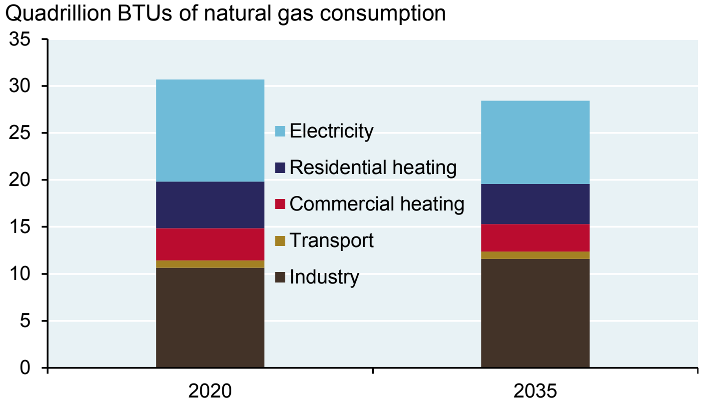
How much natural gas will the US need in 2035? In our base case, an amount not much different than today

There are a wide range of assumptions required to estimate this. Here are ours:

- Wind and solar capacity growth of 52 GW per year from 2020 to 2035, double the recent average and in the 90th percentile of all electricity capacity additions from 1960 to 2020 (Appendix A)
- At a national level, realized wind capacity factors of 35% and solar capacity factors of 25%. Capacity factors are sometimes higher in areas of peak windiness and solar irradiance, but the scope of wind and solar expansion implied in the base case requires a broader and less optimal footprint (Appendix B)
- Coal fired power plants are shut down and coal use by the industrial sector for process heat is eliminated. Furthermore, 50% of all operating nuclear power plants are decommissioned. Hydropower generation is assumed to grow by 5% (Appendix C)
- Electrification of passenger vehicles, light trucks and heavy duty trucks reaches 30%, 25% and 7.5% respectively; assumptions regarding miles driven, vehicle growth and kWh per mile are drawn from Dep't of Transportation and industry data (Appendix D). Despite short payback periods for compressed natural gas trucks and buses, we assume no growth in the very small share of natural gas used for transportation
- Consistent with patterns of the last 20 years, we assume no change in trend primary energy use or electricity demand other than from fuel switching as efficiency gains offset population growth (Appendix E)
- One third of all residential buildings using baseboard resistance heating transition to heat pumps. Furthermore, 20% of all commercial and residential buildings using fossil fuels for heating transition to heat pumps when environmentally beneficial to do so (Appendix F)
- No additional electrification of industrial energy use; electricity has been 10%-15% of industrial energy use since 1980, and there are few signs of a shift (Appendix G)

The results. According to these assumptions, the US would consume an amount of natural gas in 2035 that is not that different from the amount the US consumes today. Onshore natural gas production has contributed substantially to US energy indepdendence, and is now primarily sourced from shale and tight formations rather than conventional onshore and offshore production (Appendix H).

US natural gas consumption: 2020 vs 2035
Quadrillion BTUs of natural gas consumption



Source: JPMAM. 2020. See appendices for detailed sources & assumptions.

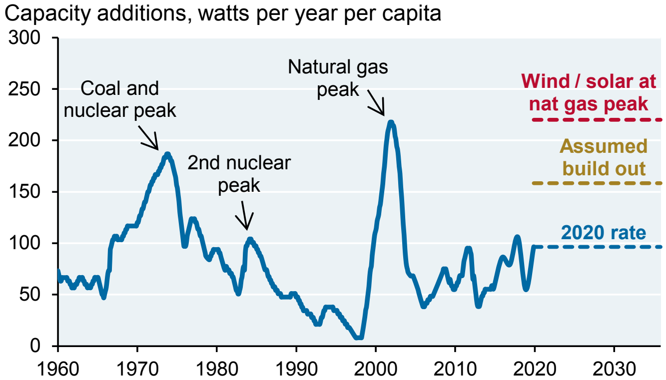
Michael Cembalest
Chairman of Market and Investment Strategy
JP Morgan Asset Management

Appendix A: Wind and solar capacity growth assumptions

The first chart shows historical growth in US electricity generation capacity from all sources. Our base case assumes 52 GW per year or 158 watts per year per capita in new solar and wind power. This rate is roughly double the recent pace and ranks in the 90th percentile of all capacity additions from 1960 to 2020. The post-war peak in capacity additions occurred for only a brief moment during the natural gas boom in the early 2000's.

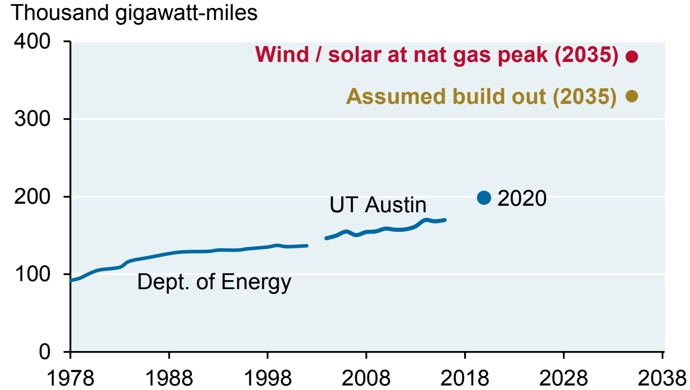
This additional wind and solar power would require a large increase in transmission grid growth compared to its history (second chart). This is a very high hurdle made more difficult by the fact that Congress has not provided the electricity transmission industry with the same eminent domain protections once provided to natural gas pipelines (1930s), interstate highway development (1950s) and broadband (1990s). Decisions by Maine and New Hampshire to block high voltage transmission lines needed to bring low-carbon hydropower from Quebec to Massachusetts, and the termination of wind-related HVDC transmission projects in the Southeast, **cast substantial doubt on more aggressive wind and solar penetration forecasts and may render our forecast too aggressive as well**. Transmission miles required per gigawatt of additional wind and solar capacity are derived from Princeton's Net Zero analysis, published in 2020[1].

Historical rates of installed electric-generating capacity
Capacity additions, watts per year per capita



Source: American Public Power Association, EIA, China Electricity Council, Fraunhofer ISE, BP, LBNL, Clack et al. (pre-2014 data), JPMAM. 2020.

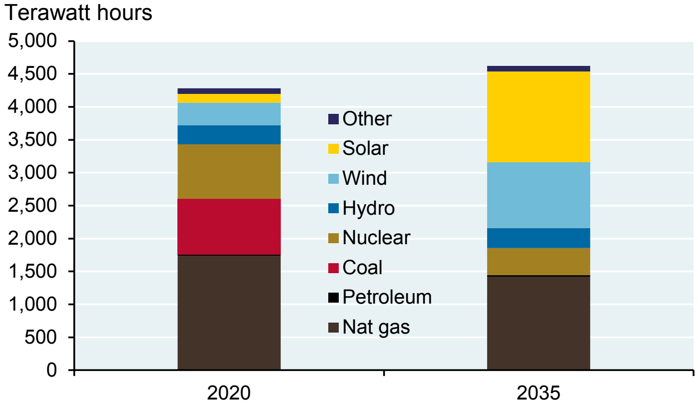
US transmission infrastructure
Thousand gigawatt-miles



Source: DOE, UT Austin, BP, EIA, Princeton Net Zero, LBNL, JPMAM. 2020.

Based on our assumptions, electricity generation grows by 10% from 2020 to 2035, and is 58% comprised of wind, solar and hydropower by 2035.

US electricity generation mix
Terawatt hours



Source: BP, EIA, Lawrence Berkeley National Laboratory, JPMAM. 2020.

[1] Larson et al, "*Net-Zero America: Potential Pathways, Infrastructure, and Impacts*", interim report, Princeton University, December 15, 2020.

Appendix B: Wind and solar capacity factors

Median capacity factors for wind/solar are sourced from Lawrence Berkeley National Laboratory[2]. Average wind capacity factors increased from 2011 to 2014, driven by an increase in the size of wind turbine rotors relative to rated capacity; tower height and wind conditions were mostly unchanged during this period. Average solar capacity factors have remained unchanged since 2013 as a result of market expansion to less-sunny regions, which has been offset by slightly more efficient solar panels.

Wind capacity factors

Source: LBNL. August 2021.

Solar capacity factors

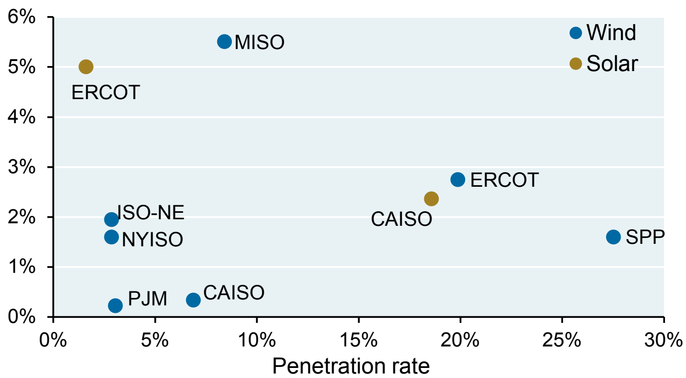
Source: LBNL. September 2021.

Conversions of wind and solar irradiance into electricity are mature processes from a technological perspective. Their unit costs may come down further, but capacity factors are unlikely to improve much by 2035. Also, there is some capacity factor degradation in aging wind and solar facilities which could offset any productivity improvements that occur by 2035.

Curtailment may also become an issue as wind and solar penetration rises further. All seven ISO's already report curtailment of wind, and both ERCOT and CAISO report curtailment of solar. Curtailment effectively lowers capacity factors, since the amount of consumed generation declines relative to the project's potential output. Co-location of battery storage can reduce or eliminate curtailment, but at substantial cost.

Solar and wind penetration vs curtailment rates

Curtailment rate in 2019



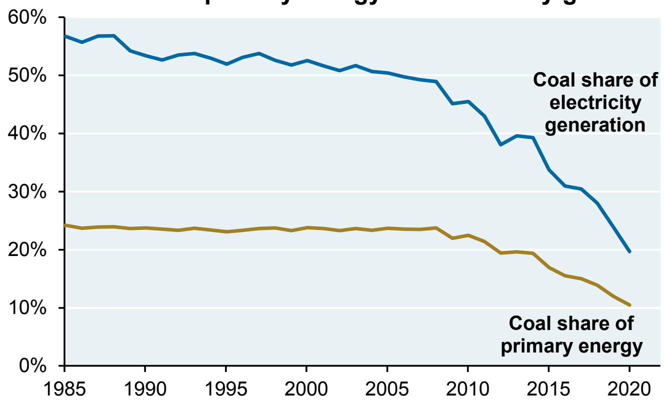
Source: Lawrence Berkeley National Laboratory, JPMAM. 2019. Label = ISO.

[2] *"Utility-Scale Wind and Solar in the US",* Lawrence Berkeley National Laboratory, December 8, 2020.

Appendix C: Coal, nuclear power and hydropower

There are no coal-fired power stations under construction in the US. The last coal plant built was completed in May 2019, a 17 MW combined heat and power plant at the University of Alaska. As for nuclear, the Union of Concerned Scientists has written on profitability challenges that constrain its development[3]. Roughly 90 TWh of nuclear power are expected to be shut down over the next decade, and another 135 TWh is already uncompetitive with natural gas[4]. Those amounts represent 30% of US nuclear generation; we assume that another 20% is taken offline as well by 2035 due to aging plant and equipment. As shown below, by 2035 a substantial number of US nuclear plants would be well beyond their typical 40-year operating lives. Hydropower growth potential is drawn from two studies from Oak Ridge National Laboratory[5].

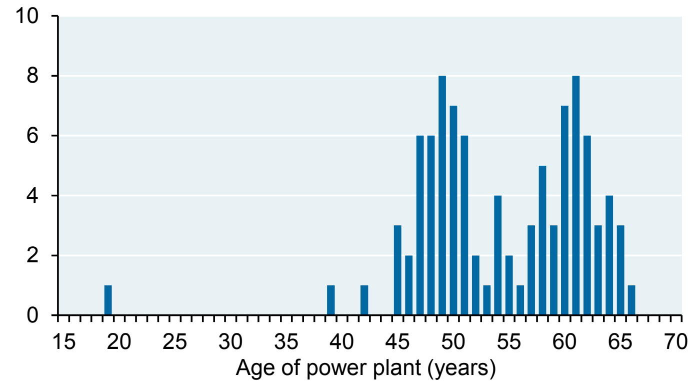
US coal share of primary energy and electricity generation



Source: BP, JPMAM. 2020.

Age distribution of existing US nuclear reactors in 2035

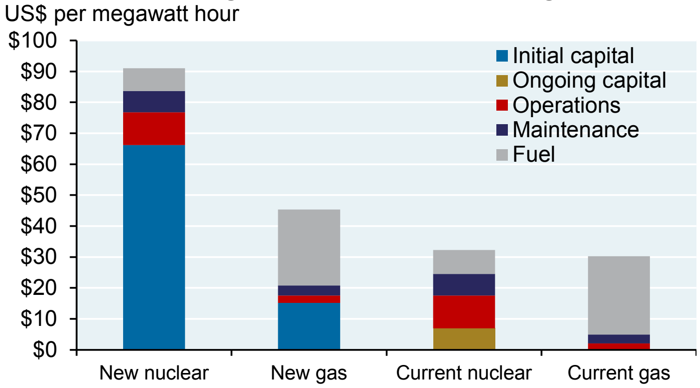
Number of plants



Source: International Atomic Energy Agency. 2020.

Levelized costs of generation for nuclear and gas

US$ per megawatt hour



Source: CarbonBrief, EIA. 2018.

[3] *"The Nuclear Power Dilemma",* Clemmer et al, Union of Concerned Scientists, November 2018.

[4] *"Mapped: The US nuclear power plants at risk of shutting down"*, Zeke Hausfather, Carbon Brief, July 2018.

[5] *"New Stream-reach Development: A Comprehensive Assessment of Hydropower Energy Potential in the United States"*, Oak Ridge National Laboratory, April 2014. *"An Assessment of Energy Potential at Non-Powered Dams"*, Oak Ridge National Laboratory, April 2012.

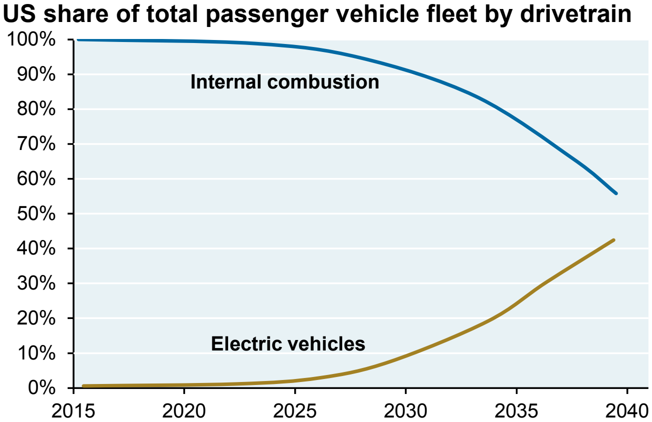
Appendix D: Electric vehicle assumptions

Passenger car EV penetration of 30% in 2035 is drawn from the May 2020 BNEF forecast[6]. Other assumptions: a starting fleet size of 194 million passenger cars; annual net vehicle growth rate of 1.9 million cars; 11,000-12,000 miles driven per year, and 3.3 miles per kWh for passenger car EVs[7,8].

BNEF also has forecasts for electrification of light and heavy duty trucks. The current US light truck fleet is 59.5 million vehicles and the medium/heavy duty fleet is 13 million vehicles. According to Bureau of Transportation Data, light trucks travel roughly the same number of miles as the average passenger car while medium and heavy trucks travel around 25,000 miles per year. We assume 2 miles per kWh for light trucks[9] and 0.5 miles per kWh for heavy trucks[10]. BNEF forecasts for 2035: 25% penetration for light EV trucks and 7.5% for heavy and medium duty EV trucks.

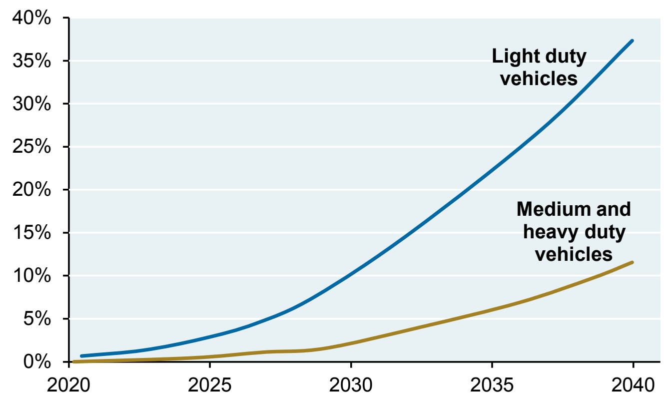
Biden's reconciliation bill contains EV incentives for new car buyers and people trading in existing vehicles. To the extent that these subsidies accelerate EV adoption, it would result in higher natural gas usage in 2035 than in our base case given the increased electricity load from EVs, and since the grid would only be partially decarbonized according to our assumptions.

US share of total passenger vehicle fleet by drivetrain



Source: BNEF. 2020.

Electric vehicle share of US commercial vehicle fleet



Source: BNEF. 2020.

[6] "*Electric Vehicle Outlook 2020*", Bloomberg New Energy Finance, May 2020.

[7] Bureau of Transportation Statistics: "Number of US aircraft, vehicles, vessels and other conveyances", and "US vehicle miles"

[8] *"Cleaner Cars from Cradle to Grave",* Nealer et al. (Union of Concerned Scientists), November 2015; Department of Energy & Environmental Protection Agency: "Fuel economy"

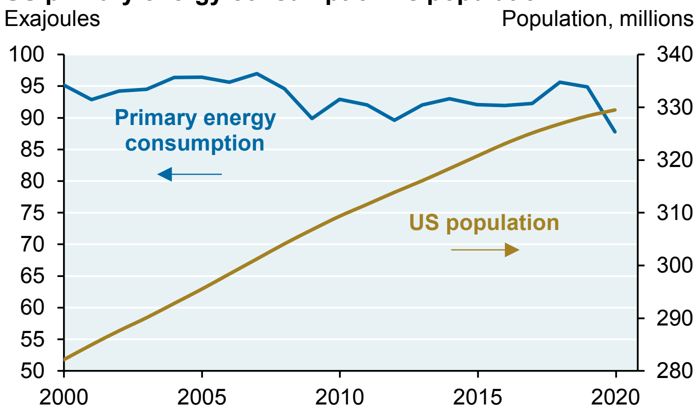
[9] *"Plug-In or Gas Up? Why Driving on Electricity is Better than Gasoline"*, David Reichmuth (Union of Concerned Scientists), June 7, 2021.

[10] Tesla Semi Truck specifications, November 8, 2021; *"Electric Big Rigs Are Coming",* Mark Vaughn (Autoweek), May 24, 2021.

Appendix E: Energy and electricity trends

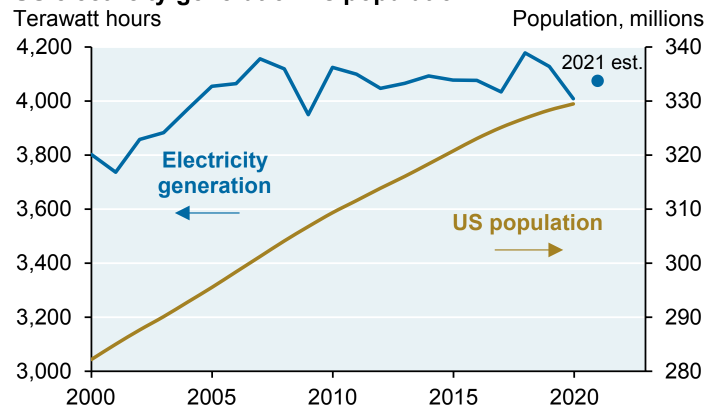
Despite steady population growth, overall primary energy and electricity consumption in the US have been roughly flat over the last 20 years. The implication: more energy efficient buildings, devices and vehicles are offsetting increased energy demand from a growing population. Other than changes in electricity generation resulting from our EV and heat pump assumptions, we do not assume any other changes in these trends. The primary energy decline in the year 2020 is pandemic related. We expect it to rebound in 2021 to 2019 levels based on high frequency data on oil consumption, industrial production and electricity demand.

US primary energy consumption vs population



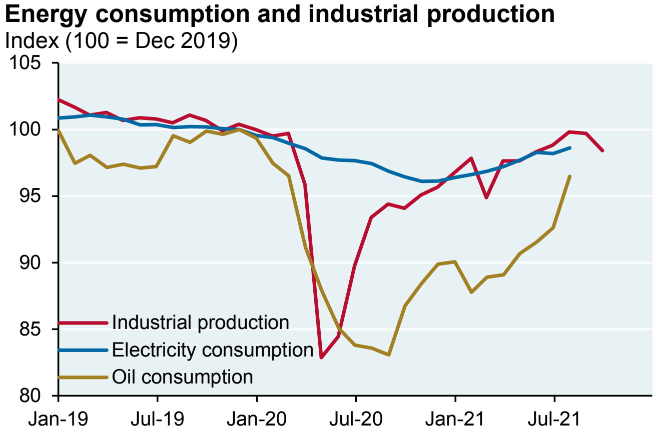
Source: BP, Census. 2020.

US electricity generation vs population



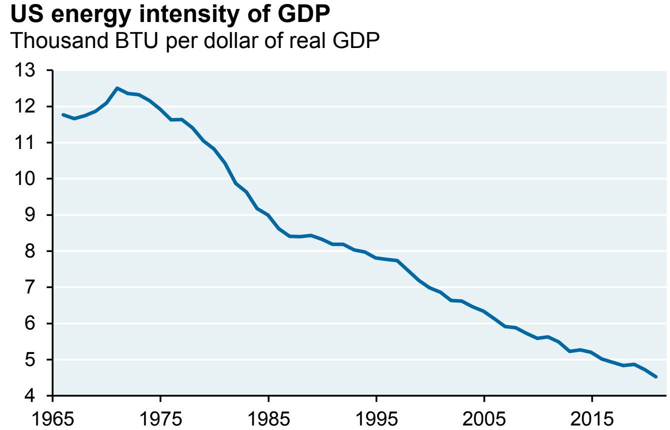
Source: EIA, Census. 2021.

Energy consumption and industrial production



Source: EIA, Federal Reserve, JPMAM. September 2021.

US energy intensity of GDP



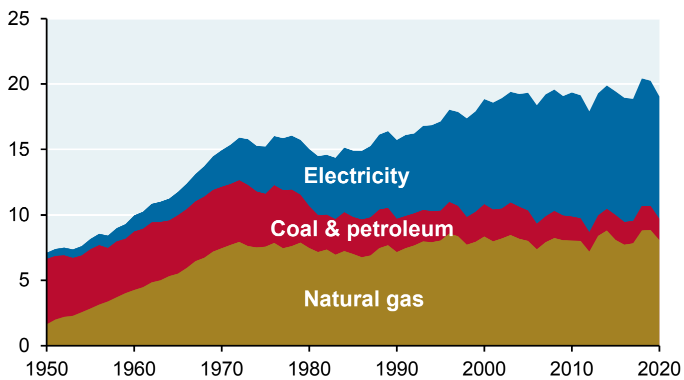
Source: BP, BEA. 2020.

Appendix F: Heat pumps for commercial and residential heating

While the share of homes using electricity for heat has risen from 26% in the early 1990's to 35%, much of this increase came at the expense of fuel oil and propane. As shown below, the amount of natural gas used for residential and commercial heating has been roughly unchanged, and is still used by ~50% of households. **The potential change on the horizon: electric heat pumps, which can reduce energy required for heating since they're often more efficient than electric baseboard systems and fossil fuel combustion systems**. A simplified explanation: there's heat in the air even when the temperature outside is freezing. A heat pump extracts that heat using refrigerants as cold as -60°F that flow through the unit's outside coil. The warmed refrigerant is then circulated to the interior via a compressor that increases its pressure and temperature, readying it to heat the interior air. The compressor is the main electricity-using component, and since it's only driving heat transfer, it uses a relatively small amount of energy when compared to combustion based heating equipment.

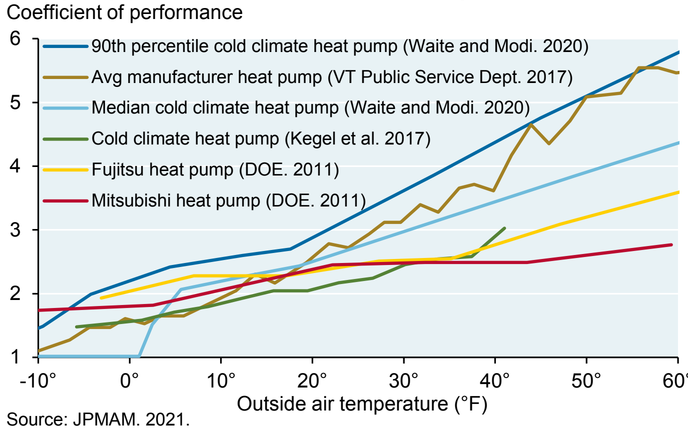
The efficiency of heat pumps can be defined by their "coefficient of performance", which refers to the amount of heat they provide per unit of electricity consumed. The higher the outside temperature, the greater the differential between the heat in the air and the unit's refrigerant, and the more efficient the heat pump will be. Estimates of heat pump efficiency vary (see below), but there's universal acceptance that they can provide heat more efficiently than other forms of heating at most ambient temperatures.

Residential and commercial energy use by type
Quadrillion BTUs



Source: EIA. 2020.

Heat pump performance vs outside air temperature
Coefficient of performance



Source: JPMAM. 2021.

That said, there are hurdles to heat pump adoption as municipalities consider new regulations regarding existing or new buildings. Switching costs can be high, and in cold areas (and in warmer areas subject to intermittent cold spells), there are risks to adoption of electric heat with no backup systems in place. If the grid were to fail, there could be catastrophic results. Furthermore, without backup fossil fuel systems, existing generation and transmission systems would have to be substantially built out to handle the few days of the year when electricity loads surge due to heating needs[11].

[11] **Heat pumps without backup fossil fuel systems can be a non-starter**. Adoption of heat pumps without backup fossil fuel systems in place can require extensive capacity and transmission build out just to meet electricity loads on a handful of cold days. Waite estimates that if heat pumps replaced fossil fuel systems in homes environmentally incented to switch, and if fossil fuel systems were not retained for backup heating:

- A handful of cold days would cause electricity demand to spike in certain places
- 54% of all census tracts would experience electricity demand above current peak loads on at least one day
- In those census tracts, the aggregate peak load increase would be 96% (almost a doubling of the load)

Since heat pump adoption is still low (only 7% of all heating energy consumed by US households), we assume a gradual rate of adoption by 2035 rather than a complete transformation. Even our assumptions may be too aggressive given the difficulty in dislodging incumbent energy systems. We worked with Michael Waite of Columbia University to develop these heat pump scenarios, drawing on his extensive research on the subject[12]:

- *Residential transition from electric baseboard resistance heating to heat pumps*. Currently, 20% of US space heating energy delivered is consumed by households using baseboard heating. If this entire cohort of households switched to heat pumps, electricity consumption would decline by 257 TWh. While emissions and heating costs would decline for all these homes, there are switching costs and payback periods to consider, and market structure issues as well: how would landlords recoup the cost of a heat pump if renters do not reward them for lower utility costs? All things considered, we assume that by 2035, one third of baseboard heating homes switch to heat pumps, reducing electricity consumption by 85 TWh
- *Residential transition from on-*site *fossil fuel combustion to heat pumps*. Currently, 69% of US energy of US space heating energy delivered is consumed by households using on-site fossil fuel combustion. The assumptions here are more complex: the modeling assumes that only households that have an incentive to switch for environmental reasons do so (i.e., households in much colder climates may not end up switching since very cold temperatures reduce heat pump efficiency; the same is true for households where grids are still heavily reliant on fossil fuels). There are questions about how such a transition would occur, who would pay for it, etc. We assume that by 2035, 20% of households with environmental incentives to switch actually do so. If so, electricity generation needs would increase by 44 TWh, offset by a large decline in natural gas consumption of 0.7 quadrillion BTUs per year
- Other assumptions: Waite assumes a coefficient of performance for heat pumps in the 90th percentile of existing commercially available pumps; we consider this reasonable given the scope for efficiency gains by 2035. We also assume that municipalities allow residences to retain backup fossil fuel systems for the reasons described above. Finally, we assume that commercial buildings adopt heat pumps at the same pace as residences, resulting in a similar pro-rata decline in their natural gas consumption
- Our heat pump assumptions would reduce US demand for natural gas in 2035 by 1.2 quadrillion BTUs due to residential and commercial switching

[12] Waite, M. and V. Modi, "*Electricity load implications of space heating decarbonization pathways*", Joule, 2020; and Waite, M. and V. Modi, "*Deep space heating emissions reductions in the U.S. through environmentally beneficial electrification and an evolving electricity system*", Quadracci Sustainable Engineering Laboratory, Columbia University, April 2020

Appendix G: Industrial sector energy consumption and the barriers to electrification

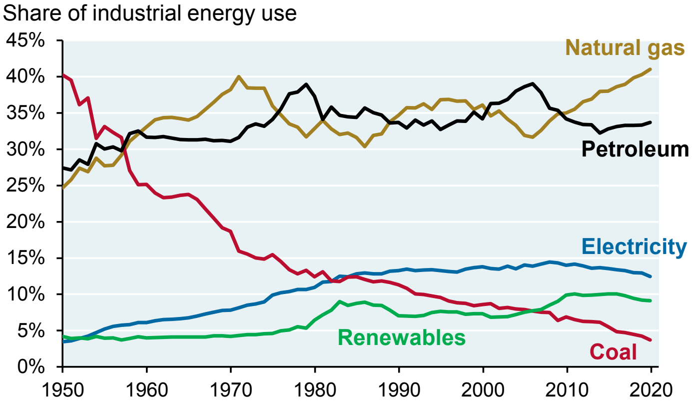
One third of natural gas consumption is used by US industry. Could some industrial processes be electrified to eventually use renewable energy as the grid is decarbonized? In 2018, Lawrence Berkeley Laboratory outlined the possibilities: some primary metals, secondary steel, machinery, wood products, plastics and rubber. Most use fossil fuels primarily for "process heat" which could be replaced by electric heat. Other candidates: certain mining activities related to transport, excavation, pit crushing and belt conveying systems.

For other uses, it gets harder. Chemicals, pulp/paper and food take advantage of integrated systems in which fuel combustion waste heat powers related processes, referred to as **CHP** (combined heat and power). CHP-intensive sectors are harder to electrify since producers would need to purchase energy previously obtained at little to no cost, and/or redesign the entire process. Other hard to electrify sectors include non-metallic minerals such as glass, brick and cement which require temperatures in excess of 1400°C, and which are non-conductive solids (i.e., harder to electrify production of things that do not conduct electricity). Finally, oil/coal refining exploits "**own-use**" fuel consumption, a source of energy lost when switching to electricity.

In addition to upfront switching costs, industrial companies would face electrification costs per unit of energy that are **3x-6x higher for electricity than for direct use of natural gas**. Electric heating efficiency gains vs direct gas combustion could offset part of this cost, but not all of it.

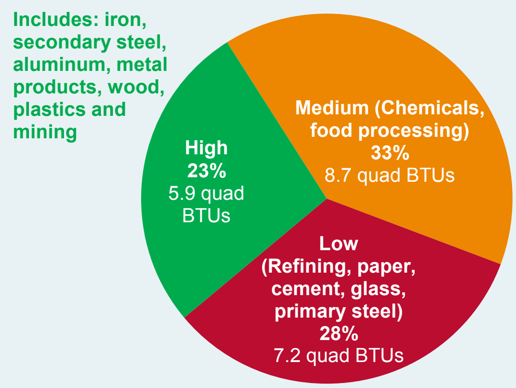
Bottom line: chemistry and cost explain why the electricity share of US industrial energy use has been **roughly unchanged at 12%-15% since the early 1980's**. We assume that this share does not change by 2035.

Industrial energy use by type
Share of industrial energy use



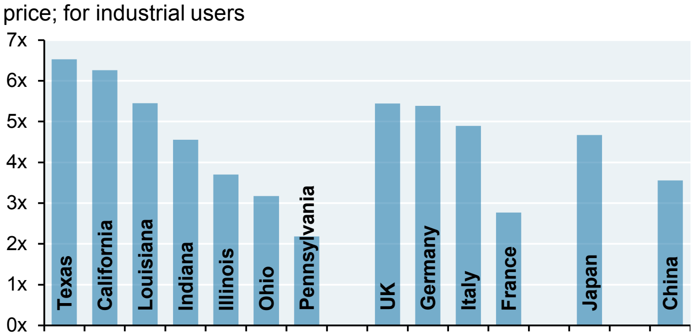
Source: EIA. 2020.

US industrial energy use by electrification potential



Source: EIA (2020), LBNL, *"Electrification of buildings and industry"*, 2018.

Electricity is 3x-6x more expensive than natural gas
Cost per megajoule of energy, electricity price divided by natural gas price; for industrial users

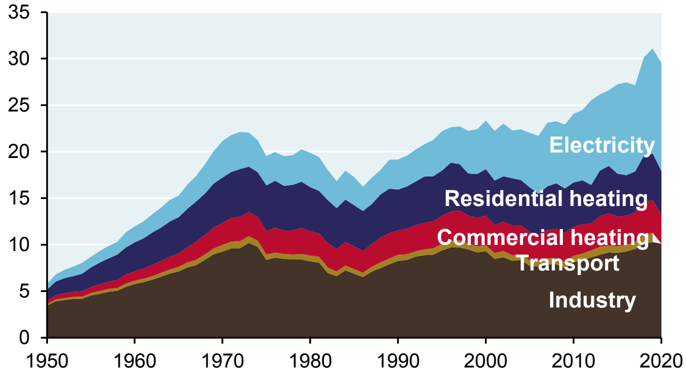


Source: EIA, Eurostat, IAEE, CEIC, IFPEN, JPMAM, World Bank. 2019.
States shown are largest industrial users of US primary energy.

What about steel?
Secondary (recycled) steel can be created with "green" electricity since it's produced in an electric arc furnace. In the US, secondary steel accounts for ~70% of total production. Primary steel accounts for the rest, and relies on blast furnaces and coke ovens that use carbon as a reducing agent to strip oxygen from iron oxide, which produces CO_2. While there are some demonstration projects underway in Europe to decarbonize primary steel by using hydrogen as the reducing agent (which would produce water instead of CO_2 as a byproduct), mass commercial production may not occur for at least 20 years.

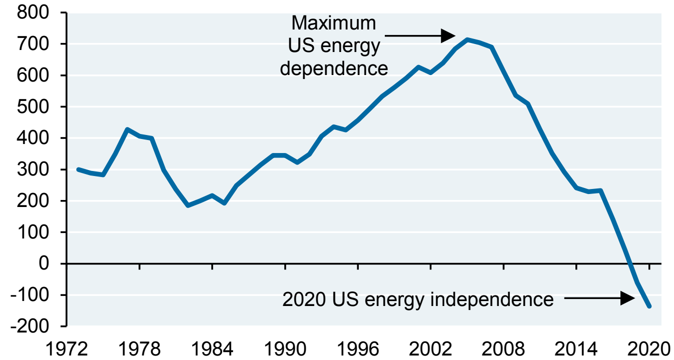
Appendix H: Natural gas facts and figures

US natural gas consumption by sector
Trillion cubic feet



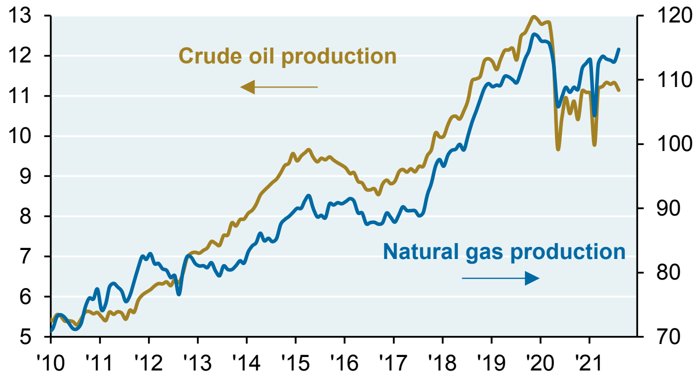
Source: EIA, LBNL, JPMAM. 2020.

US net energy deficit, in energy terms
Net imports of oil, natural gas and coal in million tonnes of oil equiv.



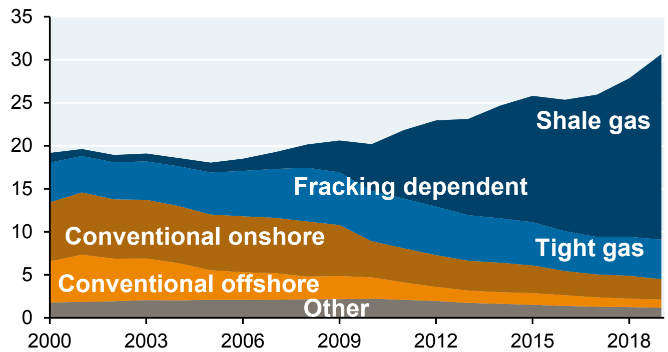
Source: EIA, JPMAM. December 2020.

US crude oil and natural gas production
Million barrels per day
Billion cubic feet per day



Source: EIA. August 2021.

US dry natural gas production by type
Trillion cubic feet per year



Source: EIA. 2019.

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