Pace of Progress Methodology

JANUARY 2024: BASELINE REPORT & LOCAL TOOL RELEASE

Project inspiration

This analysis was inspired by work originally done in this report created by Evolved Energy Research for the Princeton Net Zero America project. Specifically, the figures below (Fig. 11) inspired us to create similar visualizations which would calculate a pathway towards 100% stock of heat pumps in residential buildings by 2050, effectively decarbonizing residential heating.

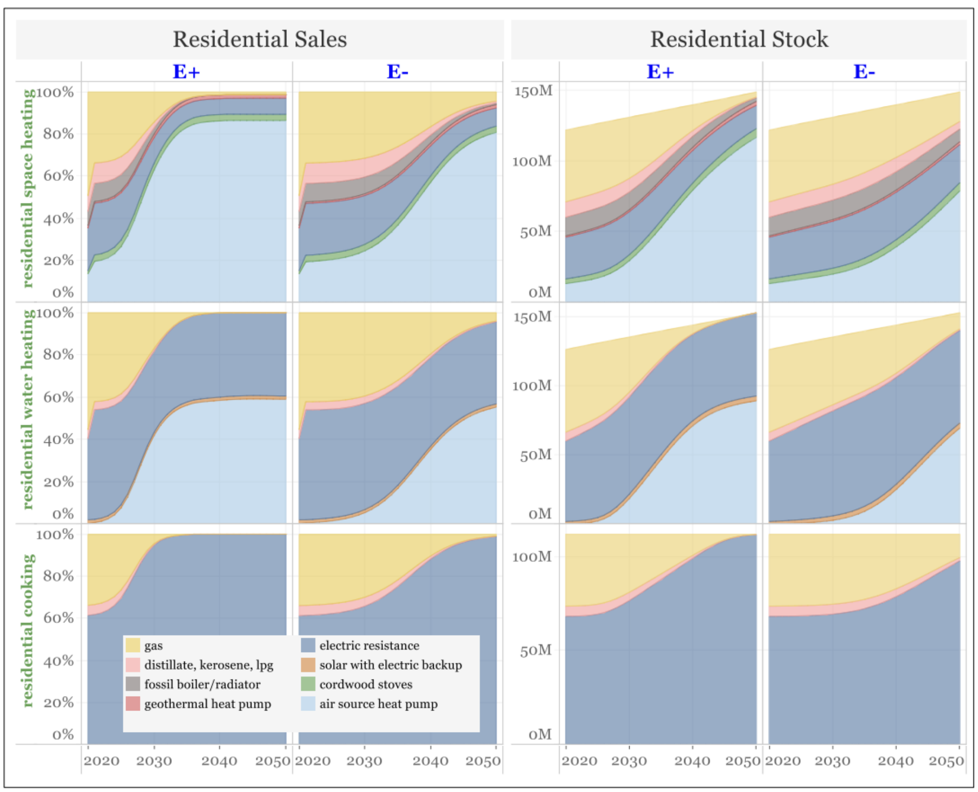

Figure 11. Exogenously assumed residential sector sales of heating and cooking units (left panel) and resulting stocks of same (right panel).

We then wanted to replicate the exercise for other types of electric appliances necessary to fully decarbonize households like cooking, water heating, transportation, and rooftop solar.

Key terms

The following definitions provide detail about key terms presented throughout this methodology:

→ **Machine**: a household device like a vehicle, HVAC system, stovetop, or dryer that has traditionally been powered using fossil fuels that can now be upgraded to an efficient, electric alternative.

→ **Machine category**: the machines in this analysis are categorized based on their function within a household, including space heating, water heating, cooking, transportation, and solar energy.

→ **Machine type**: the method by which the machine is powered. It can refer to the fuel that goes into a machine like methane gas or fuel oil, or the way it uses electricity like electric resistance or induction.

Data sources

The following data sources serve as inputs to our Pace of Progress modeling.

EIA Residential Energy Consumption Survey 2020

→ The Energy Information Agency Residential Energy Consumption Survey (RECS) from 2020 forms the backbone of our national and state-level analysis. The survey provides data from a nationally representative sample of 18,500 households. The energy consumption patterns and appliance ownership of these households are then weighted to represent the 123 million housing units within the US. For the purposes of the Pace of Progress analysis, this data provides **machine** counts by state in 2020. RECS data also allows us to assign the **machine category** and **machine type** for each **machine** counted. With this data, we can say, for example, how many households in Texas heat their homes with gas, delivered fuels, electric resistance, or heat pumps in 2020. We then use these respective percentages of each **machine** within a **machine category** to feed the sales and stock curves going forward.

While RECS data is primarily used in our state-level analysis, it is also important for some **machines** that do not have data available at the county or city level. For induction stoves, counties and cities will have varying rates of induction stove adoption depending on both state-level RECS data on the adoption of induction cooking and county or city-level ResStock data on the adoption of stoves fueled with electricity.

NREL ResStock 2021 Release

→ The National Renewable Energy Lab ResStock tool serves as our primary data source for this analysis at the county and city level. The dataset provides modeled data about the energy usage behavior of 550,000 households in the US, a representative sample of the entire building stock. For the purposes of the Pace of Progress analysis, this data provides **machine** counts by county and city in 2020. Unfortunately, ResStock does not have data for all cities in the US. It only includes city-level data for cities with at least 15,000 modeled residences which translates roughly, but not exactly, to 50,000 residents.

Like RECS, ResStock allows us to assign the **machine category** and **machine type** for each **machine** counted. With this data, we can say for example how many households in Orange County, CA or Los Angeles, CA heat their homes with gas, delivered fuels, electric resistance, or heat pumps in 2020. We then use these respective percentages of each **machine** within a **machine category** to feed the sales and stock curves going forward. Although ResStock shares many similarities with RECS, it unfortunately does not have accurate counts of rooftop solar installations so we do not include this **machine type** at the county or city level.

Note: An observant user of our data exploration tool might notice that the state-level count of a particular **machine type** does not equal the sum of all counts of that same **machine type** for the counties within that state. This is because the data used to calculate these two values comes from two different sources. All state-level data comes from the 2020 RECS Survey while all county-level data comes from ResStock. ResStock is built on both the 2009 and 2015 RECS surveys, earlier versions of the same survey that informs our state-level data. Since the 2020 RECS data is the most up to date version of the data, we use it as our preferred data source where possible however it is currently unavailable at the county level.

AFDC Alternative Fuel Vehicle Registrations

→ The Alternative Fuels Data Center (AFDC), within the DOE, provides data on the number of vehicle registrations for each state. This allows us to establish the respective count of

machines for the **machine category** of transportation. These **machine** counts and relative percentages of each **machine type** are available for each state in 2020. With this data, we can say for example how many households in Texas drive gas, diesel, hybrid, or electric cars in 2020. We use this data as an input into our models that will generate sales and stock curves going forward. Unfortunately the AFDC transportation data is only available at the state level so we can not provide projections for this **machine type** at the county or city level.

NREL Solar Potential Data

→ The National Renewable Energy Lab (NREL) performed an analysis that provides data about the suitability of installing rooftop solar on buildings in all zip codes throughout the US. This is crucial for setting our goal for solar installations throughout the US. For example, we do not want to set a goal that expects 100% of residential buildings to install rooftop solar in a place where it's only feasible for 75% of buildings to have solar. These estimates of suitability are based on factors like North/South orientation, tree cover, or roof size. As a whole, roughly 85% of residential buildings in the US are deemed suitable for rooftop solar based on this analysis, but that percentage varies from state to state, with some in the Desert Southwest having especially high percentages of homes suitable for rooftop solar. The NREL data is used to set targets at the state level by averaging the share of suitable buildings across zip codes after weighting by the number of buildings in each.

Calculating curves

The bulk of the Pace of Progress analysis is focused on calculating the sales and stock curves that create annual targets at different geographic levels. These targets inform the number of **machines** that need to be upgraded to reach our goal of full residential electrification by 2050. In our methodology, we start with the assumption that a **machine** sold today will often be in use for roughly 15 years. That means that we can still meet our 2050 goal even if legacy machines like gas furnaces are sold over the coming few years. The methodology reasons that a gas furnace sold in 2024 will reach the end of its useful life in 2039 - at which point it will be replaced with an electric heat pump. Using this logic, our model dictates that all new machine sales need to be electric by 2035. The sales curve then shows the percentage of sales represented by each **machine type** between 2020 and 2035 to meet the goal of 100% efficient and electric sales by 2035.

Using the sales curve described above, we are able to produce a stock curve that shows how many **machines** of each **machine type** will be in use during each year between 2020 and 2050. From either the RECS or ResStock data, we know how many **machines** of each **machine type** are in use in 2020. We take the key assumption regarding machine lifetimes from above and estimate that roughly 1 out of 15 households will replace a given **machine**, like a water heater, in a given year. The exact replacement rate is dictated by the machine-specific lifetime, which we derive from a combination of the Net Zero America report and InterNACHI. Of the machines that are replacement-eligible in a given year, we let the sales percentages of each **machine type** produced by the sales curve determine how many of the replacement-eligible machines are upgraded to efficient, electric alternatives in the following year. Since the sales curve predicts 100% sales of efficient electric machines beginning in 2035, our model reaches 100% stock of all electric machines by 2050. More details on the calculations used to make these two curves are given in the following two sections.

Sales Curves

Let:

→ p_t^s denote the proportion of sales of **machine type** s in year t

→ a^s denote the current proportion of sales of **machine type** s

→ k^s denote the target proportion of sales of **machine type** s in the end year

→ m denote the inflection point of the sales-curve

→ b denote the slope of the sales-curve

$$p_t^s = a^s + \frac{k^s - a^s}{1 + e^{-b(t-m)}}$$

To put the above formula in simpler language:

→ We start with the current sales percentage of a given **machine type** from RECS or ResStock data, like heat pumps, denoted by a^s

→ We then subtract that from our sales goal for that machine type, often 0% for incumbent technologies and 100% for efficient, electric upgrades, denoted by k^s

→ That is then divided by an exponential growth function that accounts for the current year t, the desired sales trajectory b, and the desired inflection point of the exponential curve m.

- The desired sales trajectory, b, is derived from NREL Electrification Futures study and is equal to 10 over the period between the year that starts the modeling and the year where sales should reach 100% (which is 10/(2035-2020), or 2/3, for most **machine categories**). It is also equal to 1/4 the slope of the sales curve at the inflection point, m
- This is all added back to the current sales percentage, a^s, to give us the sales percentage in that respective year
- This process is repeated for all years between 2020 and 2050

Stock Curves

Let:

- X_t^s denote the sales of **machine type** s in year t, and $X_t^s = \frac{1}{l_s} \times Z_0^s$ for all $t < 0$
- p_t^s denote the proportion of sales of **machine type** s in year t
- N denote the total number of new **machine** units added to the stock each year
- l_s denote the lifetime of **machine type** s
- Z_t^s denote the stock of **machine type** s in year t, where $t = 0$ denotes 2020 and Z_0^s is assumed to be from data

$$X_t^s = p_t^s(N + \Sigma_{s' \in S} X_{t-l_{s'}})$$

$$Z_t^s = Z^s_{t-1} + X_t^s - X_{t-l_s}$$

To put the above formulas in simpler language:

- We start by taking the proportion of sales that a given machine will represent in a given year from the sales curve and denote that with p_t^s
- We multiply that by the total number of new machine purchases made that year, which is derived by seeing how many new homes are built that year, N, and adding it to all machines that need replacement in the same year, $\Sigma_{s' \in S} X_{t-l_{s'}}$
- With that, we find the total number of new stock units of a given machine added to the cumulative stock in that year, X_t^s

→ To find the total stock units, Z_t^s, of that machine type in a given year, we take the stock of that machine type the previous year, Z_{t-1}^s , add it to the number of new units sold, X_t^s, and subtract out the number of units that reached the end of their useful life, X_{t-l_s}

Sales Trend

While the sales curves and stock curves provide targets to meet our goal of full household electrification by 2050, we also calculate 'business-as-usual' forecasts based on current market trends for each year and each electric machine that we hope to promote. To calculate these market trends, we fit a linear trend line on historical sales for each electric technology to understand how many units are likely to sell in a 'business-as-usual' scenario. These forecasts are compared against numbers produced by the sales curve detailed above to calculate how many sales above current trends we need to spur in order to meet our goal.

For each different electric technology like heat pumps or electric vehicles (EVs) that we forecast in our 'business-as-usual' scenario, we find national data on historical market sales trends. We use this sales data to understand the pace at which the market is growing but do not use the data to determine the number of appliances that are currently in use in the US. We apply these national sales trends to each state, county, or city, as we do not have localized sales data for the sales of electric technologies. More details about the different sources for our historical market data are provided below:

→ **AHRI Heat Pump Sales:** The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) provides data on historical air source heat pump (ASHP) sales since 2003. This data helps us understand the rate at which the market for ASHPs is currently growing.
Note: Many astute readers have noticed that our heat pump sales plots present significantly lower numbers in the present day than the AHRI ASHP sales data shows. This is because the data from AHRI includes commercial ASHPs and measures units, not installations. Many homes may have multiple units for a single installation (e.g., a home may have multiple outdoor units for a whole-home multi-split system). The entire installation would be counted as a single heat pump sale in our model, while it is counted as multiple heat pump units in AHRI's data.

In this model, we scale the AHRI sales data to match the sales numbers we extracted from RECS in 2020. We then find the slope of the linear trendline fit to heat pump sales in recent years to represent the business-as-usual scenario, not the absolute number of units sold.

→ **ENERGY STAR Heat Pump Water Heater Sales:** ENERGY STAR provides heat pump water heater (HPWH) sales data that is similar to the data for ASHPs described above. Using this data, we can determine the current growth rate of the market for HPWHs.

→ **AHAM Induction Stove Sales:** We have a few limited data points from the Association of Home Appliance Manufacturers (AHAM) that allow us to extrapolate historical national sales trends for induction stoves, similar to the data on ASHPs and HPWHs described above. Using this data, we can determine the current growth rate of the market for induction cooking.

→ **BTS EV Sales:** The Bureau of Transportation Statistics (BTS) within the Department of Transportation provides data on the sales of alternative fuel vehicles in recent years. The data tracks sales of Hybrid vehicles, Plug-in hybrids, and EVs. We only use the EV data in order to establish a trend in the market growth of EVs in a similar way as the other machines above.

→ **EIA Net Metering Customer Data:** The EIA surveys utilities on how many of their customers are enrolled in net metering programs. It is common for customers to enroll in net metering programs to improve the economics of rooftop solar, so this number serves as a useful metric for the number of rooftop solar installations in the US. We use the growth of the number of net metering customers in recent years to project historical growth of the rooftop solar market as a whole.