

Residential heat pumps and fossil fuel combustion bans: more complicated than it looks

Residential heating in the US and Europe is dominated by on-site combustion of natural gas and other fossil fuels. Some European countries and US cities have banned combustion of fossil fuels in new residences; San Francisco, San Jose, Denver, Seattle and New York City¹ are recent examples and there are more bans on the way (see page 26 on European bans). The goal: require electrification of new residential heating instead, which can reduce CO₂ emissions as more wind/solar are added to the grid.

First, let’s review why electrification makes little sense using resistance (traditional baseboard) heating. In areas where grids are reliant on coal and natural gas, emissions would sharply *increase* compared to combusting natural gas on-site. The reason: the energy efficiency of gas and coal-powered electricity generation (including transmission losses) is often less than half the efficiency of on-site gas combustion that can exceed 90%².

As a result, broad use of resistance heating could cause residential electricity demand to double, and that’s not the only problem. As shown in the table, universal resistance heating could also increase peak loads in every Census tract in the US, each of whose peak loads would *more* than double³. The result: the need for more transmission and distribution which has to be built for *peak* loads rather than average ones. Given these outcomes, widespread electric resistance heating makes no sense, even in places with high renewable shares of electricity generation.

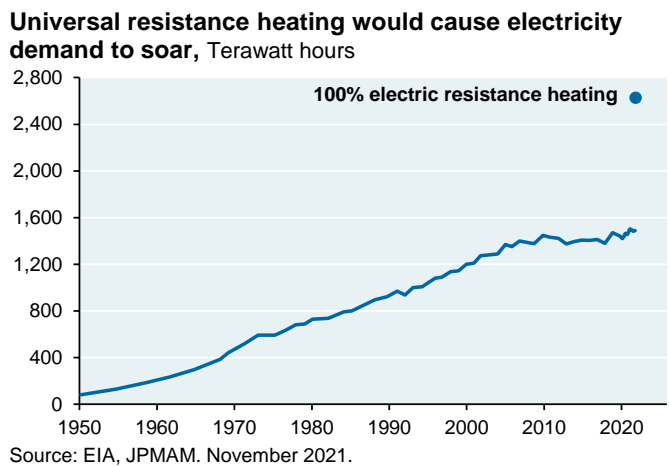
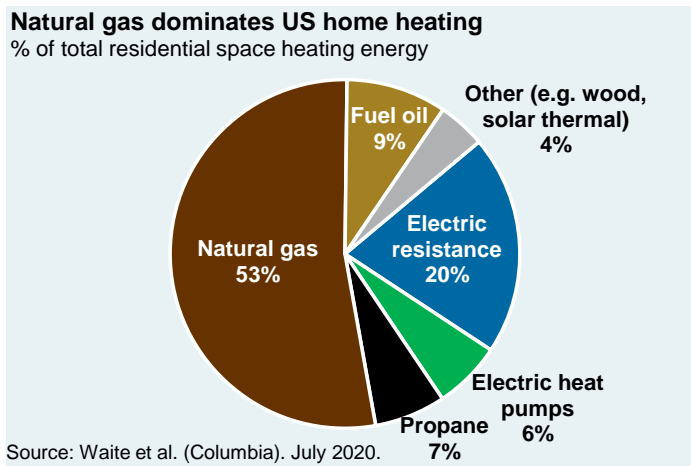


Table 1: Universal resistance heating would also cause peak loads and infrastructure needs to skyrocket

Scenario	Space heating shares			Residential emissions from all energy uses (mmt CO ₂)			Electricity demand (TWh)		Peak load increases	
	Resistance heating	Heat pumps	Fossil fuels	Electricity	Fossil fuels	All	Space heating	All energy uses	Tracts w/ increased peak load	Average peak load increase in affected census tracts
Current	20%	6%	69%	250	339	589	368	1,382	NA	NA
All residences use resistance heating	96%	0%	0%	1,084	0	1,084	1,613	2,626	100%	135%

Source: Waite et al. (Columbia). July 2020.

¹ In December 2021, the **New York City Council** banned gas-powered heat and stove appliances in newly constructed buildings. The ban takes effect on December 31, 2023 for new buildings six stories and below. By July 1, 2027, it will include all new construction irrespective of size.

² “Gas, oil and wood pellet fueled residential heating system emissions”, Brookhaven National Labs, Dec 2009

³ Tables 1, 2 and 3 show output of a model of residential home heating and emissions built at the Census tract level by Michael Waite, Department of Mechanical Engineering at Columbia University. Michael worked with us on specific scenarios we designed after reading his February 2020 article in Joule Magazine, “Electricity Load Implications of Space Heating: Decarbonization Pathways” on air-to-air heat pumps in residences.

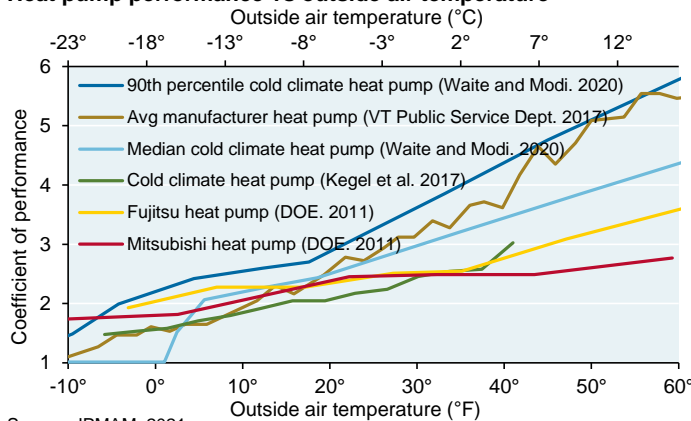
Fortunately, there’s a better way: air-to-air electric heat pumps⁴ can provide heat much more efficiently than resistance heating. A simplified heat pump explanation:

- Strange as it may seem, 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 (-51°C) that flow through the unit’s outside coil. The refrigerant starts as a low temperature liquid, it absorbs heat and turns into a low temperature vapor
- 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 less energy than resistance heating
- The efficiency of a heat pump is defined by its “coefficient of performance” (COP), which refers to the amount of heat it provides 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. A COP of 1.0 would mean that the heat pump is only performing in line with resistance heating
- Estimates of heat pump efficiency vary (see below, left), but there’s broad acceptance that they provide heat very efficiently at most ambient temperatures. As shown in the chart, heat pump COP might still be around 2.0x at temperatures as cold as 10°F (-12°C)

Heat pumps may need a seasonal average COP of 2.0-2.5 to make sense from a climate perspective, and higher to make sense from an economic perspective. Assume a home whose onsite combustion of natural gas is ~90% efficient, and that its regional utility is highly gas-reliant. Switching to gas-powered electricity would use roughly twice the energy at a COP of 1.0 given ~45% efficiency of modern combined cycle natural gas plants. So, a heat pump COP of 2.0 would be needed to match the energy/emissions of the original onsite natural gas burner.

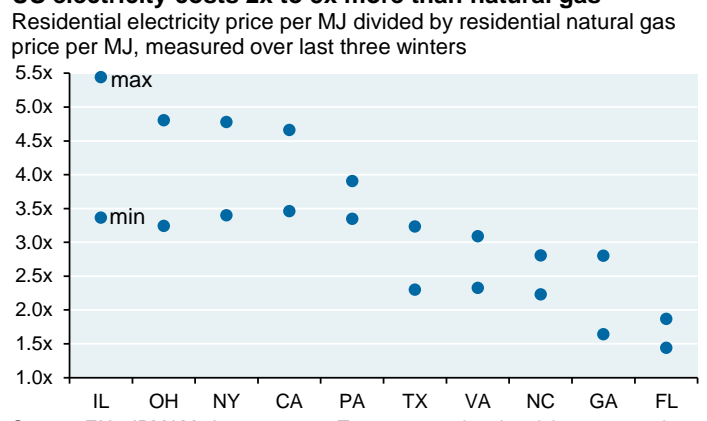
More renewable energy reduces the COP required for heat pumps to make sense from a climate perspective. However, there’s still the issue of homeowner economics. Per unit of energy, US electricity was 2x to 5x more expensive than natural gas in many states over the last three winters. **As a result, a heat pump would need a COP of 2x to 5x in these places for fuel cost expenses to break even.** In other words: a heat pump’s COP needs to be roughly equal to the multiple of electricity to fuel costs for homeowner fuel costs to break even.

Heat pump performance vs outside air temperature



Source: JPMAM, 2021.

US electricity costs 2x to 5x more than natural gas



Source: EIA, JPMAM, January 2022. Top 10 states by electricity consumption.

⁴ I recently installed several Bosch heat pump/air conditioning units in my home. Assume the temperature outside is 35 degrees and the temperature in the house is 55 degrees since the system is turned off. Assume I then turn on the heating system and set the thermostat to 68 degrees. My particular Bosch system uses the fuel oil system in tandem with the heat pump until the temperature in the house is 3-5 degrees below the thermostat target, at which point the heat pump would work on its own.

Broad heat pump adoption would entail large emissions declines, as shown in the third row in the table. But what about electricity distribution capacity which has to be built for PEAK loads, not AVERAGE loads? Broad adoption of heat pumps without backup power could cause peak loads to surge in many parts of the country on very cold winter days, requiring massive grid upgrades. The red zone in the third row shows the results: 2/3 of all Census tracts would experience higher peak loads with average peak load increases of over 100%.

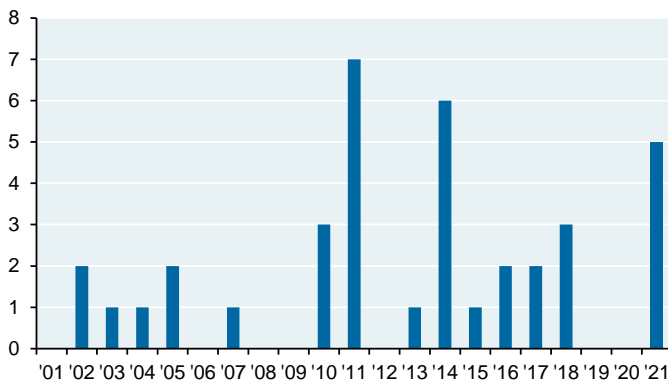
Table 2: Universal heat pump adoption slashes emissions but increases peak loads and infrastructure needs

Scenario	Space heating shares			Residential emissions from all energy uses (mmt CO ₂)			Electricity demand (TWh)		Peak load increases	
	Resistance heating	Heat pumps	Fossil fuels	Electricity	Fossil fuels	All	Space heating	All energy uses	Tracts w/ increased peak load	Average peak load increase in affected census tracts
Current	20%	6%	69%	250	339	589	368	1,382	NA	NA
All residences use resistance heating	96%	0%	0%	1,084	0	1,084	1,613	2,626	100%	135%
All residences use heat pumps, no backup thermal power	0%	96%	0%	282	0	282	415	1,429	63%	109%

Source: Waite et al. (Columbia). July 2020.

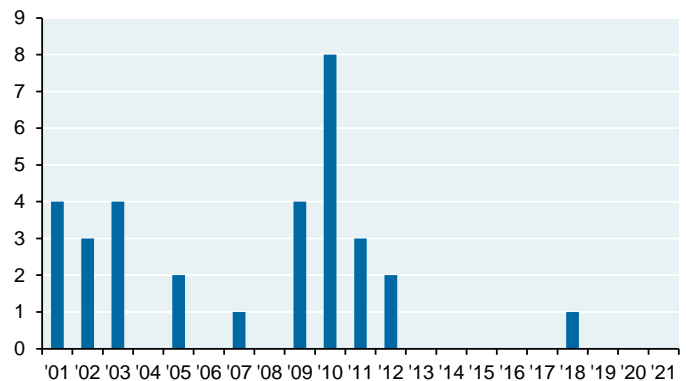
Temperature histories for Dallas and Tallahassee illustrate the issue. It doesn't get very cold that often, but there can be several days a year when minimum temperatures fall below 20°F (-7°C). As a result, any plan needs to account not just for average winter demand but for demand on the coldest days⁵ when days demand could surge as illustrated in Table 2. If so, "smart" systems that switch to non-electric backup power on the coldest days could in theory reduce peak grid surges and reduce the need for transmission grid investment.

Dallas: days with min. temperatures below 20 degrees F



Source: NOAA, JPMAM. September 2021.

Tallahassee: days with min. temps below 20 degrees F



Source: NOAA, JPMAM. September 2021.

⁵ While grid outages would negatively affect homeowners with electrified heating systems, boilers powered by gas, heating oil and propane also do not work without electricity. The big policy question: **would greater electrification of residential heating increase the frequency or duration of grid outages by overloading the grid with incremental demand?**

“Smart systems” could help...but what kind? Backup non-electric power looks like the right answer: this would still result in large reductions in fossil fuel use and emissions, but does not result in peak load increases anywhere in the US. This seems like a great solution but...**is it economically viable for the natural gas industry to maintain residential infrastructure for backup purposes only?** If not, the last row may not really be a viable outcome. Perhaps residential fuel cells could be used as backup on cold days to reduce grid surges, but now we’re talking about even more structural change and higher all-in costs.

Table 3: Non-electric backup power on cold days eliminates peak load increases and grid buildout needs, but from what energy source?

Scenario	Space heating shares			Residential emissions from all energy uses (mmt CO ₂)			Electricity demand (TWh)		Peak load increases	
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All residences use resistance heating	96%	0%	0%	1,084	0	1,084	1,613	2,626	100%	135%
All residences use heat pumps, no backup thermal power	0%	96%	0%	282	0	282	415	1,429	63%	109%
All residences use heat pumps, backup thermal power in place	0%	93%	3%	268	13	281	405	1,419	0%	0%

Source: Waite et al. (Columbia). July 2020.

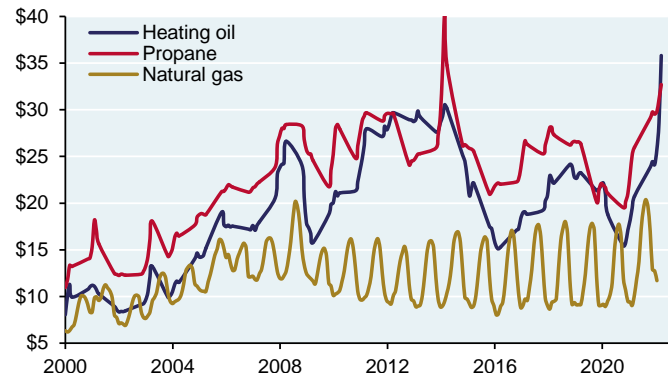
Economic incentives to switch. A separate analysis examined the economic consequences of residential heat pump adoption⁶. As shown in the next table, 40%-80% of homeowners using propane, fuel oil and electric resistance heating have economic incentives to switch to heat pumps. However, natural gas homes are by far the largest share of US residential housing stock, and the share of natural gas homeowners with incentive to switch to heat pumps is estimated at less than 10%. The primary reason for their lower incentives: **natural gas is usually much cheaper than propane and fuel oil**, as shown in the last chart.

Economic incentives to switch to heat pumps are much lower for homes heated by natural gas

Fuel type	Share of housing stock	% with economic incentive to switch
Natural gas	56%	8%
Electric resistance	20%	48%
Fuel oil	8%	40%
Propane	6%	79%

Source: Vaishnav et al (University of Michigan). 2021. Analysis assumes 2018 average fuel and electricity prices.

Natural gas is a lot cheaper than propane or fuel oil
US\$ per million BTU, residential pricing



Source: EIA, JPMAM. March 2022.

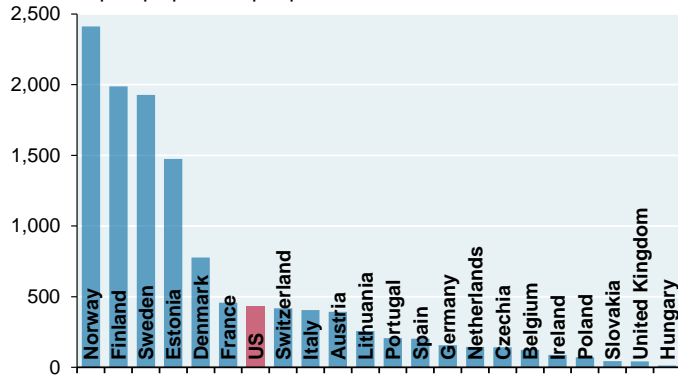
⁶ See “US residential heat pumps: the private economic potential and its emissions, health, and grid impacts”, Deetjen (UT Austin) and Vaishnav (University of Michigan), Environmental Research Letters, July 2021. Assumed heat pump costs: \$3,300 (existing central air systems), \$3,700 (without central air systems) or \$4,800 (homes requiring removal of existing boilers); plus \$143 * kW of capacity for purchase and installation; and up to \$6,000 depending on need for ductwork

Heat pump adoption without backup thermal power can be done in cold climates. Heat pumps are popular in Scandinavia where they compete favorably with resistance heating, biomass and “district” heating (centralized heating from biomass and waste timber, and from data center excess heat). In addition to air-to-air heat pumps, other heat pump types extract heat from the ground or from groundwater. These heat pumps are often more efficient and have higher capacity since they’re drawing from heat sources which are warmer than the ambient air (they also cost more due to installation and materials). As for heat pumps without backup power, homes in Scandinavia are more energy efficient as indicated by their lower energy consumption per dwelling on a climate adjusted basis than the rest of Europe⁷. US homes use ~2x the energy as homes in Europe and even more vs Scandinavia, increasing the difficulty of heating US homes via heat pumps with no backup systems in place.

Norway, for example, provided subsidies to switch, applied high fossil fuel taxes (basic plus carbon taxes are ~\$130 per metric ton for fuel oil compared to just \$11 in the US), its electricity prices are low and oil boilers were first restricted and now banned. **However, Norway is not a great template for larger, denser countries.** Norway has 5 million people, its population density is 10% of European levels and 97% of its electricity comes from cheap hydropower. The rest of the continent has to deal with larger surges in peak loads: 4x as much electricity can be used on a very cold day compared to a normal one. That might explain why heat pumps are used at lower rates in the rest of Europe: only 6% of Europe’s 240 million residences have heat pumps installed.

Heat pump adoption highest in Scandinavia

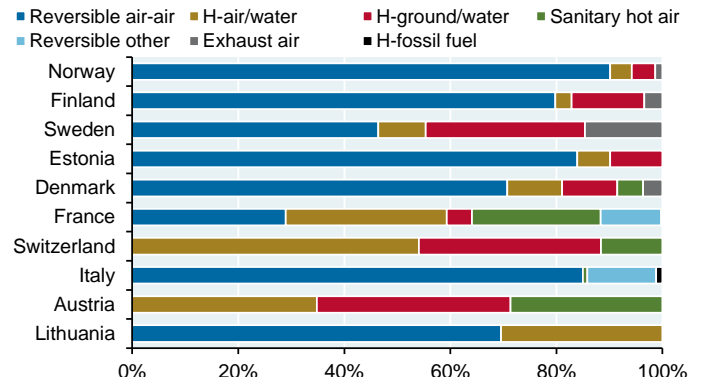
of heat pumps per 10k people



Source: EHPA, European Statistical Office, Census. 2020.

Europe heat pump types

Percent of stock



Source: European Heat Pump Association. 2018. H = hybrid heat pump.

Europe aims to phase out fossil fuels for residential heating by 2040, and the IEA’s 10 point plan for reducing European reliance on Russian energy also calls for a faster pace of heat pump adoption. To get there, 40% of residential and 65% of commercial buildings will need to be electrified by 2030 via 35 million new heat pumps⁸. As with green hydrogen, Europe will be a litmus test for the achievable pace of change in energy production and consumption. Combustion bans have expanded in Europe, which should increase heat pump momentum⁹:

- Denmark (2013) banned the installation of oil and gas boilers in new buildings
- Netherlands (2018) banned connection to the gas grid for new buildings
- Austria (2020) banned the installation of oil and coal boilers in new buildings
- Norway (2020) banned the use of oil for heating new and existing buildings
- France requires new construction after 2022 to meet maximum CO₂ emissions per square meter with different levels depending on the building type, effectively banning all mono-fuel fossil fuel systems
- Belgium’s Flemish region introduced a ban on fuel oil boiler installation for new buildings and major energy renovations in residential and non-residential buildings starting in 2022
- Germany banned installation of mono-fuel oil and coal boilers starting in 2026

⁷ “International comparisons of household energy efficiency”, Odyssee-Mure Project, EU Commission

⁸ “How Norway Popularized an Ultra-Sustainable Heating Method”, Peter Yeung, January 17, 2022

⁹ “Phase out regulations for fossil fuel boilers at EU and national level”, Institute for Applied Ecology, Oct 2021

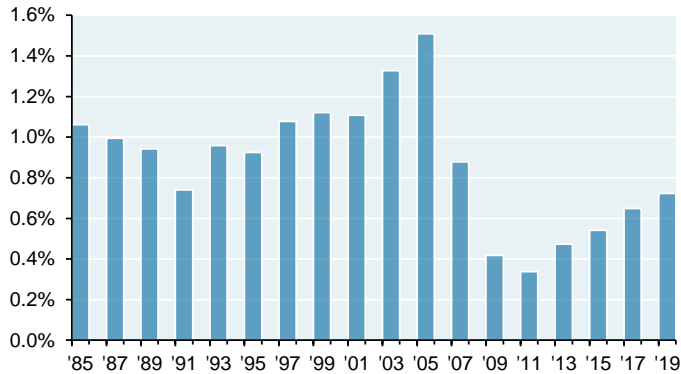
Wrapping up: heat pump adoption will be slow if it relies mostly on new homes

Both studies we cited analyzed *existing* US homes and the costs and benefits of switching to a heat pump. For *new* homes, all-in costs for heat pumps can be lower given greater energy efficiency of a new home¹⁰ and no need for retrofit ductwork. For new homes, heat pumps may even be cheaper than natural gas in more cases. In the US, heat pumps accounted for 40% of all new single family home heating units in 2020 and almost 50% for multi-family¹¹.

That’s good news, but the transition to heat pumps will be slow if it relies mostly on new homes due to changing public policy: **new homes sales in the US and Europe average just 1% or less of the housing stock each year.** Think about it this way: a car can last 10-15 years before having to be replaced, while a house can last 40-50 years or more. Of course, burners and furnaces don’t last as long as a house does. But they last a lot longer than cars do: the average life of a natural gas furnace is 15-20 years, and the average life of a fuel oil furnace is 20-25 years. Replacing them with new furnaces when they expire is also simpler than shifting to a new form of home heating. As a result, electrification of residential heating may be a slower process than electrification of transport, unless generous subsidies are provided to promote switching.

US single family home turnover per year

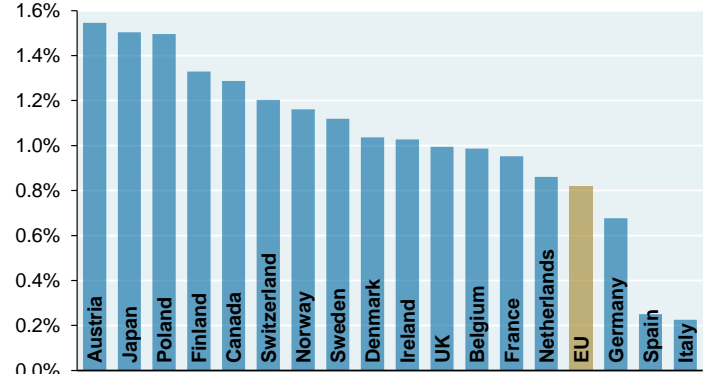
Percent, new single family home sales / single family housing stock



Source: Census, JPMAM. 2019.

European new home turnover per year

Percent, completed new homes as % of existing housing stock



Source: OECD, JPMAM. 2020 or latest year available.

¹⁰ According to Harvard’s Joint Center for Housing Studies, the average home built before 1960 consumes 42.5 thousand btu per square foot compared to 27.2 btu per square foot for a home built from 2010 to 2015.

¹¹ “Heat Pumps: More Efforts Needed”, IEA, November 2021

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