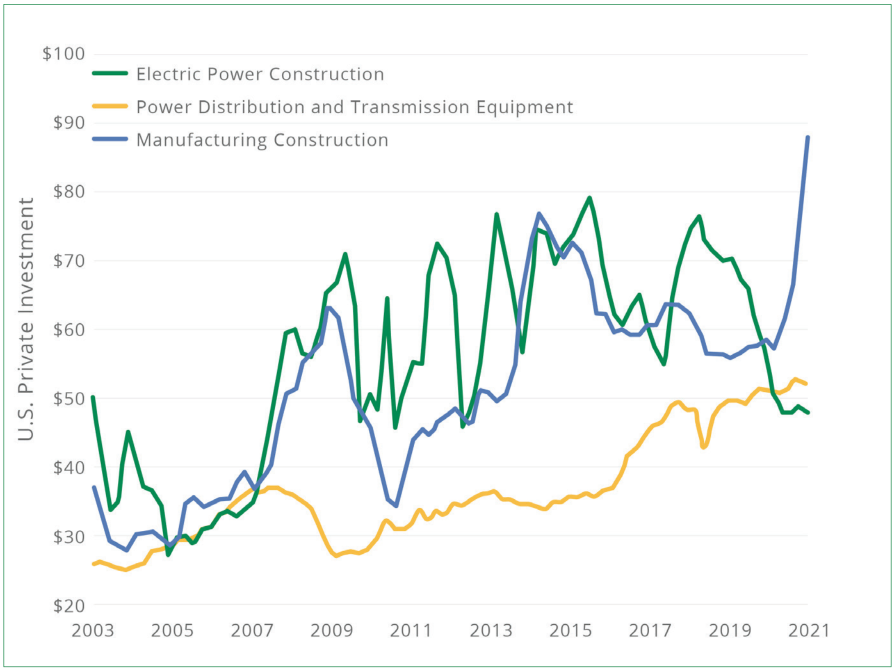
[53] Mills, "AI's Energy Appetite: Voracious & Efficient," *Dakota Digital Review*, Nov 9, 2023

FIGURE 28: U.S. SPENDING ON MANUFACTURING VS ELECTRIC POWER INFRASTRUCTURE



Source: Taplin, "Elon Musk Says We Need Way More Electricity. Is He Right?" Wall Street Journal, August 8, 2023.

Finally, there are some realities regarding efforts to stimulate local "innovation" that have implications for New Jersey insofar as state goals that seek to expand aspects of the "clean energy innovation economy" relating to stimulating advancements or inventions of relevant "clean" technologies—as opposed to merely requiring the purchase of such technologies which, it bears noting, are dominantly produced in China. One can view technology innovation in terms of three categories: improving the efficacy or cost of an existing technology, advancing to commercial viability a new technology invented elsewhere, and inventing/discovering a new technology. While states can implement policies that are relevant to all three features of foundational innovations, such policies are generally unrelated to energy domains per se, and generally entail fundamental uncertainties about if and when desired results are achieved—foundational innovation, Bill Gates has said, has "no predictor function."

There is a different context, however, if expanding a "clean energy innovation economy" is referring to assembling components produced elsewhere (which is the case for 50 to 80 percent of the components needed to fabricate, say, electric vehicles, wind turbines or solar panels), or installing "clean energy" hardware locally, regardless of where the hardware was produced. It is true that both those aspects of "clean energy" technology entail more labor per unit of energy produced for society than does the hardware and installations associated with hydrocarbons. This is a fundamental problem because it is the inverse of productivity. The general, beneficial direction of modern society has been in the steady and, over time, dramatic reduction in labor-hours needed to deliver a unit of energy to society. Policies that seek to reverse that are, by definition, inflationary.

Set aside the fact that New Jersey does not have an employment problem per se, where the state's unemployment rate is only slightly higher than the U.S. level—although in recent months NJ trends have started to diverge towards higher unemployment. But in general, the challenge for New Jersey and the U.S. in general is a shortage of workers in the skilled trades.[54] The construction trades alone, nationally, face a shortfall of a half-million workers.[55] Stimulating by subsidies or mandates a greater demand for such employment—assembling or installing energy hardware of any kind—will not resolve the labor shortages, and instead will be inflationary as well.

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[54] Cates, Ferguson, "Understanding America's Labor Shortage: The Most Impacted States," U.S. Chamber of Commerce, Feb 13, 2024.

[55] ABC, "Construction Workforce Shortage Tops Half a Million in 2023, Says ABC," February 2023.

Other Implications for New Jersey Consumers and Businesses

We note below a handful of other points for consideration in New Jersey's energy planning.

Heat pumps

Using residential heat pumps, instead of gas or oil furnaces, is a favored "decarbonization" strategy. We note that a heat pump study prepared by Diversified Energy Specialists examined the actual, rather than posited, conversion costs for over 600 homes in Massachusetts over the five-year period 2014-2019.[56] That study, relevant both because it is recent and entails comparable geography and demography, found the average cost to convert a home was nearly $23,000 for an average-sized home (1,750 square feet). That is nearly triple the assumed cost in studies often cited promoting such a strategy.[57] In addition, because heat pumps generally work poorly in very cold weather, the study found some 90 percent of the homes evaluated retained a supplementary heat source; wood stoves, electric resistance heaters, or the natural gas furnaces.

It would cost nearly $40 billion for New Jersey citizens – whether directly, or via state subsidies necessarily collected via taxes -- to retrofit 85 percent of the state's 1.9 million single-family homes, based on the above real-world experience. And it would likely cost another $10 to $20 billion to retrofit the 1.3 million multi-family units in New Jersey.[58] In the economic terms this is in the inverse of productivity, since that spending leads to change in the quantity or nature of the service delivered (other than, for many, a degradation in 'quality'). Inverting productivity is always inflationary.

Wind/solar "droughts"

Those promoting the use of wind/solar to replace conventional generation propose grid-scale battery storage as the key enabler to convert episodic power generation into dispatchable power. It is frequently proposed that such batteries, as costs continue to drop, will enable the ultimate complete replacement of conventional combustion-based generation. Such a goal is anchored in several fallacious assumptions, not least unrealistic forecasts about battery costs, but all such proposals ignore the most fundamentally challenging feature of the scale of storage required at high penetration levels of wind/solar. The majority of grid-scale battery installations are designed to operate for four hours, a reasonable time-period if the goal is to deal with frequent short-term lulls in available wind or sun, and the (obvious) diurnal nature of both. The bigger challenge, largely ignored, are long "droughts" in available wind or sun, the inevitable occurrences of days or weeks without either wind or sunlight. Both are well-established meteorological phenomenon, but are both unpredictable as to specific times of occurrence or duration.

For calibration, four hours of storage for New Jersey's grid at today's battery costs, would require spending about $100 billion based on the forecast for lower-cost grid-scale batteries in 2025.[59] That

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[56] Diversified Energy Specialists, "Case Study: Massachusetts Air-Source Heat Pump Installations, 2014-2019," Report prepared for National Oil Heat Institute, November 19, 2019.

[57] RMI

[58] Steven Winter Associates, "Heat Pump Retrofit Strategies for Multifamily Buildings," NRDC, April 2019, p. 17: $7 to $15/sq ft retrofit, w avg apartment size of 1,000 sq ft.

[59] NREL, "Cost Projections for Utility-Scale Battery Storage: 2023 Update", June 2023.

would of course keep lights on only four hours if the entire New Jersey grid were solar/wind. Planners imagine buying 2 GW[60] of grid storage for New Jersey by 2030, which would supply just a half-day of back-up (assuming no increase in electricity demand) and cost on the order of $300 billion.[61] Of course, if at the same time New Jersey's electricity consumption rises because of electrification polices for buildings and vehicles, the costs to build storage increases in lockstep with demand increase. The alternative to grid-scale storage is to either maintain (at high and rising costs) the existing conventional grid assets (as Germany has done) or to tolerate reduced reliability (more outages) and/or more (involuntary) load control. There are obvious economic and social costs to the latter.

Eliminating natural gas contemporaneous with (possible) nuclear shutdowns

If one assumed that the state's two nuclear plants (Salem and Hope Creek) close after their relicensing periods expire and that, for example, power demand doubles because of electrification, then New Jersey's grid will need to obtain sufficient wind/solar capacity to generate 140,000 GWh each year. Supplying the necessary generating capacity from solar (the now generally preferred "green" alternative) would, because of the 20 percent capacity factor, entail about $20 billion of capital to replace the two power plants.[62] This figure does not include the cost of the additional transmission and distribution investment required, nor the above noted unavoidable need for grid-scale storage. Nor do such plans consider the challenge of providing so-called "ramping" capabilities and "reactive" power that are essential for maintaining a grid's voltage/frequency stability. There are theoretical technological solutions to the reactive power challenge, none proven at scale.

Hydrogen

Most decarbonization plans include expectations of greater availability and use of hydrogen, produced specifically from "carbon-free" sources. Virtually all hydrogen today is produced by reforming natural gas. All proposals and claims for new, non-hydrocarbon sources of hydrogen entail theoretical assumptions about both the ability to produce sufficient quantities in the first place, and more problematic assumptions about lowering costs. Hydrogen produced from natural gas (the most common and lowest-cost method) is roughly three-fold more expensive than natural gas.[63] When produced from "low-carbon" sources by electrolysis, the cost is at least 10-fold higher per btu

[60] New Jersey one of ten states with energy storage goal; Assembly Bill 3723, May 2018, required goal of 600 MW of storage by 2021 2 GW by 2030

[61] EIA AEO, "Cost and Performance Characteristics of New Generating Technologies, Annual Energy Outlook 2023,"

[62] NREL, "Utility-Scale PV" 2023; ~$1,200/kW for utility scale PV, replicate 90% CF of nuclear requires close to 4x solar capacity.

[63] Florida Solar Energy Center, "Hydrogen Basics."

than natural gas.[64]

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[64] IEA, "Global levelized average cost of hydrogen," 2020.

Conclusion: Realistic Options for Reducing Use of Conventional Fuels

If the goal is to reduce consumption of hydrocarbons in a fashion that is sustainable, reliable, and affordable, there are a number of other approaches that could be considered wherein we note as examples two significant alternatives, neither of which appear to be under consideration in NJ, nor in many other states. One would be to pursue means for ensuring near-term and rapid construction of new nuclear plants, as well as exploring means for extending the operating life of existing ones. The other would be to establish transportation incentives that encourage the purchase of more efficient internal combustion engine vehicles. Both options are feasible and economically viable with technologies that exist.

First, a point of principle. There is a central social error in policies that seek to rapidly de-carbonize energy systems: It is in making the reduction of CO_2 emissions the overwhelming priority superseding the three key metrics that have long dominated mankind's pursuit of energy: low costs, high operational and geopolitical reliability, and acceptable environmental impacts. With regard to costs, one sees in many plans and proposals either insufficient transparency about economic costs, or over-enthusiastic acceptance of theoretical claims for future costs. The same can be said about both classes of reliability issues. And insofar as the unavoidable fact that environmental impacts are an inherent feature of civilization, the challenges are similar; energy transition goals explicitly put a far higher priority on future CO2-related impacts than on the range of immediate impacts across the entire spectrum of environmental issues whether land-use or chemical uses.

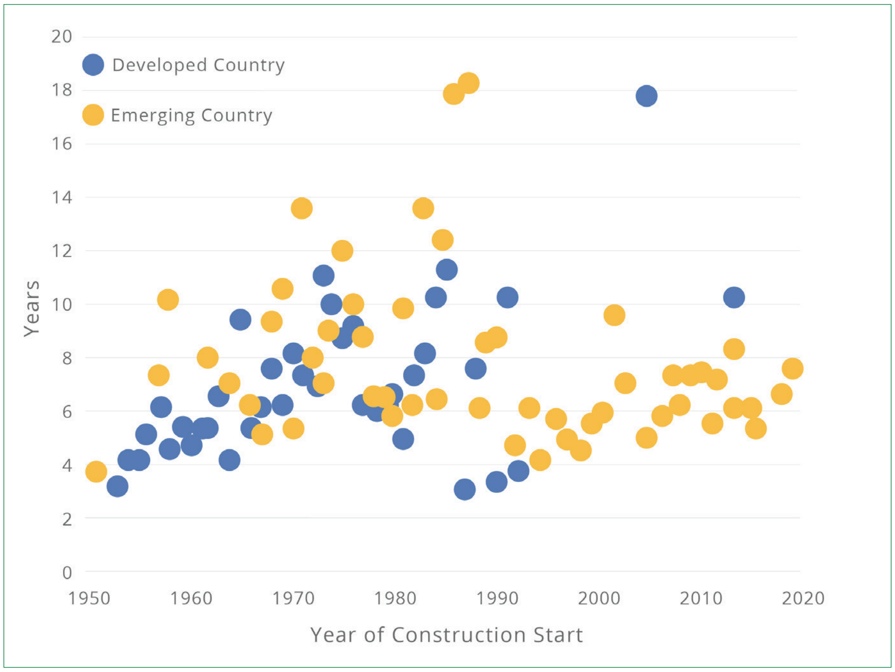
Incentivize next generation nuclear energy

With regard to nuclear energy, policymakers can consider both categories of possibilities; encourage greater use of proven technology, and incentivize the emergence of next-generation nuclear tech.

There is great potential for building far more of the class of large GW-scale nuclear reactors with well-established technology and track record. Large grids can accommodate, indeed need, big power plants. Not only is it clear that today's reactor designs can operate at 90 percent capacity factors as reliable baseload power, but it is also clear that they have operating lifespans that can easily exceed 50 years. We note that solar and wind hardware have 15-to-20-year lifespans, at best, and evidence is mounting that the lifespans may be shorter (which, arithmetically, increases lifetime costs). It is reasonable to expect that next-generation light water reactors could have one-century operational lifespans comparable to hydro dams. The lifecycle cost benefits of such capital investments should be self-evident. And as the global data show, given the correct regulatory environment, conventional nuclear power plants can be built in a half-dozen years. (**FIgure 29**)

Then there is the longer-term potential to see commercialization of next-generation nuclear power designs, so-called small modular reactors, and even microreactors, the latter suitable in scale to locally power industrial facilities, datacenters, or town microgrids. While there are dozens of designs of such small next-generation reactors, and a comparable number of ventures already launched to commercialize such technologies, none are yet proven. However, neither are there yet the appropriate programs in place collaborate on technology deployment, and on federal regulatory reform, the latter needed to accelerate permitting rules.

FIGURE 29: AVERAGE CONSTRUCTION TIMES FOR NEW NUCLEAR PLANTS



Source: Michael Cembalest, "Electravision," JPMorgan, 2024.

Incentivize improved vehicle fuel effciency

The most straightforward and cost-effective—and least disruptive path—for reducing automotive oil use would be to pursue greater use of more efficient internal combustion engines. Improvements in conventional automobile efficiency (and thus, the associated goal to reduce CO2 emissions) are possible by using inherently superior engines as well as the hybrid-electric propulsion architecture. Technical analyses of engine technology progress shows that 30–50 percent gains in fuel efficiency are on offer by 2030. (**FIgure 30**)

In fact, truly radical, nearly two-fold gains are still possible with combustion engines. Designs with 70 percent combustion efficiency, versus today's average of 35 percent, have been developed and demonstrated.[65] (**FIgure 31**) Some new engine designs have as few moving parts as an electric mo-

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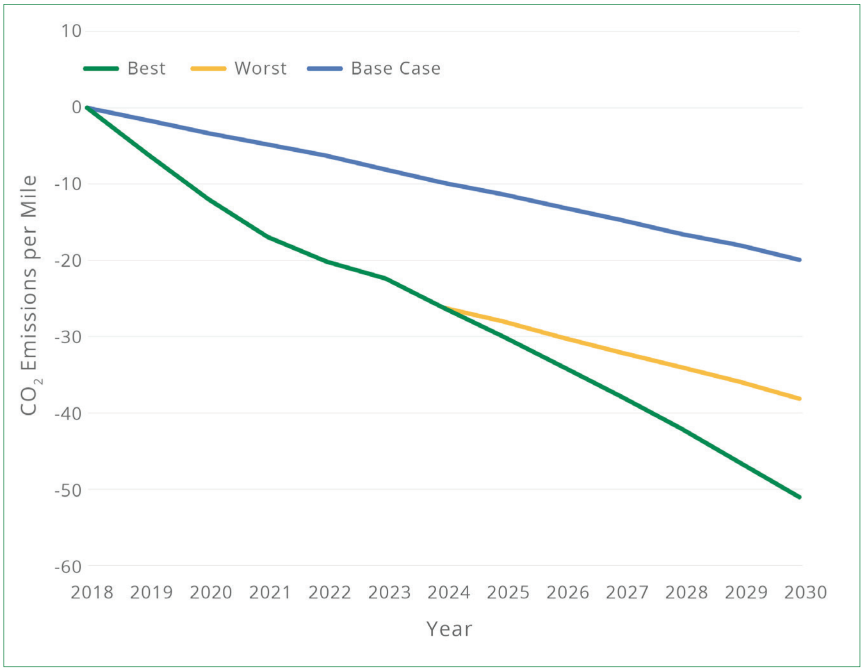
[65] TechXplore, "There's still life in the old combustion engine: Meet the Argon Power Cycle," March 2021.

tors.[66] Automakers including Mazda, Nissan, and Toyota, for example, have already developed engines that are commercially available or are ready-to-commercialize that achieve 30 percent increases in thermodynamic and thus fuel efficiency compared to the most common engines in use.[67] Mazda, for example, introduced (in Japan) a model that combines light-weighting with a high-efficiency engine to yield a 70 mpg.[68]

Similarly, a "light" hybrid (the propulsion architecture pioneered by the Toyota Prius) offers average fuel savings of about 30 percent while using a battery roughly one-tenth the size of an EV.

FIGURE 30: KNOWN POTENTIAL FOR INTERNAL COMBUSTION ENGINE CO_2 EMISSIONS PER MILE



Source: Challa et al, "Well-to-Wheel Greenhouse Gas Emissions of Electric Versus Combustion Vehicles from 2018 to 2030 in the US," Journal of Environmental Management,"April 2022.

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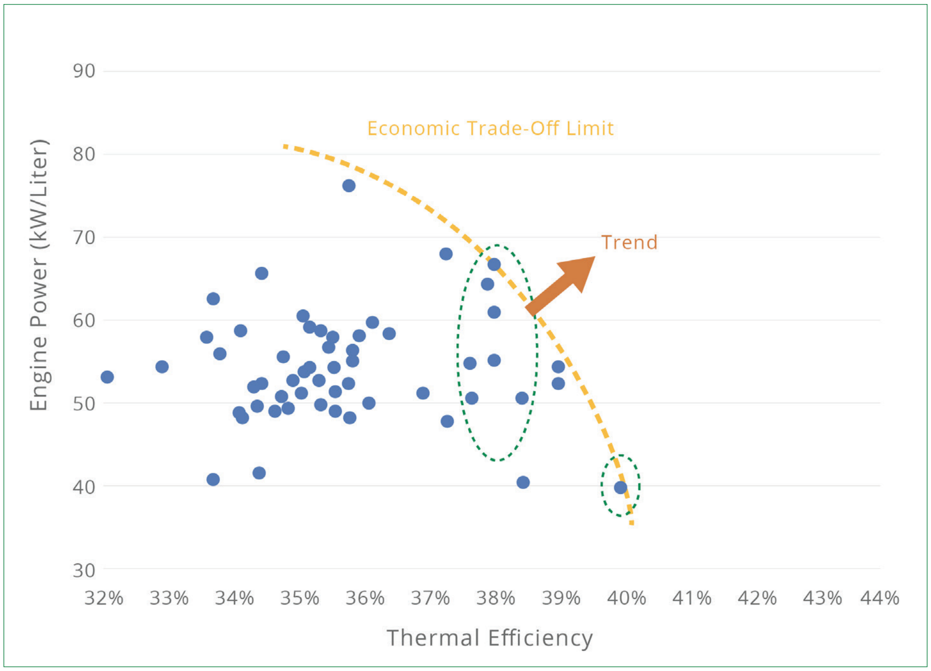
[66] PR Newswire, "Aquarius Engines Inks Five-Year R&D Contract with the U.S. Army," August 2022.

[67] Stub, "The Car Engine of Tomorrow: Cleaner, Lighter, With One Moving Part," Wall Street Journal, June 20, 2019.

[68] Bullis, "khttps://www.technologyreview.com/s/421303/70-mpg-without-a-hybrid/," MIT Technology Review, October 25, 2010.

FIGURE 31: TRENDS IN THERMODYNAMIC EFFICIENCIES AUTOMOBILE INTERNAL COMBUSTION ENGINES



Source: Green Car Congress, 2016

Returning to the central goal of the EMP, to reduce CO_2 emissions, it's instructive to compare the future emissions associated with the use of EVs in NJ, versus using a superior conventional car based on available technology. Given the realities of how different regional electric grids will be powered between now and 2030, the CO_2 emissions from driving an EV can vary widely and entail far more modest emissions savings than often assumed. As a recent study showed, based on EVs and grids that exist, and conventional cars that also exist, in some states the EV leads to greater emissions than associated with driving an efficient conventional car (assuming the latter has 30 percent greater fuel efficiency than today's average). The analysis considered a number of states, while one was not New Jersey, the case for New York is indicative. (**FIgure 32**) We note the analysis focused on the fueling of the vehicles and did not consider the additional variables in upstream supply chain emissions noted earlier in this paper.

FIGURE 32: EMISSIONS: EV VS VEHICLE W MORE EFFICIENT INTERNAL COMBUSTION ENGINE (ICE)

(New York case)

Source: Journal of Environmental Management (2022)

To the extent that policymakers feel compelled to use subsidies to reduce CO_2 emissions, those subsidies could be redirected away from wealthy EV owners (the primary buyers of EVs) to lower-income drivers. Instead of a subsidy directed at EVs, the same subsidy (in terms of dollars offered per barrel of oil reduced over a vehicle's life) could be offered towards the purchase of a more efficient conventional vehicle. That would buy far greater, and documentable, emissions reductions per dollar, and would allow consumers the choice to purchase vehicles based on the individual's use-case and income.

From a social equity and a cost efficacy perspective, greater emissions/fuel savings could be realized per dollar, if incentives/subsidies targeted the drivers that constitute "super-users" of gasoline. In the U.S., 10 percent of drivers consume roughly one-third of all gasoline.[69] (**FIgure 33**)

Super-users typically own larger vehicles and drive some three-fold more miles annually than the average driver. Rather than today's per-vehicle EV subsidy (which, again, data show favors wealthy and low-mileage drivers) subsidies could target those who use the most fuel, the latter easily determined by odometer data chose. In addition to a more equitable outcome, this would lead to far more fuel and emissions savings per dollar of incentive. Similar logic could be applied to heavy-duty on-road trucks, where there are no practical EV options (regardless of EPA mandates that imagine there are), but where diesel engine efficiency has steadily improved with substantial technological gains are already in the pipeline. Greater than 30 percent gains in freight efficiency are feasible and far more likely to be deployable than battery options (or hydrogen) for large trucks.[70]

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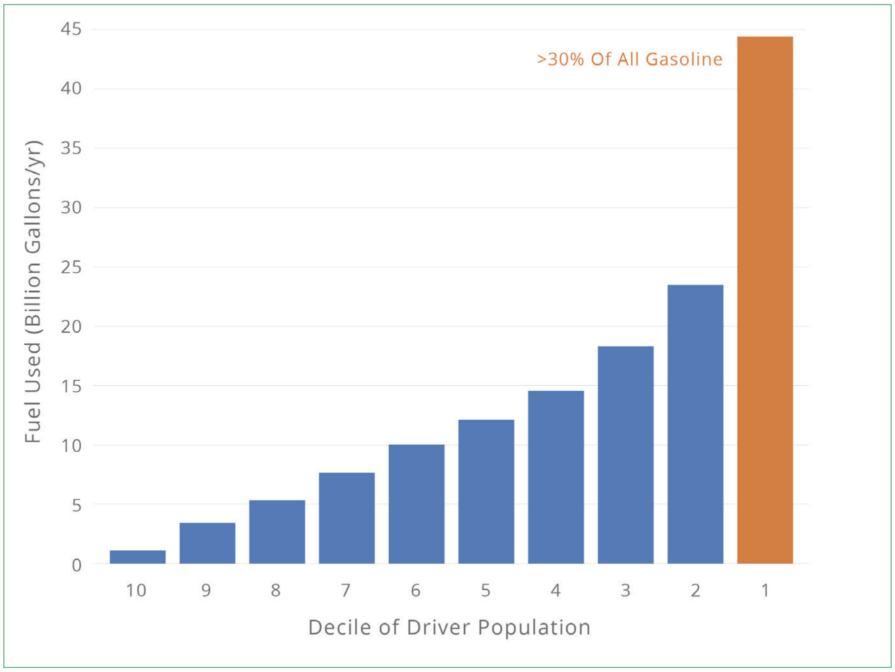
69 "Gasoline Superusers," Coltura.org, July 2021.

70 Pierce et al, "High temperature materials for heavy duty diesel engines: Historical and future trends," Progress in Materials Science," June 2019.

FIGURE 33: DISTRIBUTION OF GASOLINE CONSUMPTION



Sources: Coltura 2021 per Cembalest Eye of the Market, 2022

Conclusion

As we noted at the outset of this report, the scientific domains regarding the study of and forecasts about the planet's climate are entirely different than those associated with the technologies underlying society's energy systems. For the latter, the possibilities with existing technologies, and the associated economic or environmental consequences, are fundamentally unrelated to climate science. And as a practical matter, far more is known with far greater certainty about *energy* science and technology. Given that reality, and the scale in monetary and social terms that energy transition policies entail, it behooves policymakers to ensure full knowledge and transparency regarding the uncertainties about consequences of choices that constrain or reshape how energy is supplied to society today.

As is widely acknowledged, all energy decisions entail trade-offs in environmental and economic factors. Many alternative energy plans are overt choices to incur higher near-term costs or inconveniences in exchange for avoiding future costs or effects. The trade-offs can entail the exchange of qualitatively different risks such as greater ground water pollution from mining in, say, Africa, order to reduce carbon dioxide emissions in, say, New Jersey. The existence and magnitude of such factors are too often absent from considerations in the rush to reduce hydrocarbon use.

Furthermore, such choices are not only trade-offs in terms of the time-value of money or social equity (i.e., the well-being of citizens in the present versus those in the future), but also an explicit and incorrect symmetry attached to impacts that are *measurable* in the present versus those that are *estimated* and *forecast* for the future. While it is the case that decisions of such kinds are made regularly by governments and citizens, there is normally an attempt if not obligation to ensure maximum transparency about what's knowable and what's theoretical. The logic in energy transition policies is often analogized to that of accident or life insurance, i.e., incurring costs in the present to minimize consequences of knowable if unpredictable future outcomes. That analogy has merit but should be tempered by transparency about present costs (as is required by law for selling insurance), and realism about the uncertainties in the probabilities of future events.

While it is reasonable to make forecasts when it comes to predicting society-wide and planet-wide future events of any kind (not just the climate), it is unreasonable to believe and act on such forecasts as if they have equivalent accuracy as measuring and estimating present-day impacts. Indeed, it is notable how often over history one finds the fallibility of forecasts of all kinds, especially involving extraordinarily complex, macro systems.

Finally, the fact that energy transition strategies often contain flaws if not outright errors regarding the capabilities of many energy technologies does not obviate the reality that radically new energy technologies are not only feasible but arguably inevitable, including those that could significantly reduce or even eliminate the use of hydrocarbons in many applications. Today's battery technology is useful mainly for a relatively limited deployment of electric vehicles where costs and performance features are appealing to wealthy multi-car-owner households. That segment is not insignificant and likely represents a total addressable market of perhaps 50 million EVs in the US, half of the nation's multi-car households.[71] Today here are only about two million EVs on the roads in the U.S.[72] In an otherwise normal market, without mandates or subsidies, EVs would constitute an appealing market opportunity for auto companies since it represents the potential to replace about 15 percent of all registered light-duty vehicles.

But for EVs to universally replace conventional cars, radically better and different battery technology will be needed. It is reasonable to expect that possibility; the technical literature is replete with examples.[73] There are even possibilities for batteries based on so-called "metal-air" technologies that have over ten-fold higher energy density than today's lithium batteries and thus begin to approach the energy density of petroleum.[74] But the timelines from proof-of-principle to commercial viability at civilization-level scale are measured in decades; it took over three decades for today's lithium technology to emerge from inception to the production of the first Tesla S sedan, and that class of EV is only now reaching market-moving penetration another decade later.

Similar realities attend to the technologies associated with energy production whether, for example, next-generation photovoltaics or new approaches to hydrogen production. But when it comes to legislated or mandated use of energy technology, history does not show that radically new technologies emerge because of government mandates or taxes. To put it simplistically, the aircraft did not emerge because of taxes on or the prohibition of the use of ships; the same can be said about the car and the horse-and-buggy, and of course essentially all other foundational innovations. Instead, government mandates and diktats tend to lock-in what is now feasible, i.e., yesterday's technologies, and thus create disadvantages for new players and options.

And when new energy-using and energy-producing technologies do emerge, history shows that,

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[71] American Association of State Highway and Transportation Officials (AASHTO), "Commuting in America: The National Report on Commuting Patterns and Trends 2021."

[72] Note: data on total number of registered EVs frequently, erroneously, include or not as a footnote, PHEVs (plug-in hybrids).

[73] Itani, De Bernardinis,"Review on New-Generation Batteries Technologies: Trends and Future Directions," Energies, September 20, 2023.

[74] Jin, et al, "Self-sufficient metal–air batteries for autonomous systems," Nature Chemical Engineering, March 2024.

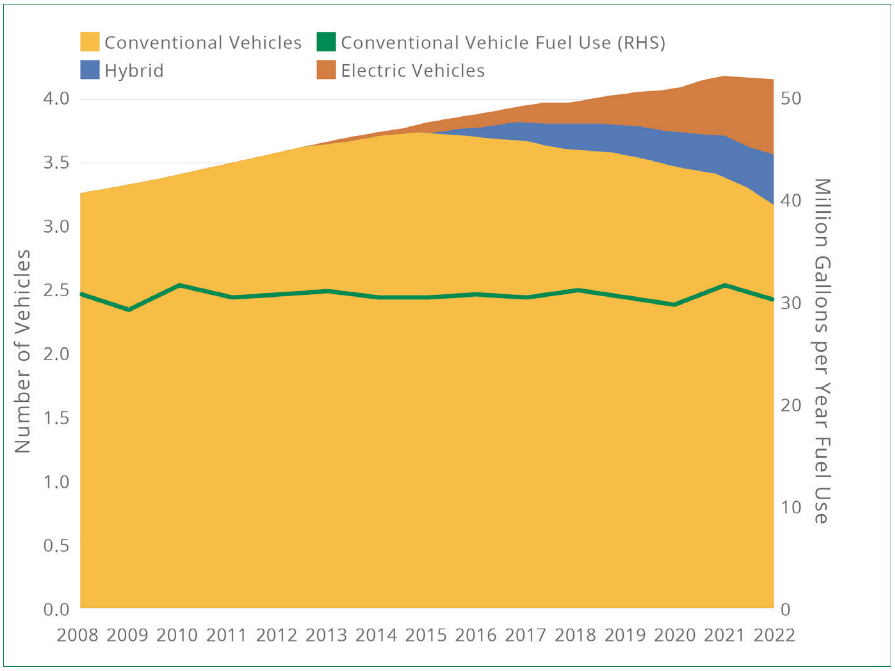
with rare exceptions, the new complements the old, rather than leading to a wholesale replacement. The car replacing the horse is the exception, not the rule. Again, analogously, in the world today there are more of both aircraft and ships, and more coal and nuclear energy, and more natural gas and photovoltaics. The odds overwhelming favor the pattern continuing.

Appendix: Unbundling Realities About EV Emissions

The experience in Norway regarding vehicle electrification provides some indication of the challenges in "decarbonizing" transportation. That nation is similar in size (five million people vs New Jersey's nine million) and, since it is significantly wealthier ($100,000 per capital GDP vs N.J. at $65,000)[75] Norway has more easily achieved a very high penetration of on-road EVs, rising from near zero two decades ago to 80 percent of new vehicle purchases last year, leading to a 20 percent of all on-road vehicles.[76] However, thus far the overall result in Norway has been to see no significant change in total roadway fuel use. (**FIgure 34**)

It appears that wealthy Norwegians use EVs in a manner similar to what studies show for how wealthy Americans use them; as a second or third car for episodic low mileage driving. This outcome has been greeted by calls to either force or "induce" the retirement of conventional vehicles to "fix" the "leakage" in behaviors, or to outright prohibit the continued licensing – or even resale/export -- of an older, conventional vehicle.[77]

FIGURE 34: THE NORWAY EXAMPLE: EV PENETRATION AND ROADWAY FUEL USE



Source: Berman, "EVs Will Have No Effect on Oil Demand," January 8, 2024.

While forced elimination of older existing conventional vehicles would of course reduce gasoline use—and it is worth noting that used cars constitute the primary choice of U.S. consumers with roughly 40

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[75] Statista

[76] Klesty, "Tesla extends lead in Norway sales, EVs take 82% market share," Reuters, January 7, 2024.

[77] European Commission, "End of Life Vehicles Regulation - details of the proposal."

million purchased each year vs 14 million new cars[78]—such an approach would have self-evident property ownership, social and economic implications. And, regardless of such possibilities, the central question remains: how much are global CO_2 emissions reduced using EVs vs combustion-engine cars?

The key fact not shown in tracking the Norwegian experience is the uncounted upstream CO_2 emissions caused by obtaining the materials to build the EVs in the first place. Those emissions can range from 20 tons to over 45 tons of CO_2 per vehicle purchased, emissions that occur before the first mile is driven, but occur elsewhere. Norwegian buyers are of course responsible for those, uncounted, emissions. And if the actual fabrication emissions per vehicle are closer to the upper range, then even on Norway's hydro-powered grids, those drivers will not reduce global CO_2 emissions.

The poor state of knowledge regarding an accurate assessment of those lifecycle, and upstream CO_2 emissions in EV supply chains has been ably summarized by researchers at the U.S. Argonne National Labs noting that the relevant data "remain meager to nonexistent, forcing researchers to resort to engineering calculations or approximations."[79] And, per the IEA, data on the emissions intensity of specific minerals can "vary considerably across companies and regions."[80] Thus, as a practical matter, estimates about upstream emissions necessarily entail myriad unknowns about obtaining and processing materials to fabricate the battery. Those factors not only vary wildly but can be significant enough to lead to an EVs overall global CO_2 emissions the same as, even greater than, emissions from using a conventional gasoline vehicle.[81]

These features of EV emissions constitute a complete inversion of the locus and, critically, the transparency and certainty compared with combustion vehicles. For a conventional car, the emissions come from the quantity of gasoline burned which is directly measurable and forecastable with precision. The critical factor for estimating upstream EV emissions starts with knowing the energy used to access and fabricate battery materials, all of which are more energy-intensive (and more expensive) than the iron and steel that make up 85 percent of the weight of a conventional vehicle.[82] The energy used to produce a pound of copper, nickel, and aluminum, for example, is two to three times greater than steel.[83]

We note that some manufacturers have published lifecycle CO2 estimates, including for example

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[78] Statista

[79] Qiang Dai et al., "Life Cycle Analysis of Lithium-Ion Batteries for Automotive Applications," *Batteries* 5, no. 2 (2019).

[80] IEA, "The Role of Critical Minerals in Clean Energy Transitions," May 2021.

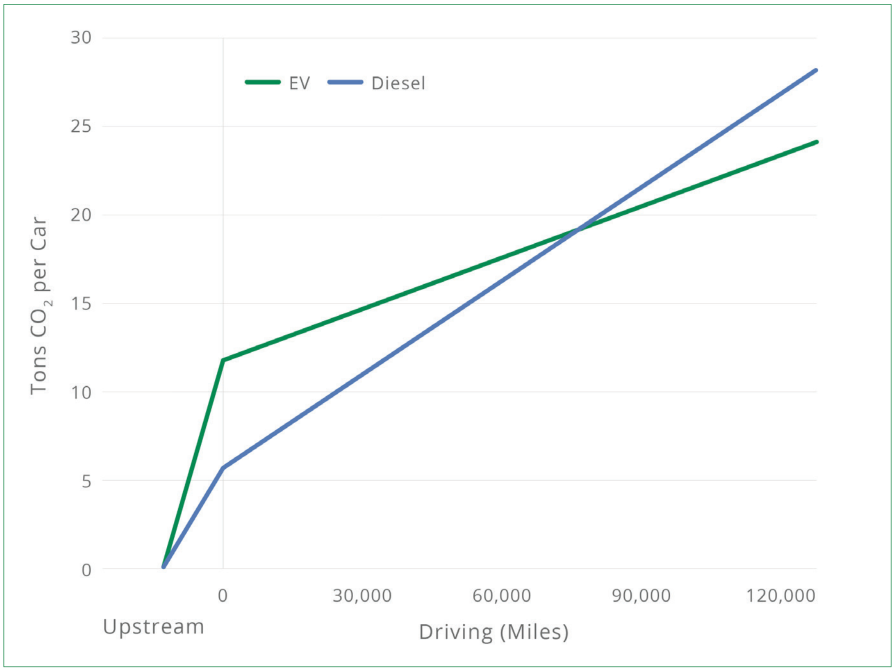
[81] Mark P. Mills, Electric Vehicles for Everyone? The Impossible Dream, *Manhattan Institute Policy Paper*, July 2023.

[82] Mekonnen Asmare Fentahun and Mahmut Ahsen Savas, "Materials Used in Automotive Manufacture and Material Selection Using Ashby Charts," *International Journal of Materials Engineering* 8, no 3 (2018): 40–54.

[83] IEA, "The Role of Critical Minerals in Clean Energy Transitions."

Volvo, in addition to an EU-funded analysis of Volkswagen's e-Golf, the latter a discontinued vehicle, but for the record, a small sedan using a small battery.[84] The analysis found that an e-Golf's upstream emissions, combined with *average* EU grid emissions yield cumulative CO_2 emissions *greater* than the diesel version of that car for the first 60,000 miles of driving. After 120,000 miles, the accumulated emissions for the EV are estimated to be about 20 percent lower than the ICE version. (**FIgure 35**).[85]

FIGURE 35: LIFECYCLE EMISSIONS: VOLKSWAGEN EV VS DIESEL



Source: "From the Well to the Wheel," Volkswagen Group, Apr. 24, 2019

A similar analysis by Volvo compared that company's gasoline-driven XC40 SUV with its electric Recharge SUV which has a mid-sized 69 kWh battery.[86] The upstream emissions associated with fabricating the vehicle, especially the battery, are roughly double that of the VW e-Golf, because of the bigger battery. Similar to the VW analysis, Volvo found that its EV had greater total emissions than the comparison gasoline vehicle for the first 45,000 miles of driving (again assuming *average* emissions from electricity supplied on the EU grid). After 120,000 miles, Volvo estimates that its EV has a cumulative emissions reduction of less than 30% (**FIgure 36**).

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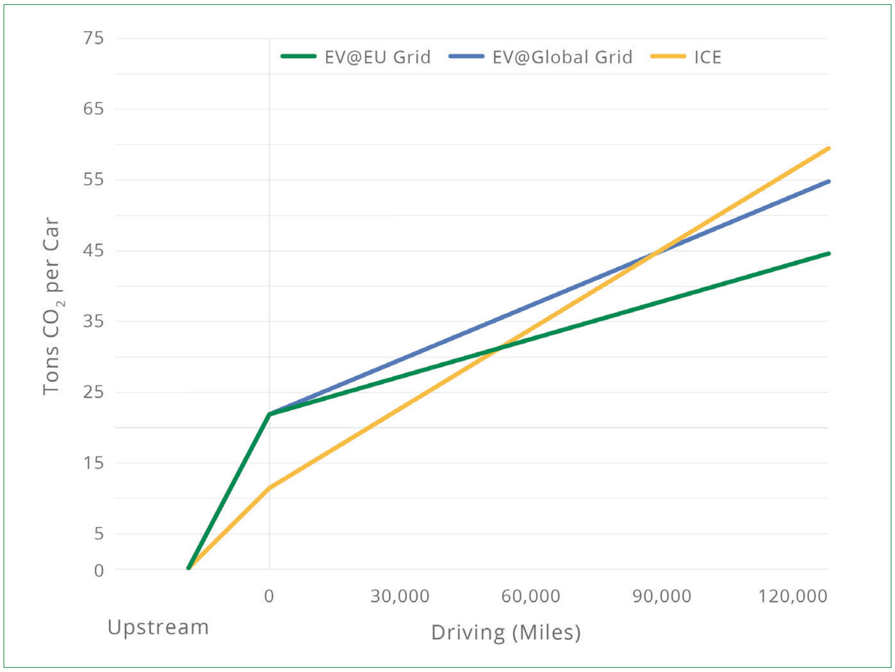
[84] VW published its own analysis, "From the Well to the Wheel," Volkswagen Group, Apr. 24, 2019, with similar outcomes. VW discontinued the e-Golf in late 2020 and removed that analysis from its web site in early 2023; the press release, as of this writing, was still at the VW newsroom, here. VW now markets its ID.4 EV which has far larger battery options, 62 kWh or 82 kWh.

[85] Volkswagen Group, "From the Well to the Wheel,"Apr. 24, 2019.

[86] Evrard et al., "Carbon Footprint Report: Volvo C40 Recharge," VolvoCars.com: analysis based on a 69 kWh battery EV and 24 mpg XC40 conventional SUV.

FIGURE 36: VOLVO SUV LIFECYCLE EMISSIONS: EV VS GASOLINE



Source: Evrard et al., "Carbon Footprint Report: Volvo C40 Recharge," VolvoCars.com

The estimated lifecycle emissions savings can shrink of course if one assumes an EV using the larger batteries used in the majority of popular EVs; 80 to 90 kWh.[87] The "choice of methodology," as Volvo's study noted, "has a significant impact on the total carbon footprint."[88] Volvo, for example, assumed a "global average electricity mix" for emissions arising from producing and refining battery materials.[89] That may sound reasonable but it doesn't reflect the actual emissions where most of those materials are processed which, given supply chain realities, are often on coal-dominated grids. China refines 50–90 percent of the world's energy minerals used for EVs.[90] The CO_2 emissions associated with refineries in China are 1.5x greater than those in the EU or US.[91]

We note that a technical review of 50 different analyses reveals that the bottom lines for embodied EV emissions vary by a factor of five.[92] With such a wide range, it is meaningless to use an average number. As a practical matter, actual lifecycle emissions for EVs will be dominated by assumptions made for three key variables: the size of the battery (which can vary by a factor of two or more), the location of the mines (leading to two- to three-fold variations in energy use per pound mined)[93], and the location of the relevant refineries (also two-fold or greater emissions variabilities).

EV proponents commonly invoke recycling as the solution to these enormous upstream materials and emissions issues, especially in pursuit of a so-called "circular economy," i.e., 100 percent

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[87] Dan Mihalasc, "EVs Made Up 5.6 Percent of US Car Market in 2022 Driven by Tesla," InsideEVs, Feb. 20, 2023.

[88] Ibid., p. 6.

[89] Ibid., p. 27

[90] Localizing Clean Energy Value Chains Will Come at a Cost," BloombergNEF, Nov. 7, 2022.

[91] Kelly, et al, "Globally Regional Life Cycle Analysis of Automotive Lithium-Ion Nickel Manganese Cobalt Batteries," *Mitigation and Adaptation Strategies for Global Change* 25 (March 2020): 371–96.

[92] Aichberger and Jungmeier, "Environmental Life Cycle Impacts of Automotive Batteries." Also: Maciej Neugebauer et al, "Cumulative Emissions of CO2 for Electric and Combustion Cars: A Case Study on Specific Models," *Energies*, April 6, 2022.

[93] IEA, "The Role of Critical Minerals in Clean Energy Transitions."

recycling. As a practical matter, recycling will be largely irrelevant for a long time as a means for mitigating upstream "energy minerals" demands. Since manufacturers claim EV batteries will last a decade, that means there won't be anything significant available to begin recycling until the early 2030s.[94] The IEA analyses of the potential for recycling minerals found that it would, at best, meet two percent of demand for battery minerals by 2030, and thus is irrelevant in the emissions calculus.[95] As for the following decades, even if unrealistic claims of near-perfect recycling were feasible, there would still be the need for an unprecedented rise in overall minerals supplied.[96]

Finally, for planners seeking to reduce future CO_2 emissions, one of the key overlooked factors in accounting for future upstream emissions is the known fact that as minerals demand rises (to build EVs and collaterally, other batteries, wind, solar, etc.) the next marginal tons of minerals are associated with *increasing* energy use per pound of acquired and refined.[97] Put in geologists terms; the average ore grade for minerals has been declining for centuries and will continue to decline. Average nickel ore grade is under 2 percent and for copper below 1 percent which means, arithmetically, at least one ton of rock (excluding the overburden) must be dug up, ground up, and processed to obtain, respectively, 40 pounds and 20 pounds of metal.[98] Such geological realities determine the amount of energy used by the machines used to do the digging, moving, grinding, refining, etc. Thus, estimating future EV energy emissions requires including the trajectory for ore grades. There is no evidence that any study is doing so.

The IEA has pointed this out in its own analyses: "Future [minerals] production is likely to gravitate towards more energy-intensive pathways."[99] The word "likely" is an understatement given the geological trends and data. Copper is typical and is one metal for which there are no substitutes for building EVs, or wind and solar hardware. As a National Renewable Energy Laboratory paper pointed out, "a decrease in copper ore grade between 0.2% and 0.4%, will require seven times more energy than present-day operations."[100] That rapid increase in energy use per next marginal ton of copper necessarily translates into far greater future CO_2 emissions, a factor that is *not* modelled in transportation forecasts.

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[94] Ferris, "Why Recycling Is No Golden Ticket to Endless Critical Minerals," Energy Monitor, Mar. 24, 2023.

[95] IEA, "Global Supply Chains of EV Batteries," July 2022, p. 60.

[96] Moana Simas, Fabian Aponte, and Kirsten Wiebe, "The Future is Circular: Circular Economy and Critical Minerals for the Green Transition," SINTEF (for World Wildlife Fund (WWF)), Nov. 15, 2022.

[97] For conventional cars, the current and future upstream emissions from oil production and gasoline refineries have very little variability and a high degree of transparency. That's because that industry is well-established, happens in places and with processes that are well-understood and tracked, and most of the supply for domestic cars takes place in the U.S.

[98] IEA, "The Role of Critical Minerals in Clean Energy Transitions."

[99] IEA, "The Role of Critical Minerals in Clean Energy Transitions."

[100] Tsisilile Igogo et al., Integrating Clean Energy in Mining Operations: Opportunities, Challenges, and Enabling Approaches, NREL (National Renewable Energy Laboratory), July 2020.