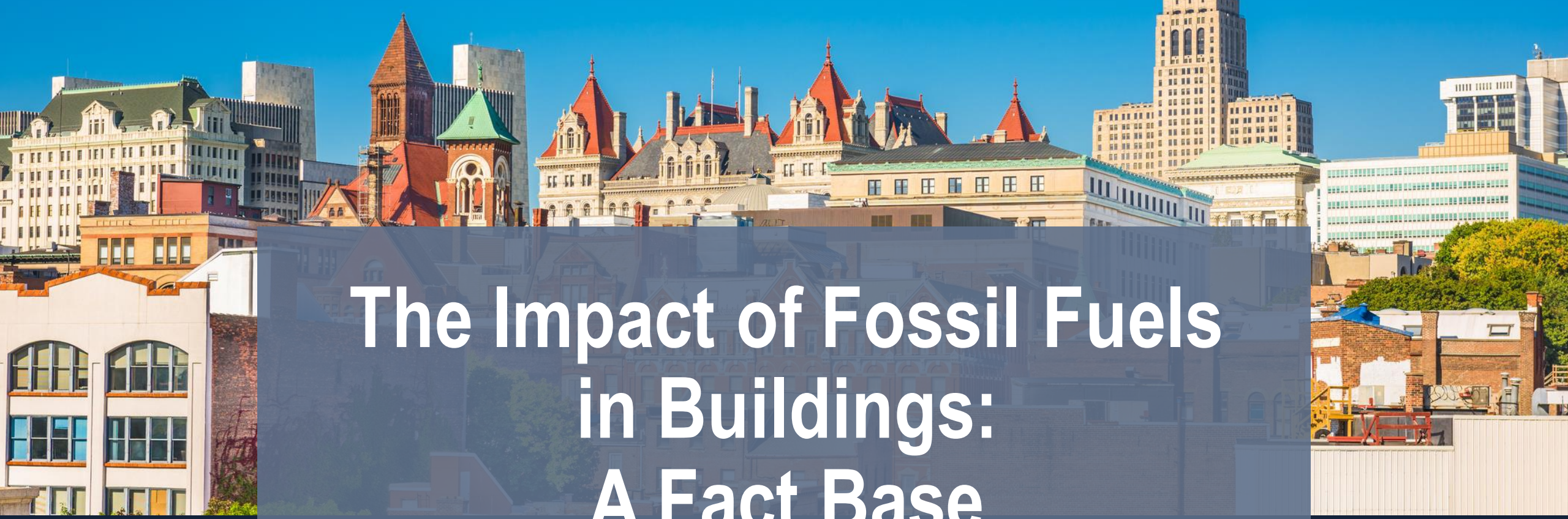

The Impact of Fossil Fuels in Buildings: A Fact Base

December 2019

Transforming global energy use to create a clean, prosperous, and secure low-carbon future.

Executive Summary

A tenth of US carbon emissions come from burning fossil fuels—primarily gas—in homes and businesses across the country. The data and charts that follow form a cross-cutting fact base that characterizes where these emissions come from and how they fit into the overall emissions picture in the United States. This fact base also provides an understanding of the utilities and infrastructure that deliver gas, the buildings and appliances that use it, and implications for air quality and human health.

Across the US economy, gas has now surpassed coal in its overall contribution to climate change. With coal's decline, electric power-sector emissions have fallen by a quarter in the past decade, but emissions from fuels burned in buildings has not budged. The majority of these emissions are the result of burning gas (about 450 million tons of CO_2 per year), with propane (78 million tons) and heating oil (64 million tons) still producing significant emissions. Methane, the main component of gas, leaking directly into the air contributes additional emissions—anywhere from 130 million tons of CO_2 equivalent up to 465 million tons. All told, building fuels account for 735 million tons–1,067 million tons of CO_2 equivalent emissions.

These emissions are fairly concentrated, with just 10 states accounting for 56% of direct building emissions. Three states—New York, California, and Illinois—account for a full quarter of these emissions. The 10 states where buildings contribute the highest proportional share of statewide emissions have each committed to 80% or greater carbon emissions reductions, indicating that major changes are on the horizon.

While the gas distribution system has consistently expanded, improvements in energy efficiency have kept overall gas use relatively flat. Nonetheless, annual capital expenditure on the gas distribution system has soared in recent years, reaching roughly $15 billion in 2017. The majority goes to expanding the system, rather than replacing existing infrastructure. As a result, the gas system is getting older—in the last 15 years, the average age of gas mains has risen from 28 years to over 33 years. At today's rate of replacement, it will take more than 230 years before all existing gas mains are replaced.

Gas burned in homes and businesses also produces byproducts that are hazardous to human health, including NO_2. Cooking with gas can produce indoor NO_2 concentrations that exceed the outdoor standards for safe air. Most home cooks rarely or never use proper ventilation when cooking with gas.

There is precedent for rapid change in this sector—in the 1940s, coal was the dominant heating fuel in US homes, but by the 1970s its share had fallen to below 5% of households, and it was virtually eliminated by the 1980s. Although gas was the primary replacement, electricity has gradually eroded gas's share over the past several decades. The most recent data shows that 25% of US households and 29% of commercial buildings are all electric, up from 21% each over roughly a decade ago. Nearly 40% of US households use electricity as a primary heating source. From 2010 to 2017, 49 states and the District of Columbia all saw increases in the share of households relying on electric heat.

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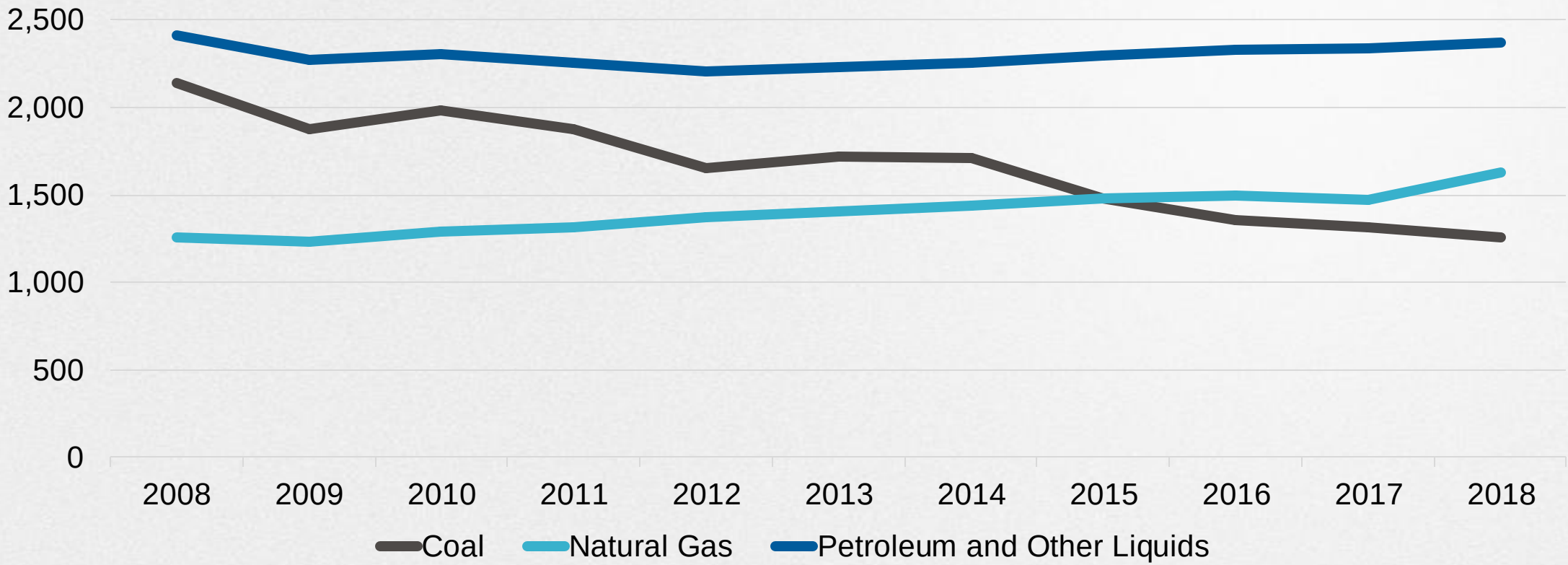
Carbon emissions from gas, which increased by nearly 10% in 2018, drove an overall increase in US emissions. Emissions from gas have exceeded coal since 2015.

US energy-related CO_2 emissions by fuel

Million metric tons CO_2, 2008–2018

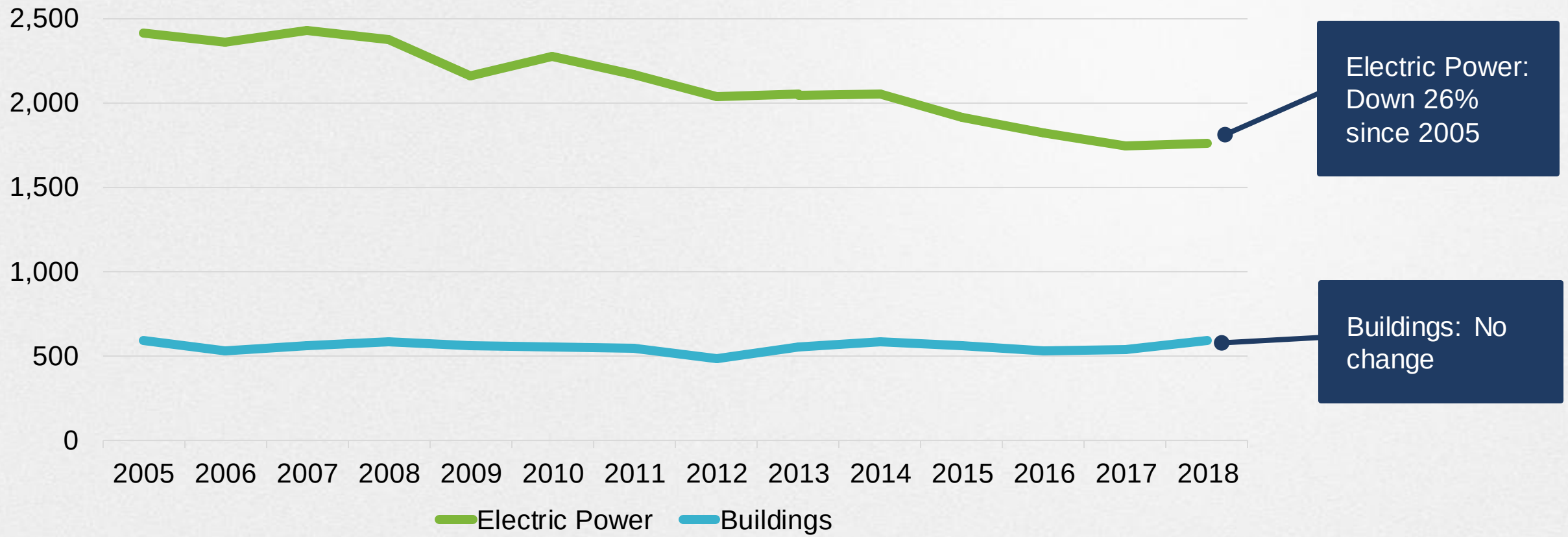


Source: U.S. Energy Information Administration (EIA) 2018

The United States has reduced carbon emissions in the electricity sector, but not in the buildings sector

Annual CO_2 emissions from electric power and buildings sectors

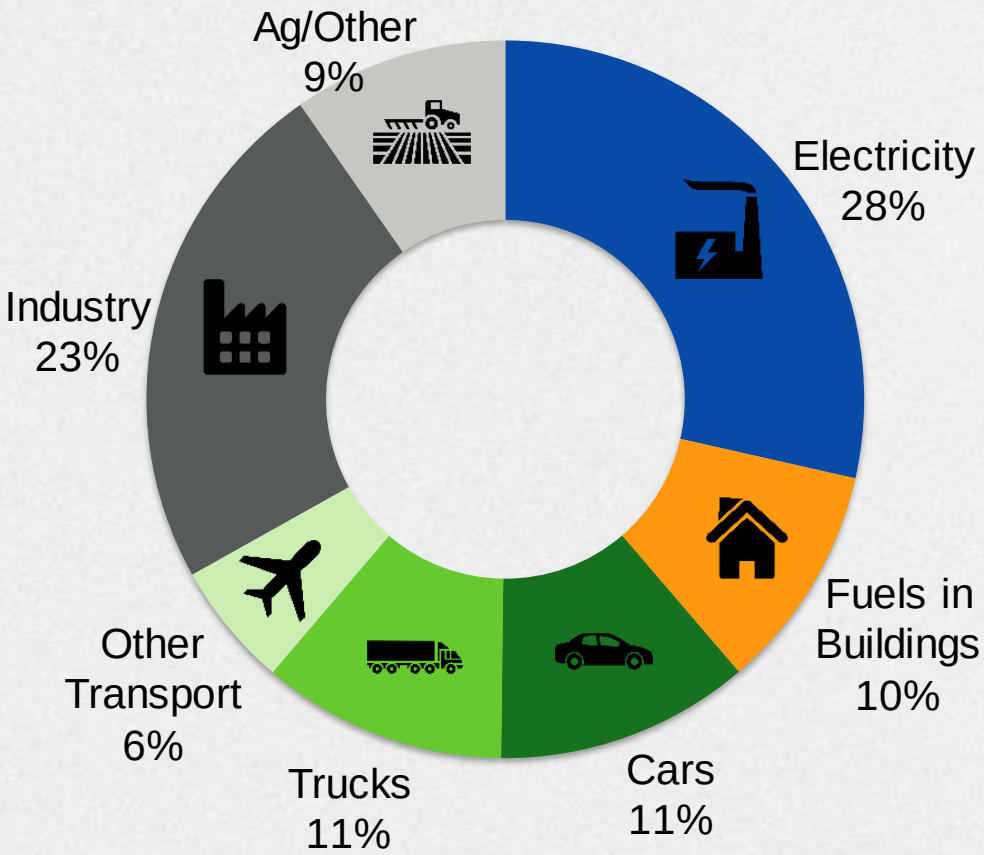
Million metric tons CO_2, US total, 2005–2018



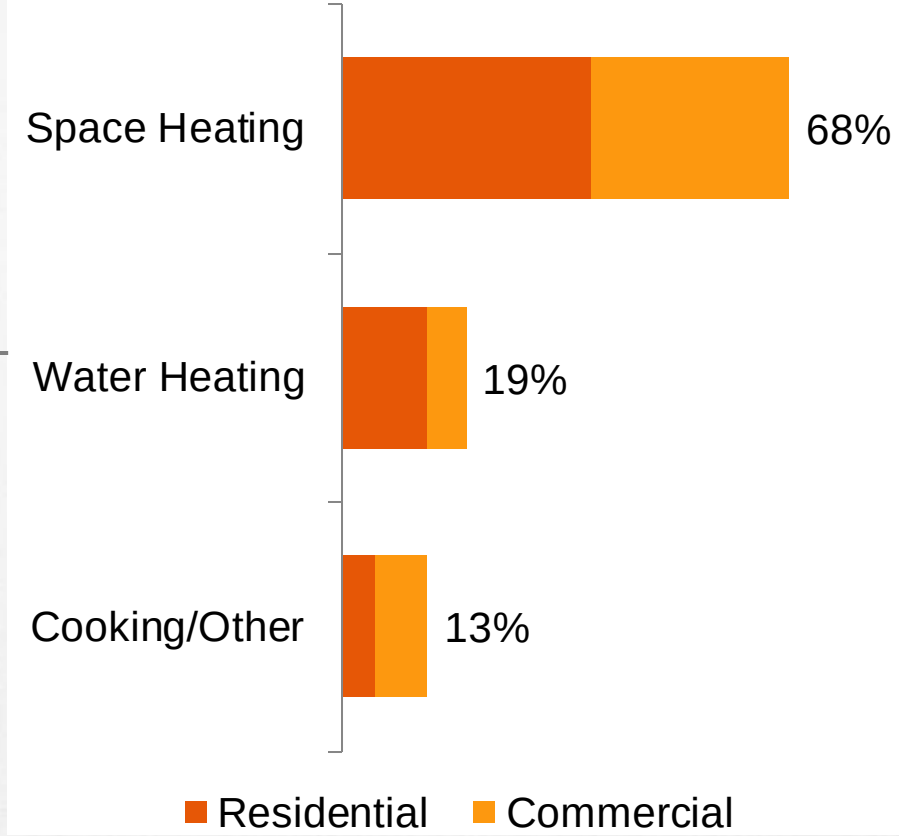
Source: EIA 2018

Fuels burned in 70 million homes and businesses account for 10% of US carbon emissions

Sources of US greenhouse gas emissions by share of total, 2017



Breakdown of fuel emissions in buildings

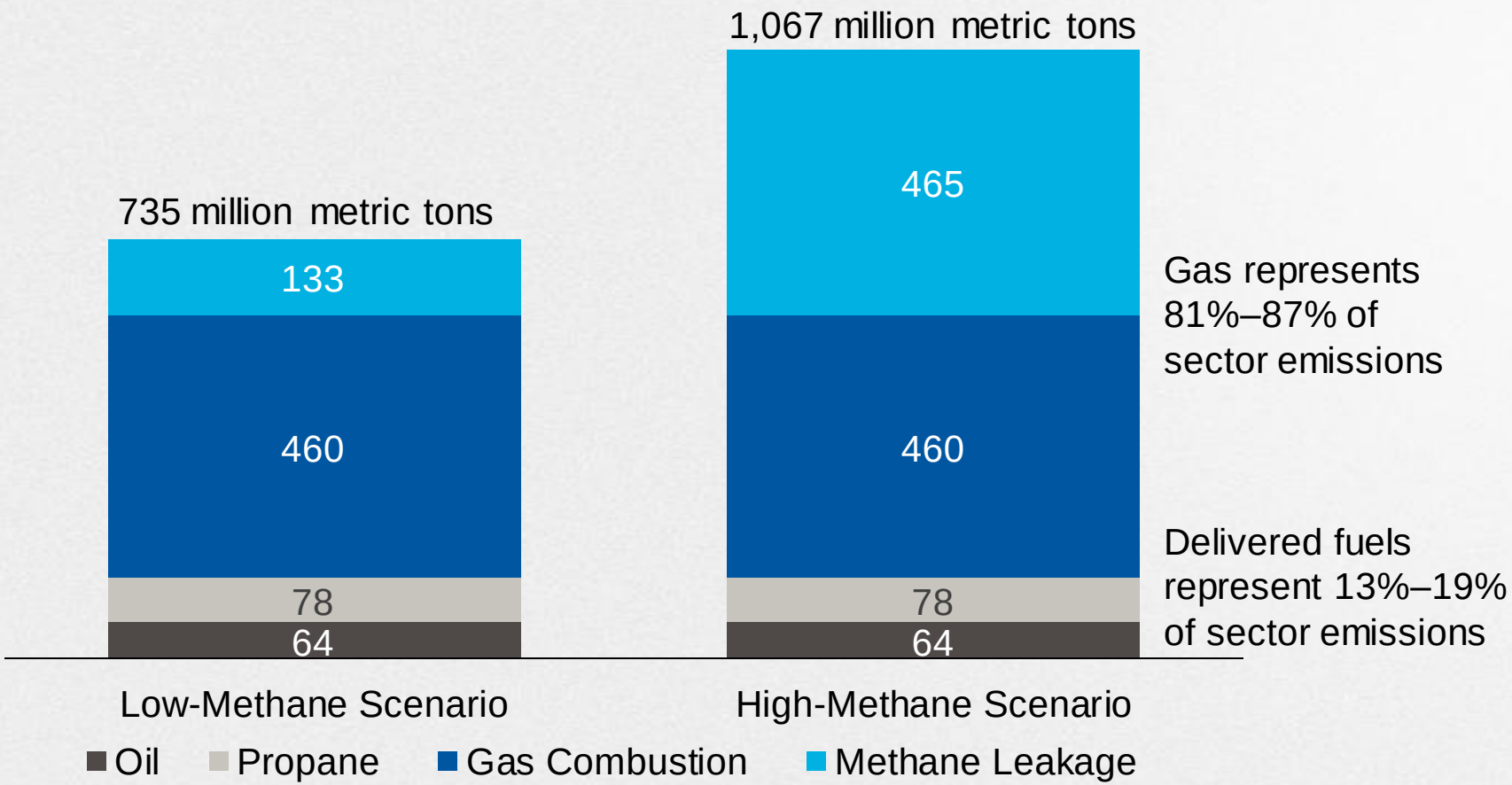


Sources: EPA Greenhouse Gas Inventory, 2017 (excludes land use, land use change, and forestry); EIA Residential Energy Consumption Survey (RECS), 2015

Gas is responsible for the majority of direct building emissions

Greenhouse gas emissions by building fuel

Residential and commercial sectors, US, 2018



Methane leakage estimates vary by total percentage leakage and global warming potential (GWP).

The total buildings-sector methane leakage may be 18% to 44% of buildings-sector climate impacts.

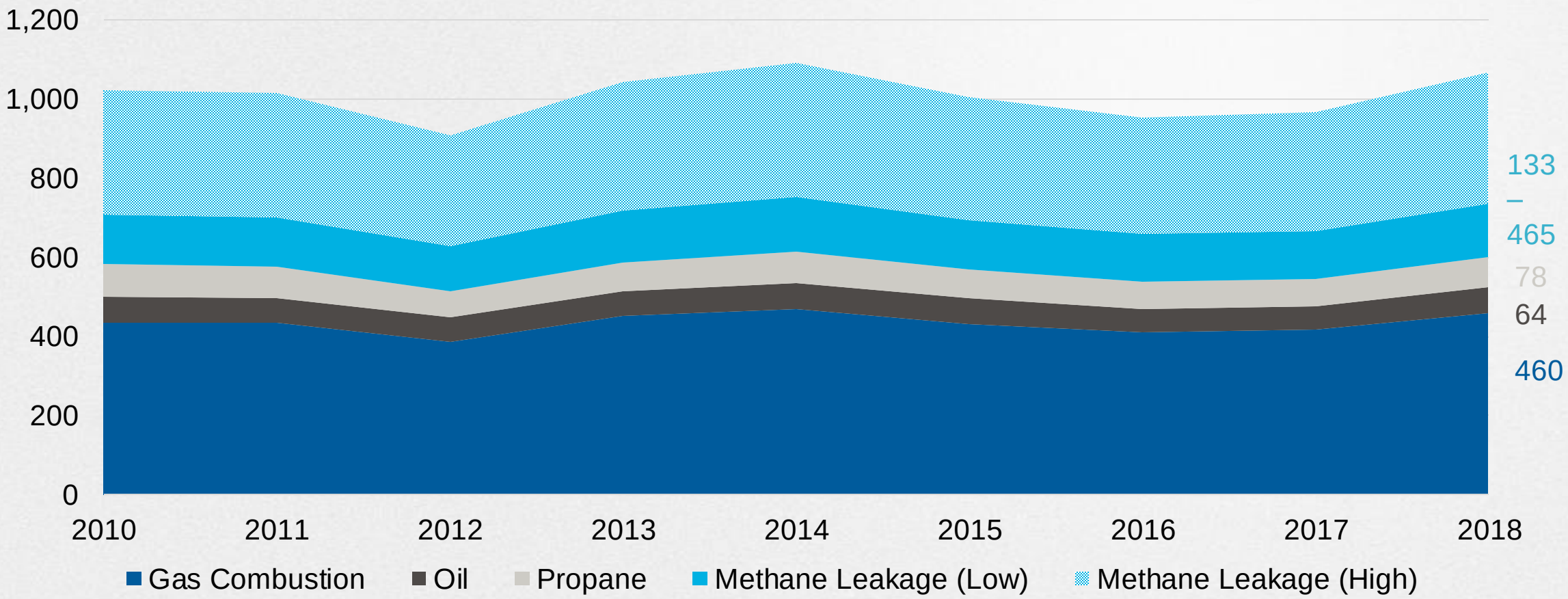
More information regarding these uncertainties is available later in these slides.

Note: "Direct" buildings-sector emissions refers to emissions from burning fuels, not those from electricity use.
Source: RMI analysis

Direct building emissions have remained flat over the past decade

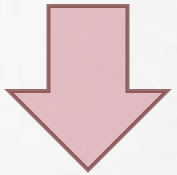
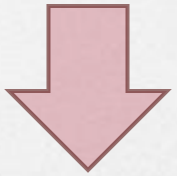
Greenhouse gas emissions by building fuel

Million metric tons CO_2e, residential and commercial sectors, US, 2010–2018



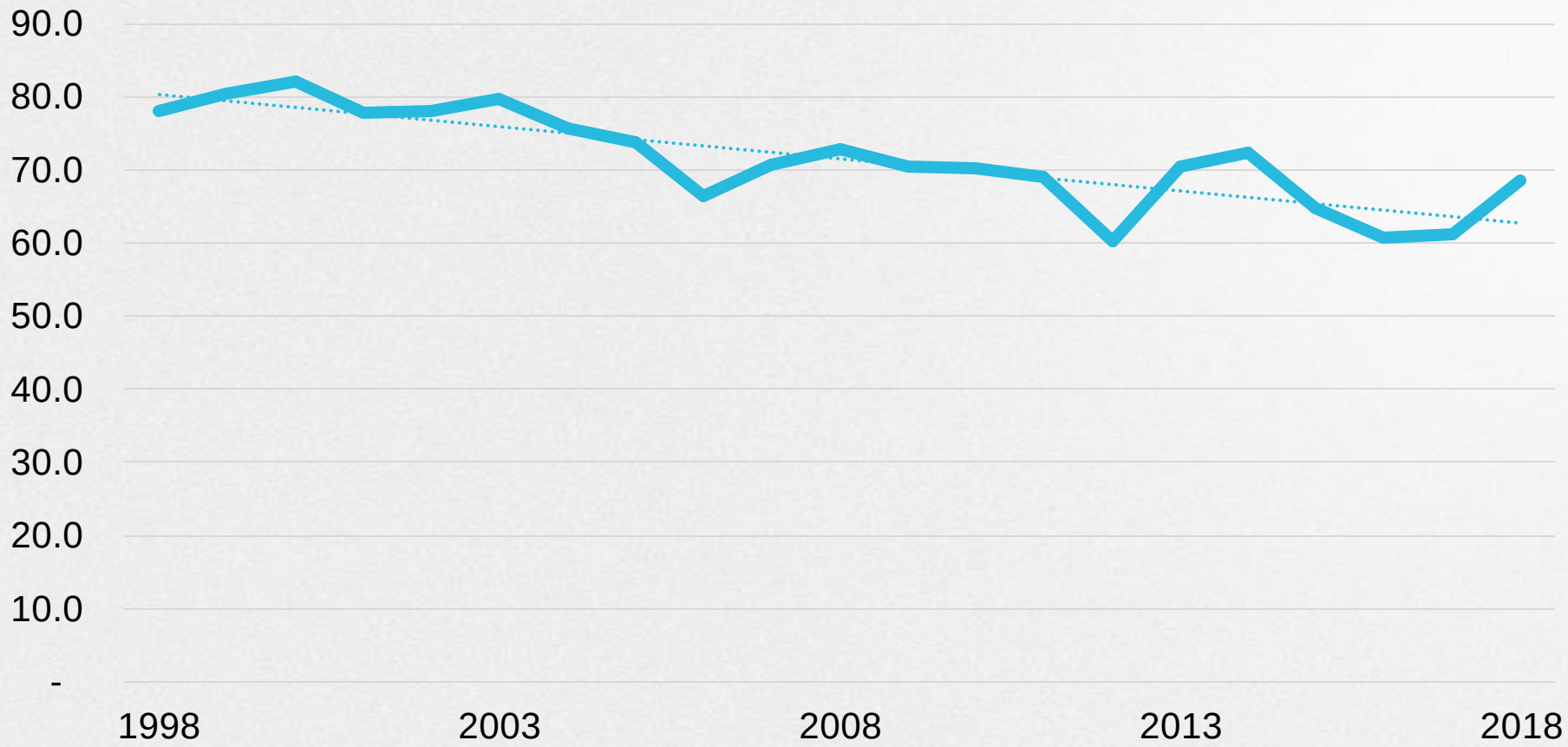
Note: “Low” leakage scenario represents 2.2% leakage at 100-year GWP; “High” represents 3.9% leakage at 20-year GWP.
Sources: EIA 2018, Rhodium Group 2019, RMI analysis

Gas sales to residential and commercial customers have been flat, but this disguises multiple underlying drivers

		Impact on gas consumption
Trend 1	US building stock continues to grow	
Trend 2	Growing share of buildings are all-electric, or use electricity as primary source of heat	
Trend 3	Heating oil use has declined as customers switch to gas or electricity	
Trend 4	Gas customers have become more energy efficient	

Gas customers have become more energy efficient

Annual gas consumption per residential customer
Mcf, US average, 1998-2018

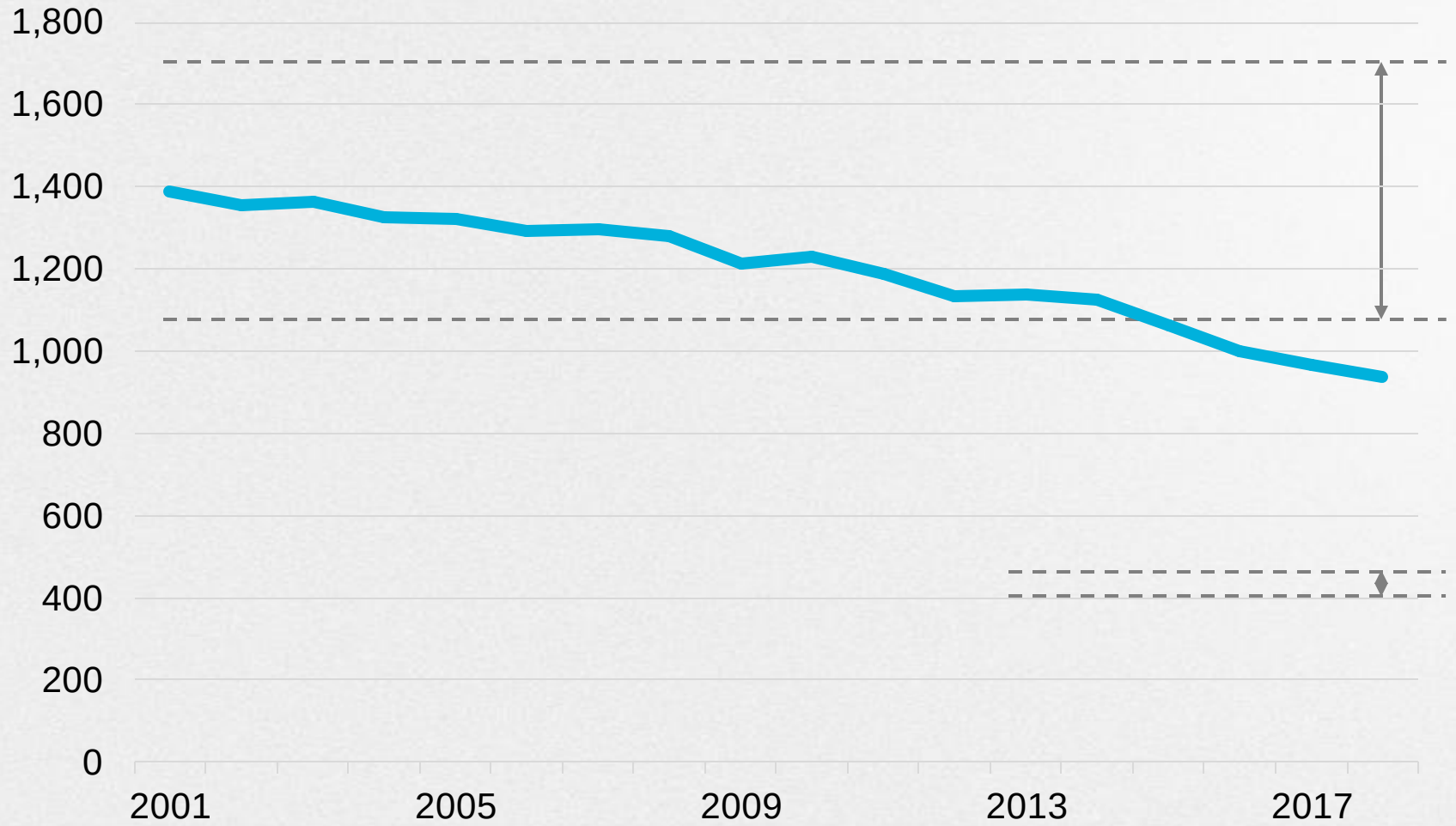


Weather contributes to interannual fluctuation, but trendline indicates average decline of 0.9 Mcf per customer per year

Source: EIA

With today's electric grid, efficient electric heat pumps reduce carbon emissions compared to gas appliances. As market forces drive a cleaner grid, electric heating will reduce emissions further.

Carbon intensity of US electric system
lbs/MWh, 2001–2017



Break-even range
lbs/MWh

1,650 lbs/MWh
Mild climate

The use of electric heat pumps produces less carbon emissions than gas appliances.

1,050 lbs/MWh
Cold climate

Inefficient electric appliances (e.g., resistance heat) produce less carbon emissions than gas ~400 lbs/MWh–450 lbs/MWh.

Note: "Mild" climate modeled as single-family home in Oakland, CA; "Cold" climate modeled as multifamily residential building in Boston, MA. Sources: emissionsindex.org, RMI analysis

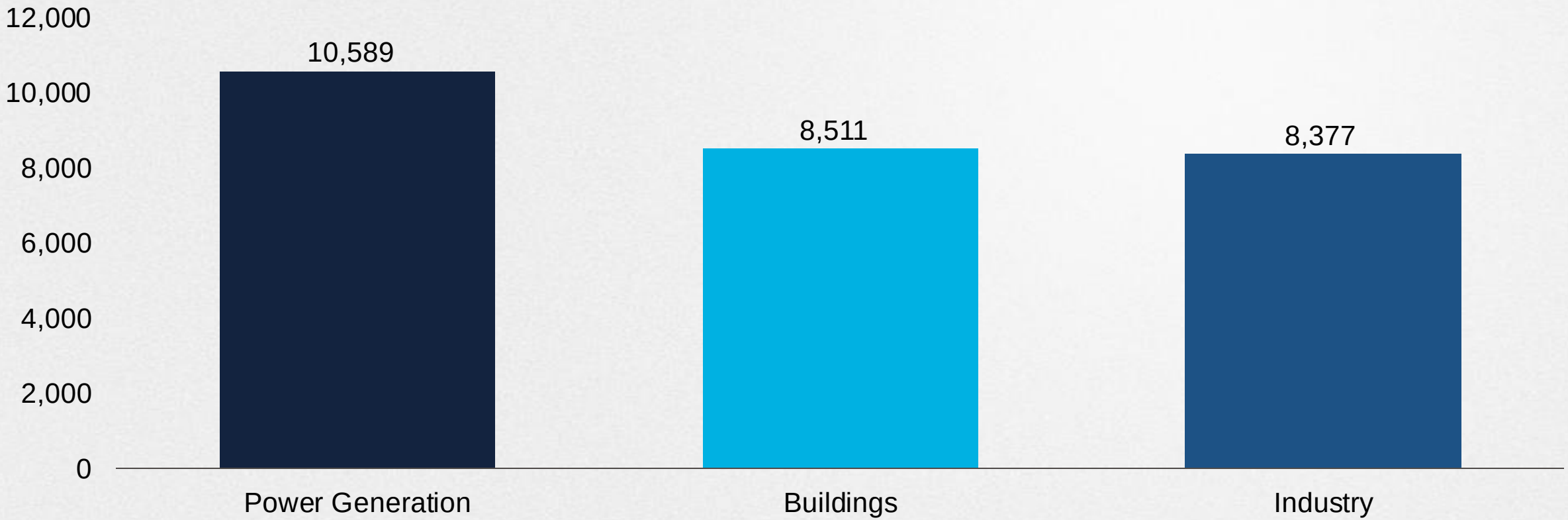
Even burning gas in a power plant to run a heat pump is more efficient than a gas furnace or boiler

	Gas Consumed	Power Generation	Energy Input to Distribution System	T&D Losses	Energy Input to Appliance	Appliance Efficiency	Thermal Energy Output
Gas Furnace	**10.5** MMBTU	n/a	**10.5** MMBTU	**0.4%** Leakage	**10.5** MMBTU	**0.95** AFUE	**10.0 MMBtu 2,921 kWh**
Heat Pump	**9.6** MMBTU	 CCGT Heat Rate 7,812 Btu / kWh *~44% efficient*	**4.2** MMBTU **1,235** kWh	 5% Line losses	**4.0** MMBTU **1,173** kWh	**2.49** COP	

Sources: EIA (average US line loss and gas plant heat rate);
EnergyStar (appliance efficiencies benchmarked at EnergyStar qualification level)

Power generation is the major user of gas in the United States, but building use has exceeded that of industry

Gas consumption by sector
Billion cubic feet, US, 2018

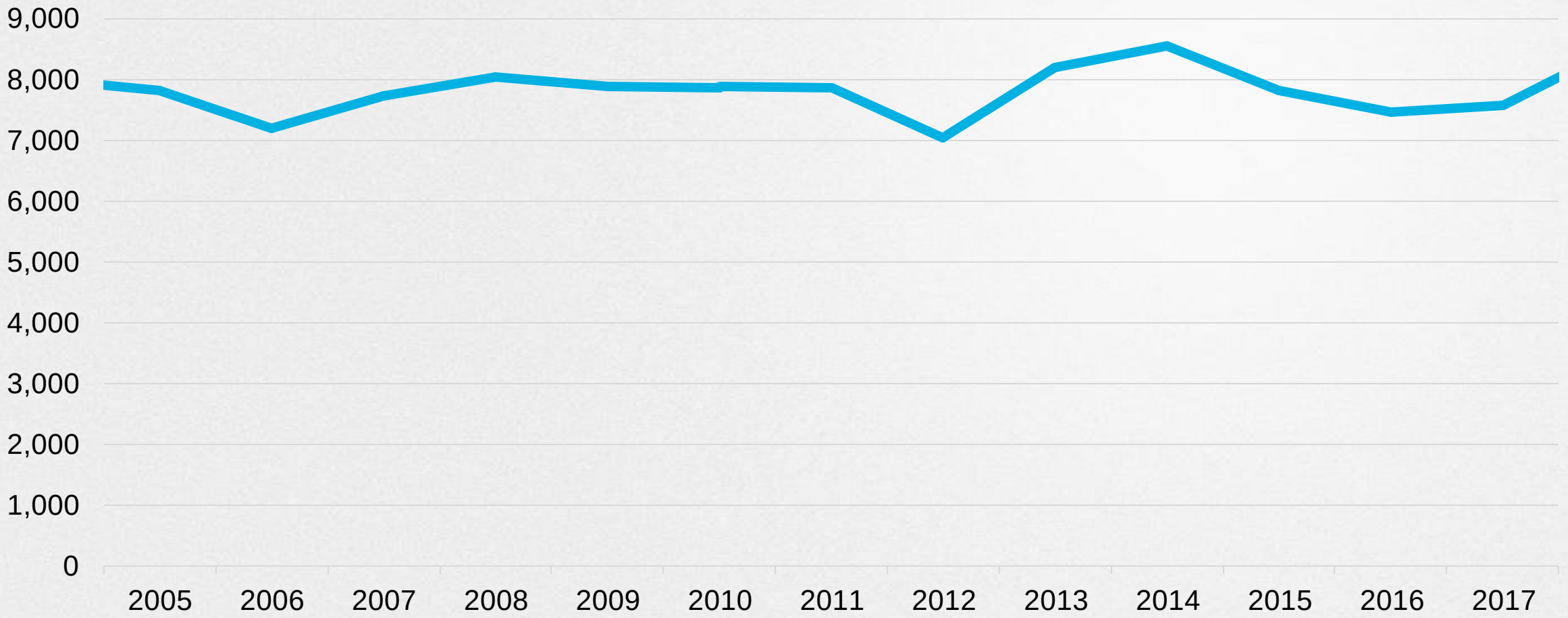


Note: These three end uses represent 92% of gas consumption.
Source: EIA 2018

Gas use in buildings has remained flat since 2005

US gas consumption

Billions of cubic feet, residential and commercial sectors, 2005–2017

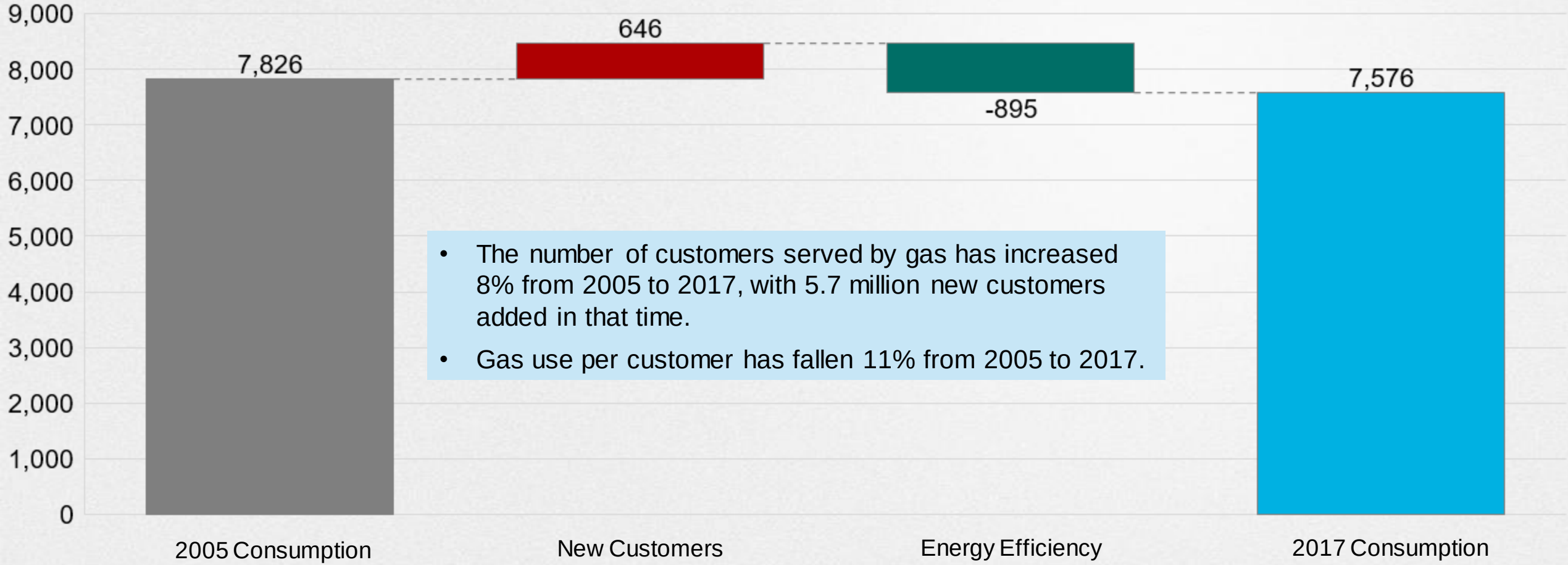


Source: EIA 2017

Total gas consumption has remained flat for the past decades because energy efficiency improvements are nearly equivalent to consumption by new gas customers

Impact of new customers and energy efficiency on gas consumption

Billion cubic feet, residential and commercial sectors, US

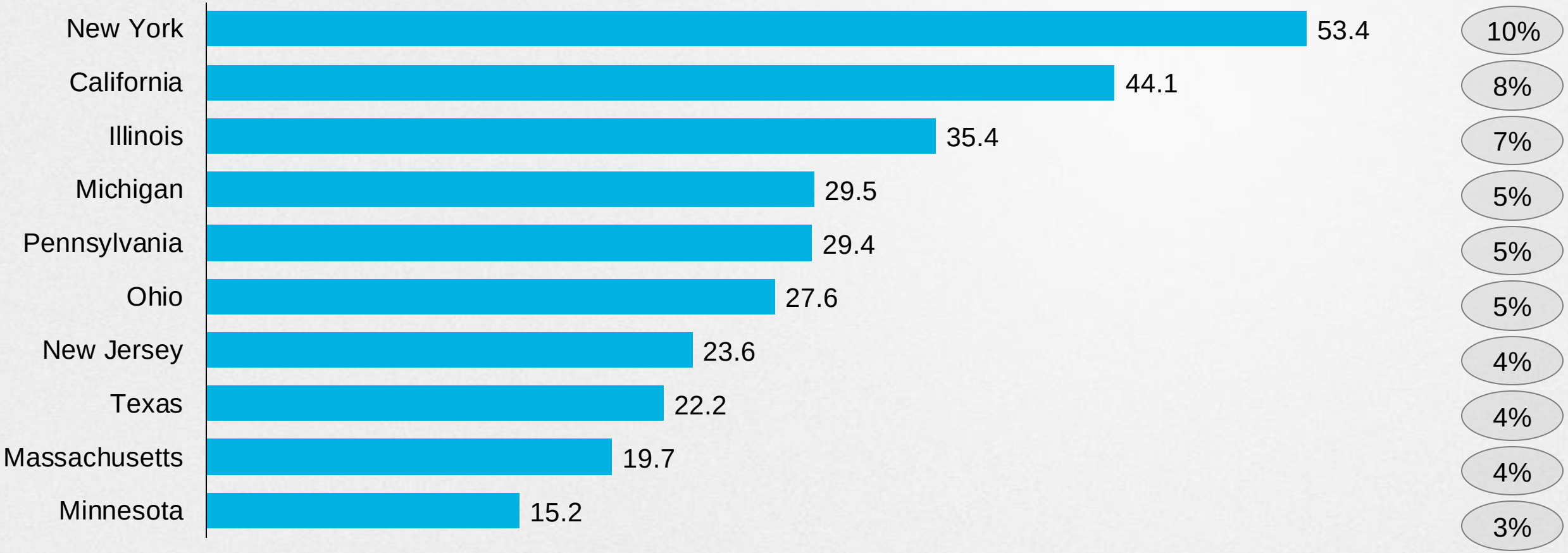


- The number of customers served by gas has increased 8% from 2005 to 2017, with 5.7 million new customers added in that time.
- Gas use per customer has fallen 11% from 2005 to 2017.

Sources: EIA 2005, 2017, RMI analysis

Ten states are responsible for 56% of direct building emissions nationally

Building greenhouse gas emissions by state
Million metric tons CO_2e, 2017

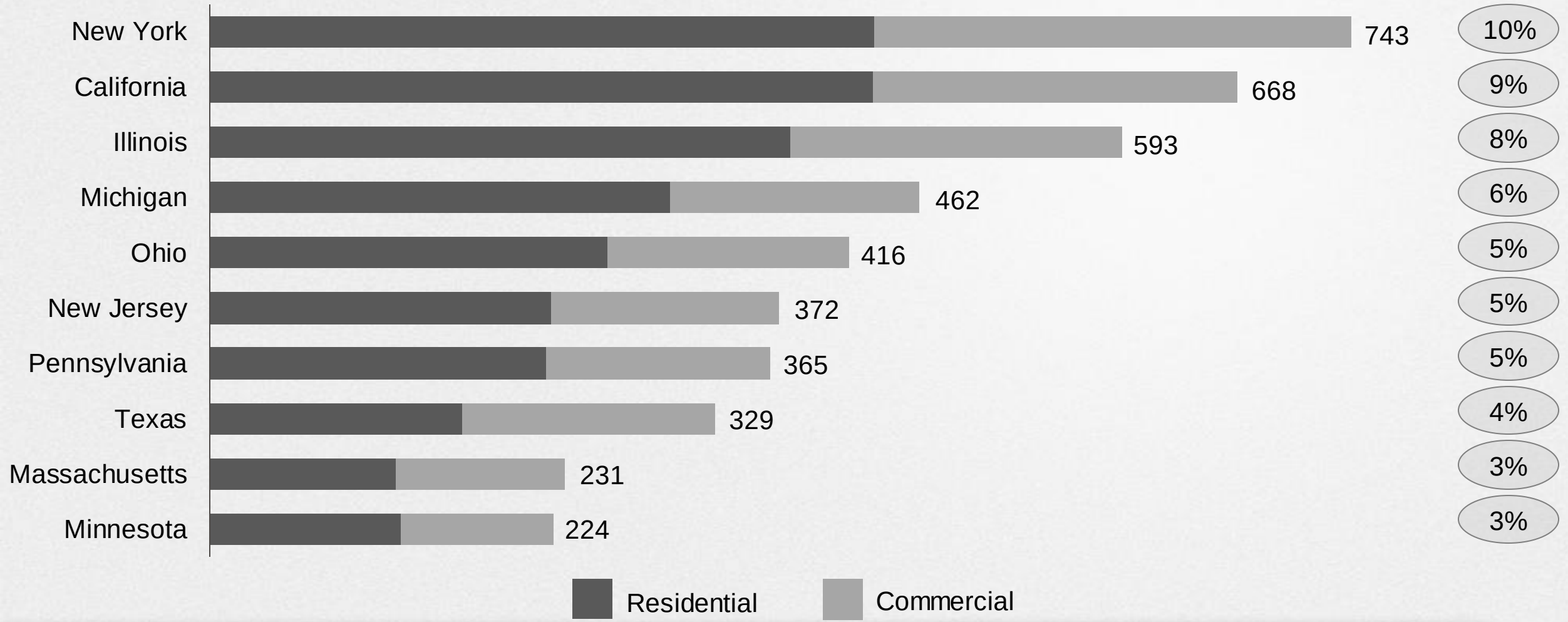


Note: Excludes methane leakage.
Source: EIA 2017

The top 10 states accounted for 58% of direct building gas use in 2017

Gas delivery by state

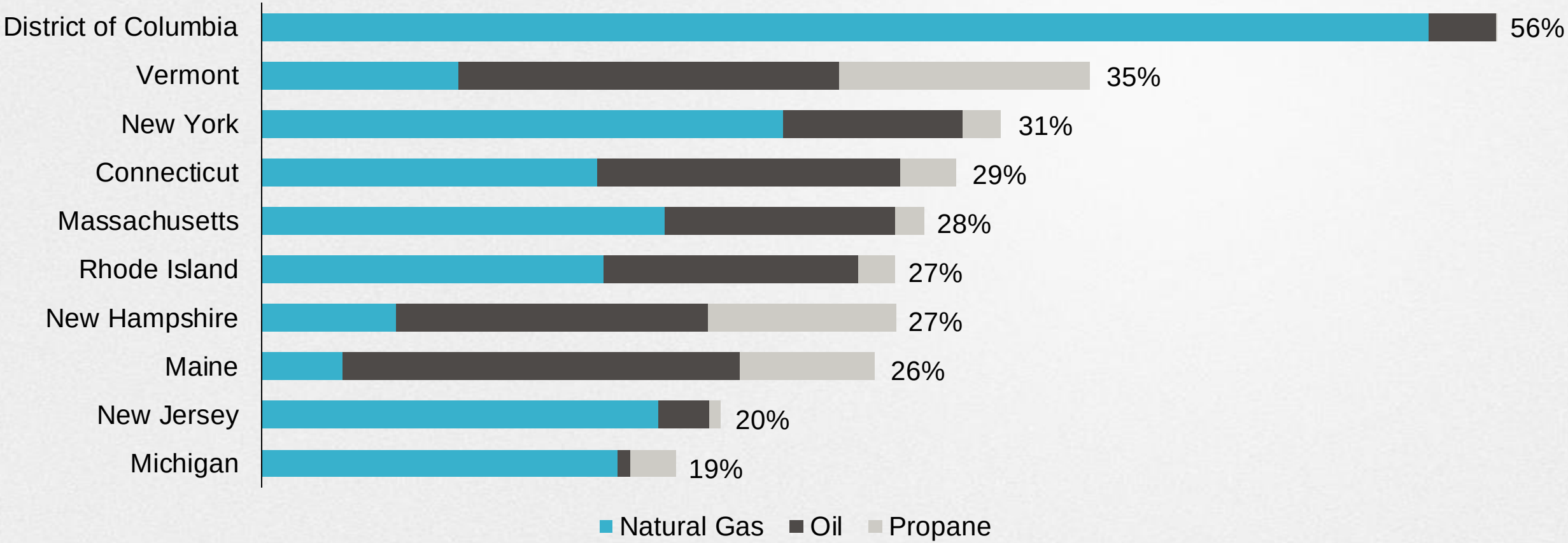
Billion cubic feet, 2017



Source: EIA 2017

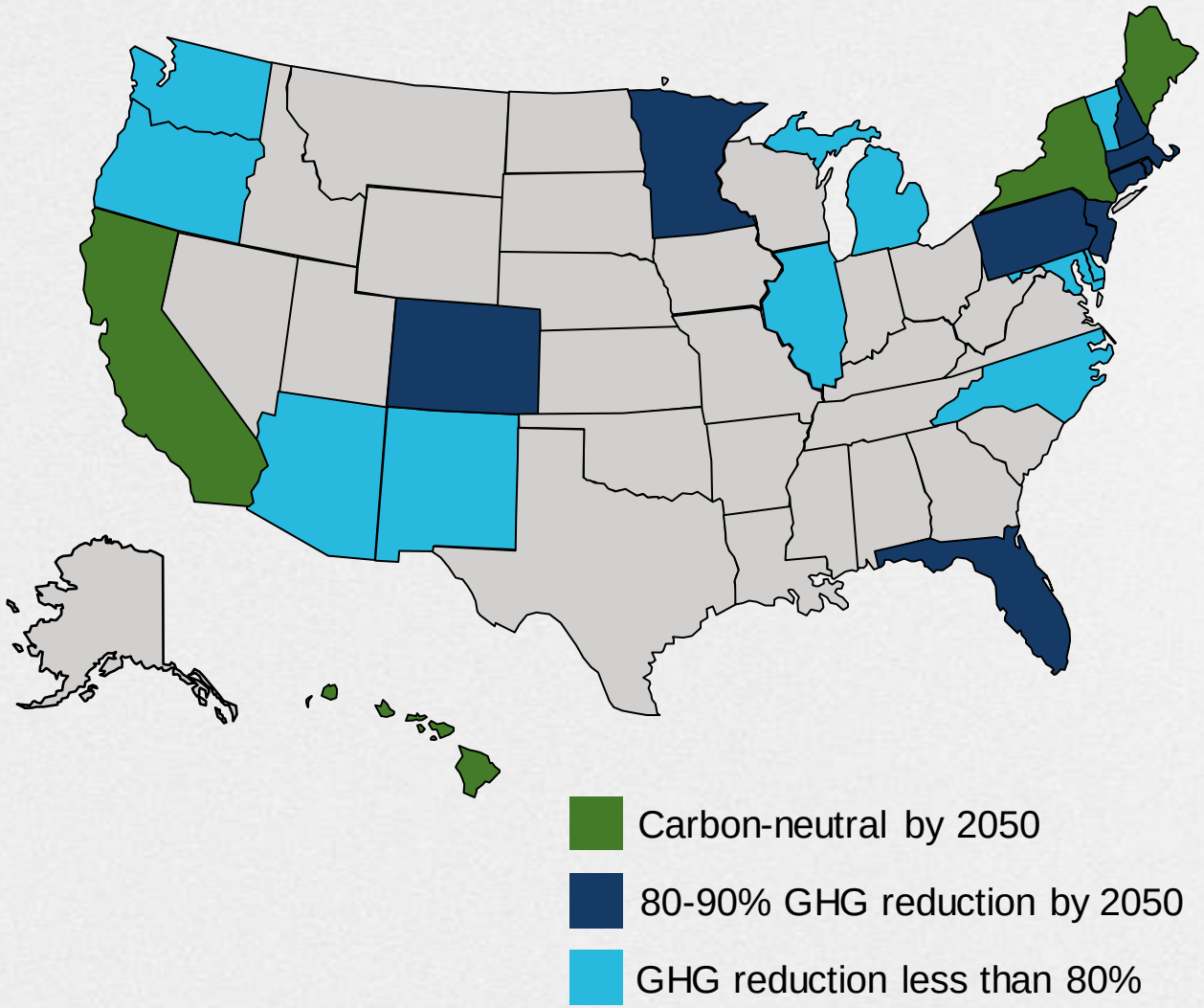
Most of the states with the greatest proportion of energy-sector carbon emissions from burning fossil fuels in buildings have committed to 80% decarbonization by 2050

Direct building share of energy-related total emissions
2016



Note: EIA data accounts for in-state electricity production only, not emissions from imported electricity.
Source: EIA 2016

State-level climate commitments are expanding and increasing in ambition



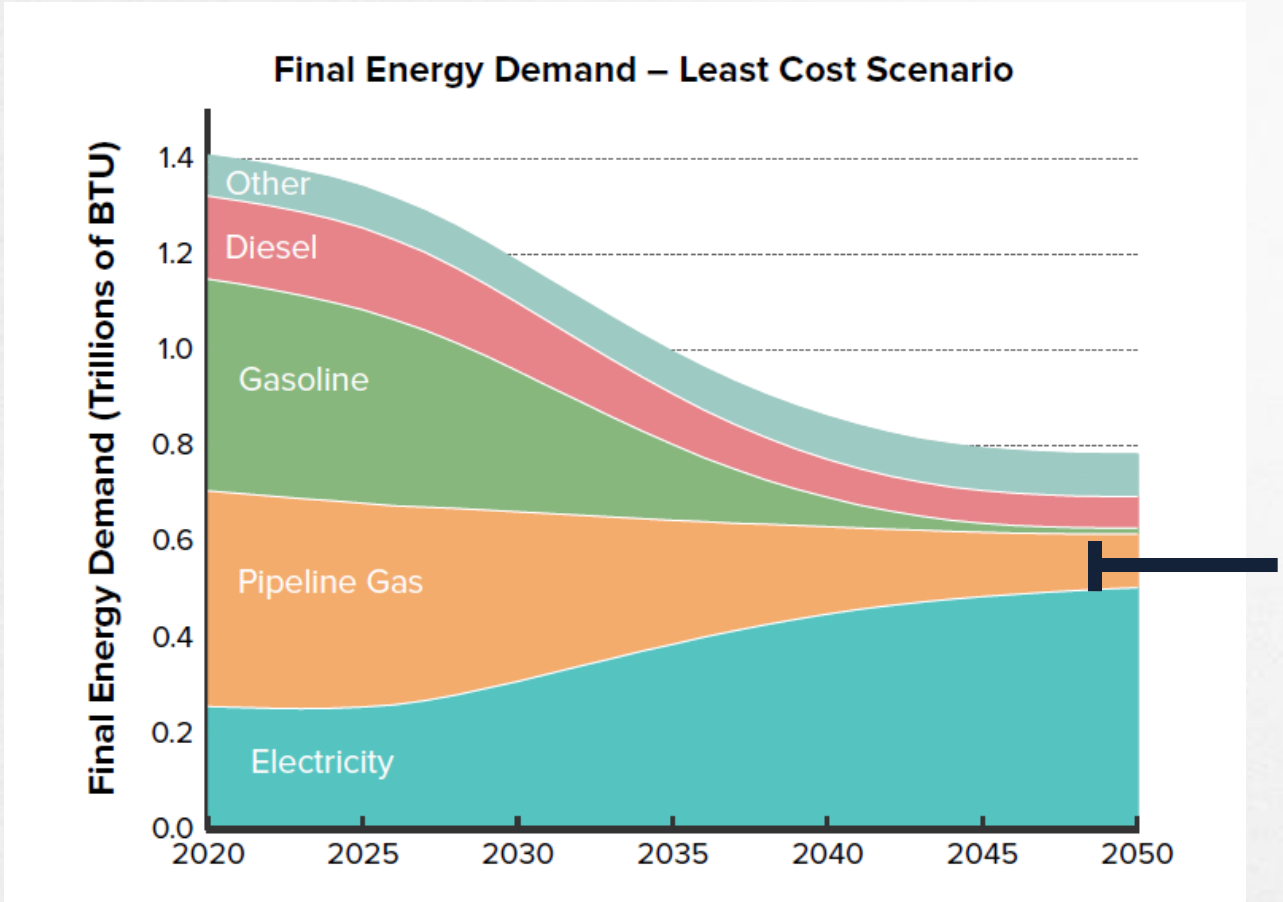
24 States have committed to statewide GHG emission reduction targets.

- California and Hawaii committed to achieving carbon neutrality by 2045 and New York has committed to carbon neutrality by 2050 and 9 States have committed to reducing their carbon emissions by 80% or more by 2050.
- Represents **55% of the US population** and a **$11.7 trillion economy.**
- Has generated **$3.8 billion** in new investment in utility-driven energy efficiency improvements in 2016 *(60% increase from 2010)*
- **Florida:** enacted nonbinding targets in 2007 for reducing emissions: 2000 levels by 2017, 1990 levels by 2025, and 80% below 1990 levels by 2050.
- **New Mexico:** issued an executive order in 2019 for emissions reduction targets: 45% below 2005 levels by 2030.

Source: United States Climate Alliance Annual Report 2018; C2es U.S. State Greenhouse Gas Emission Targets

New Jersey's Energy Master Plan concludes least cost pathway to 80% GHG reduction relies on building electrification and major reductions in gas use

New Jersey's new Energy Master Plan foresees substantial declines in gas use, in order to meet climate targets



This Least Cost Scenario includes electrification of 90% of New Jersey's residential and commercial buildings

Pipeline gas consumption must drop 75%

Source: New Jersey Integrated Energy Plan, Public Webinar, November 1, 2019
https://nj.gov/emp/pdf/NJ%20IEP%20Public%20Webinar%20Nov1%20Final.pdf

Northeastern states have been leaders in developing markets for cold climate air source heat pumps and ground source heat pumps

Maine

- State law set a goal of 100k new heat pump installations from 2019 through 2024 (in a state with ~550k households) and provided funding
- Existing Efficiency Maine programs have provided 40k heat pump installations in past 5 years
- Maine has committed to reduce emissions 80% by 2050.

Vermont

- Vermont's Renewable Energy Standard includes a separate requirement for utilities to reduce customer fossil fuel use
- Increasing targets for fossil fuel reduction have directly driven heat pump deployment
- Vermont has committed to 50% below 1990 levels by 2028 and, if possible, 75% by 2050.

New York

- New York Public Service Commission is requiring utilities to achieve part of their energy efficiency targets with heat pumps
- Equivalent to ~80k households by 2025
- NYSERDA developing road map to carbon-free buildings
- New York has committed to a carbon neutral economy by 2050 from 1990 levels.

Massachusetts

- Massachusetts utilities now including strategic electrification in efficiency plans
- MassCEC leading new pilot programs for whole-home heat pump solutions without gas
- Massachusetts committed to reduce emissions: 25% below 1990 levels by 2020 and 80% below 1990 levels by 2050.

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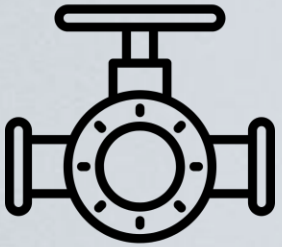
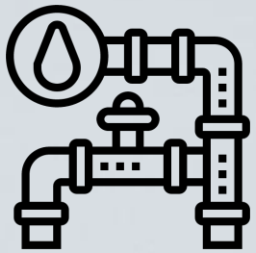
In 2018, an estimated 223 billion cubic feet of methane was leaked while delivering 7,576 billion cubic feet of gas to buildings

Gas Production

Processing and Storage



Transmission



Distribution

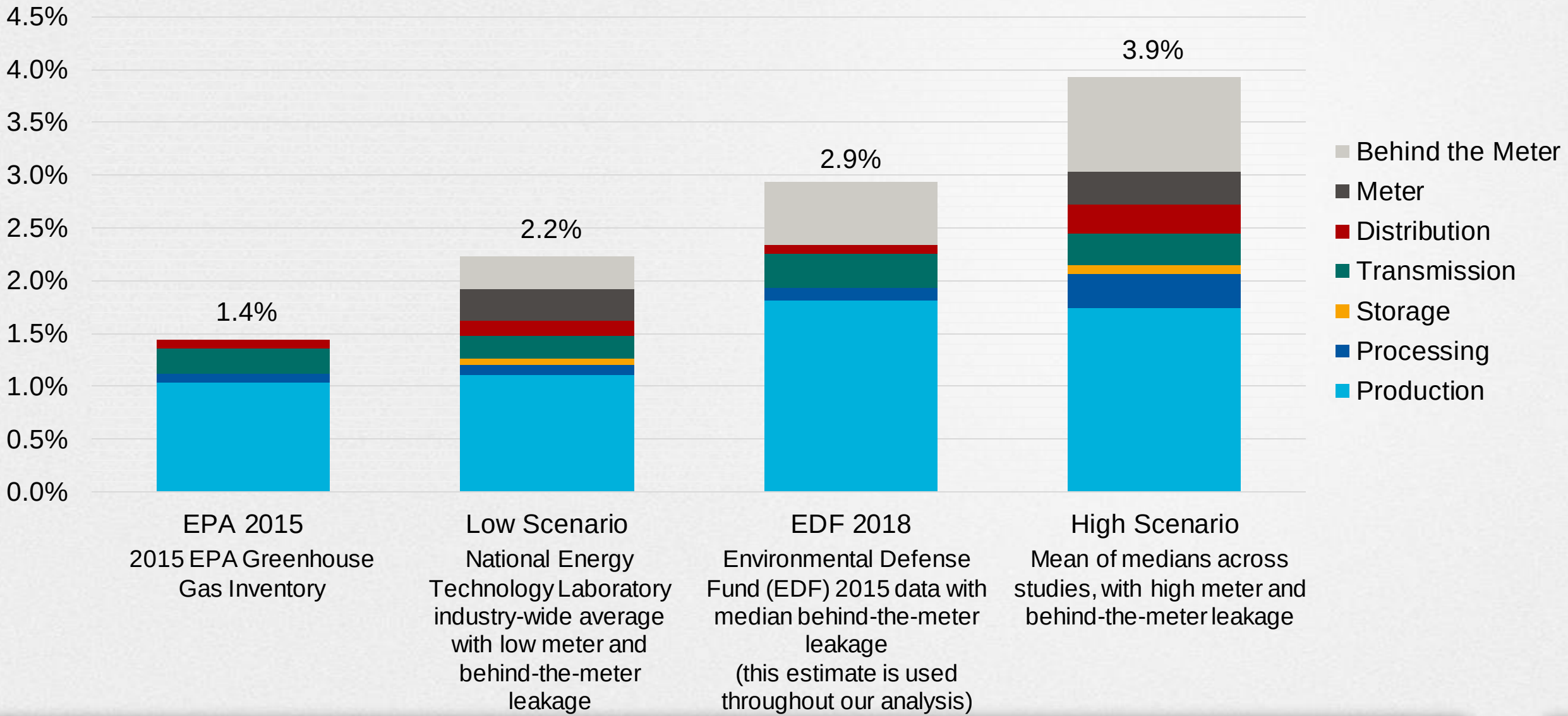
Building-level

Leak volume billion cubic feet

Gas Production	Processing and Storage	Transmission	Distribution	Building-level
1.81%	0.13%	0.32%	0.08%	0.60%
(1.04%–1.81%)	**(0.14%–0.41%)**	**(0.21%–0.32%)**	**(0.08%–0.32%)**	**(0.60%–1.21%)**

Sources: EIA, RMI analysis, and Ramón A. Alvarez et al, "Assessment of Methane Emissions from the U.S. Oil and Gas Supply Chain," *Science,* July 13, 2018, accessed November 20, 2019, https://science.sciencemag.org/content/361/6398/186.

Scientific assessments of location and size of methane leaks vary



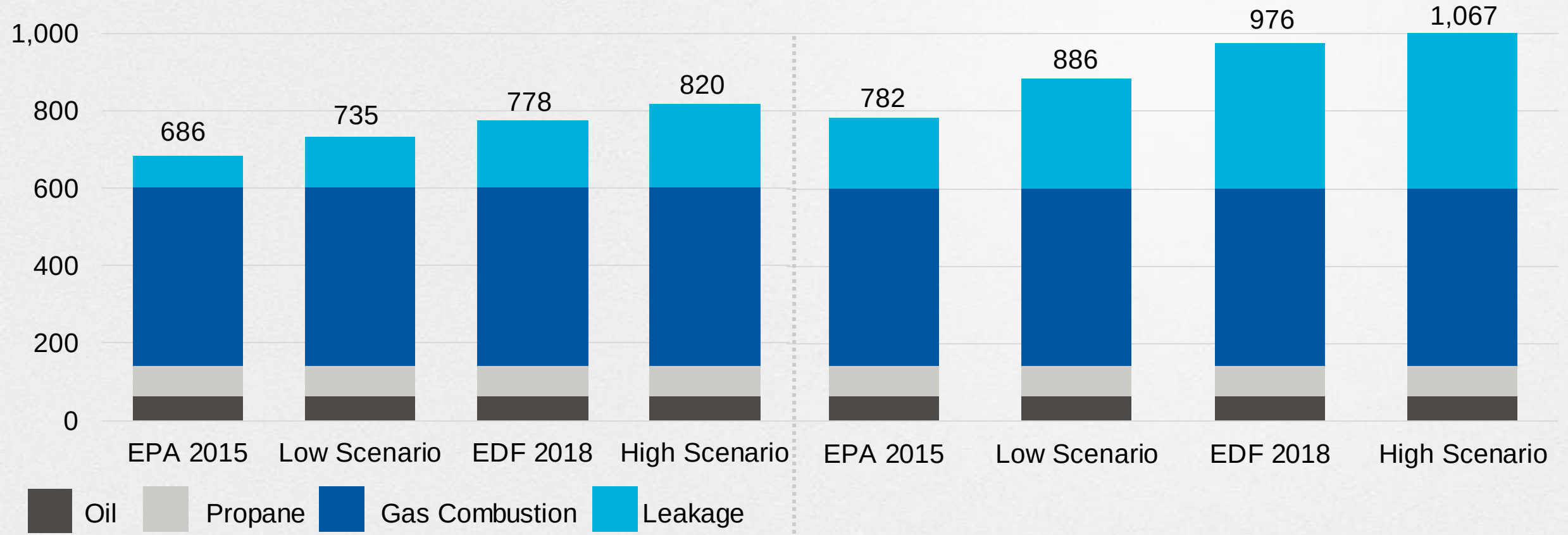
Note: These percentages depict methane leakage as share of gas consumed in residential and commercial buildings.
Source: RMI analysis of EPA 2015, NETL 2019, EDF 2018, and other peer-reviewed methane leakage analyses

These differences in studies impact the total buildings-sector-related carbon emissions from fossil fuel combustion and leakage. Further, there is disagreement about the use of a 20-year or 100-year GWP, leading to more divergent results.

Greenhouse gas emissions from fossil fuels in buildings

Million metric tons CO_2e, 2018, with **100 Year GWP**

Million metric tons CO_2e, 2018, with **20 Year GWP**



Source: RMI analysis

EPA estimates show the highest distribution system methane leakages in large states like California, New York, and Texas …

Distribution system methane leakages
Cubic feet, 2016

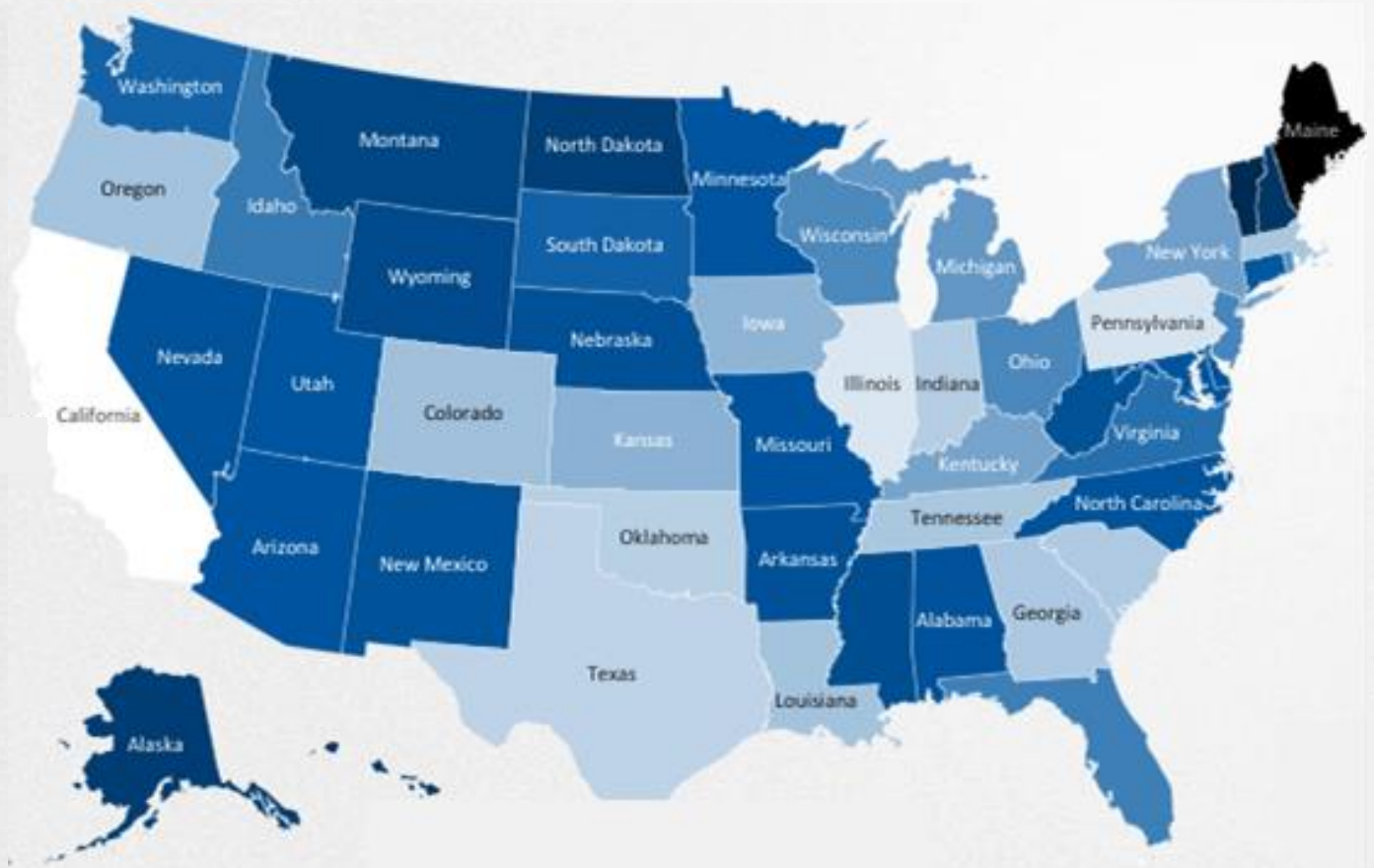
Low leakage High leakage

Source: EPA Greenhouse Gas Inventory 2016

… but many less populous states have especially high leakage per customer

Distribution system methane leakage per customer
Cubic feet per residential and commercial customer, 2016

Low leakage High leakage



Source: EPA Greenhouse Gas Inventory 2016

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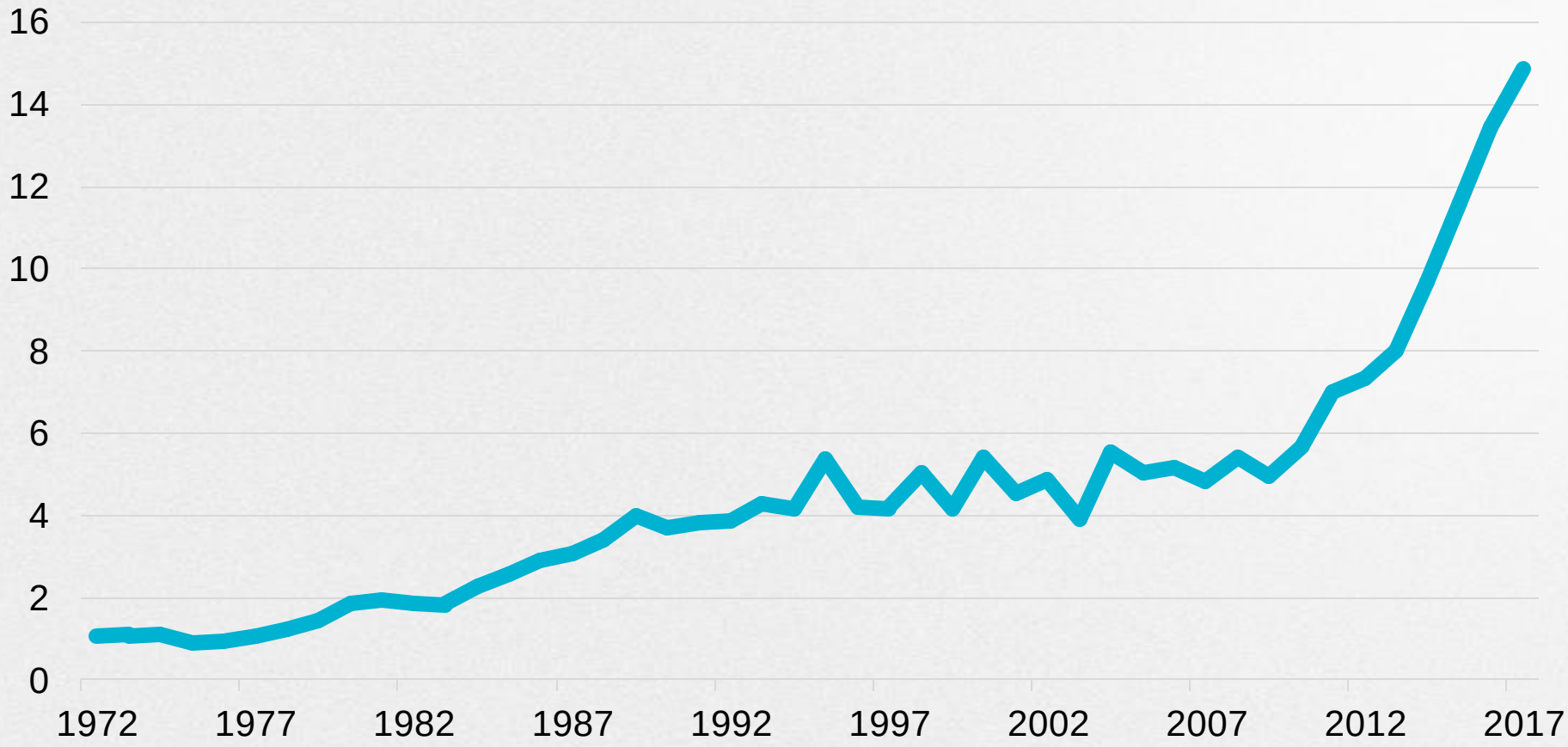
Gas distribution system expenditures tripled between 2009 and 2017, rising to $14.9 billion per year. These costs vary widely by region.

US gas distribution system expenditures

USD billion, 1972–2017

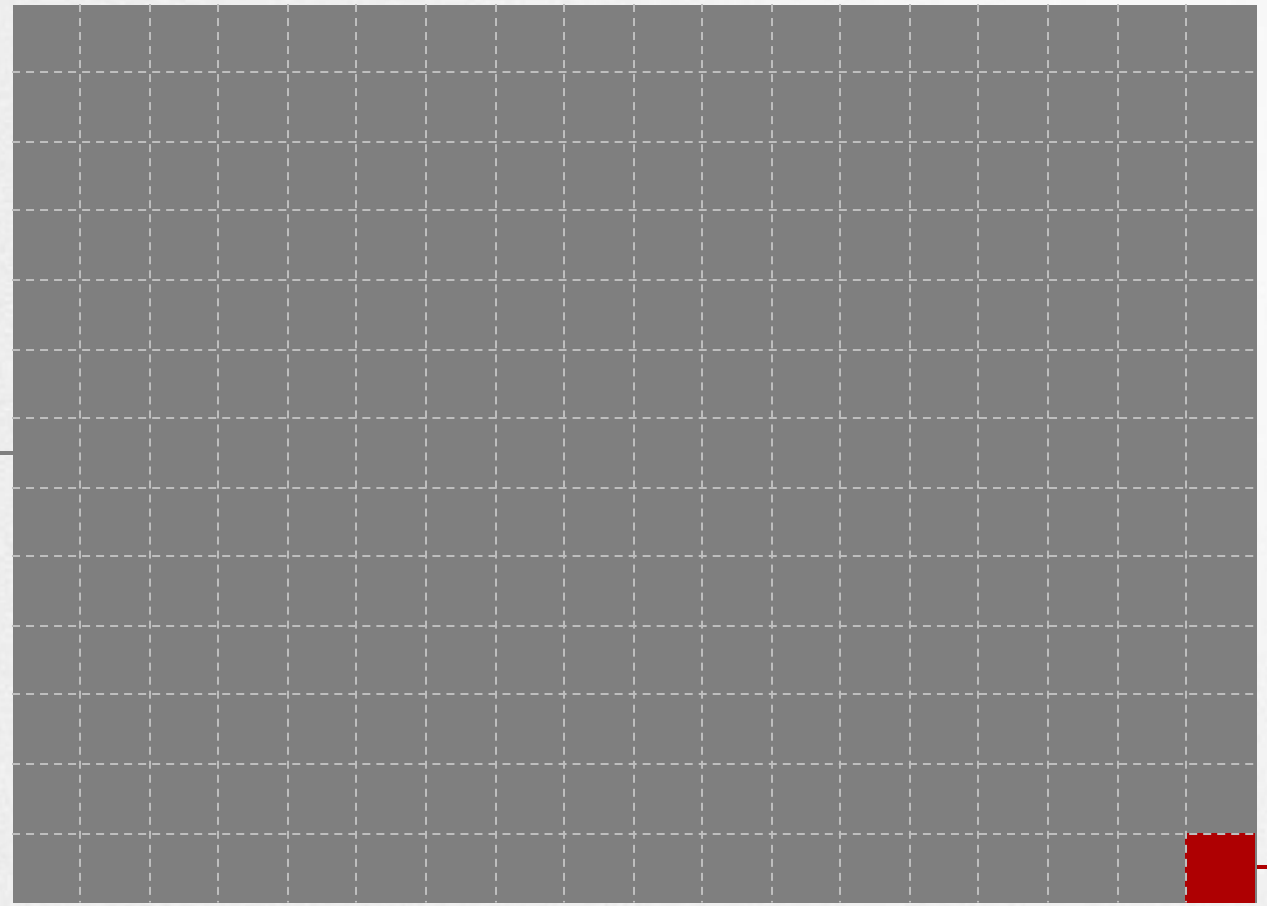


Appliance sales account for another $18 billion annual expenditure:

- ~4M gas water heaters, totaling $4B–5B
- ~3.4M gas furnaces, totaling $14.5B

Sources: American Gas Association 2017, RMI analysis

Over the last decade, 5,600 miles of gas mains have been replaced per year. At this rate, it would take over 230 years to replace every pipe in the system.



US gas distribution system

1.3 million miles of gas mains

+

On average, the system gets 0.8% larger each year, growing by 9,800 miles.

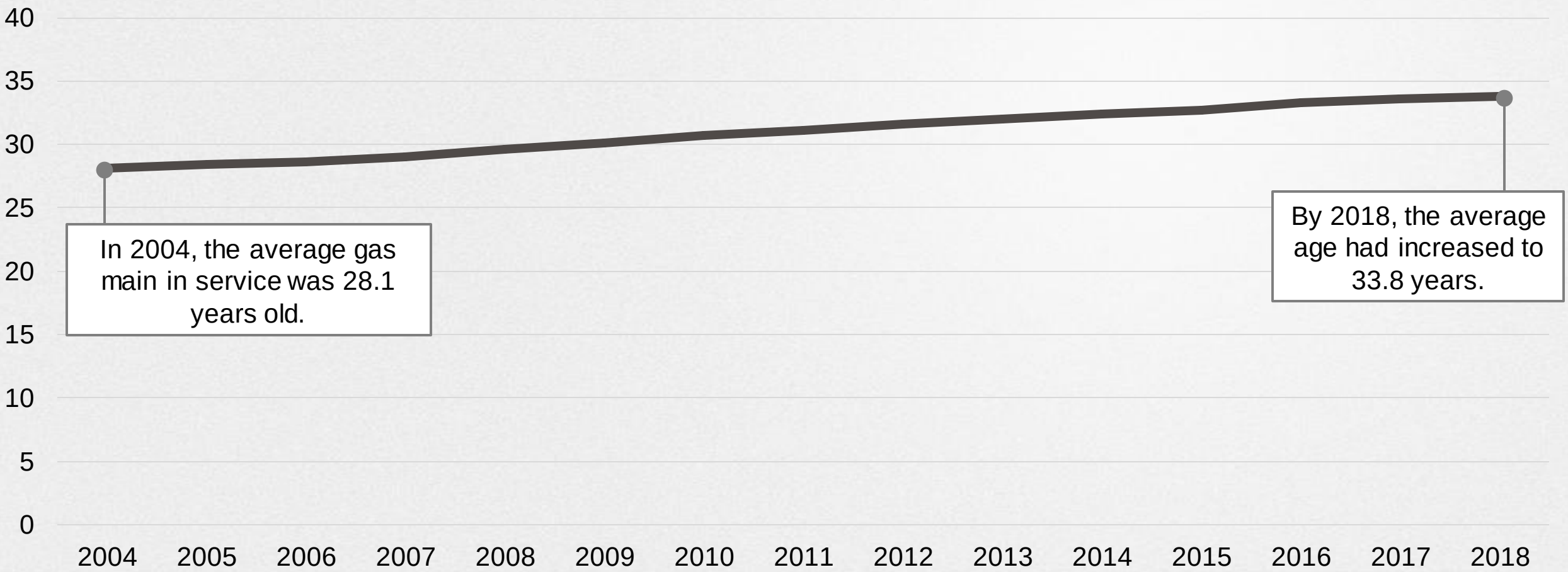
About 5,600 miles of existing gas mains are replaced each year (0.43% of the system).

Sources: U.S. Pipeline and Hazardous Materials Safety Administration (PHMSA) 2018, RMI analysis

The US gas distribution system is getting older

Average age of US gas mains in service

Years, 2004–2018

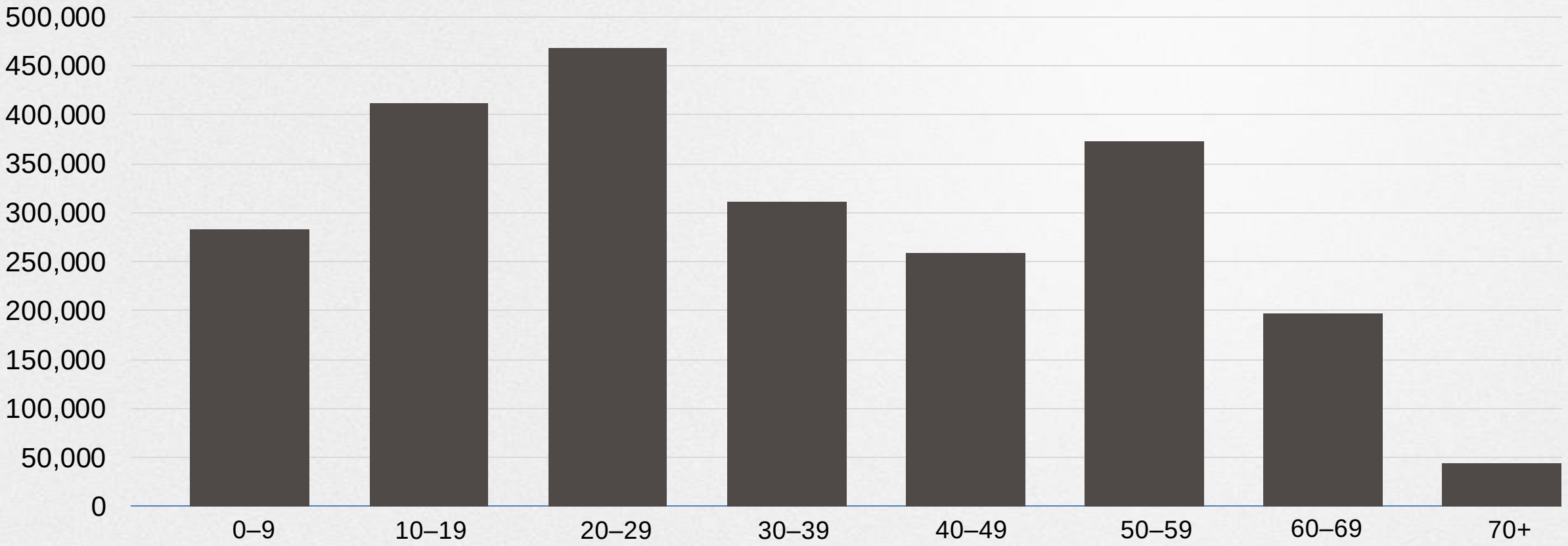


Sources: PHMSA 2018, RMI analysis

The average gas distribution main is over 30 years old, and 25% of active gas mains are more than 50 years old

Age of gas distribution mains currently in service

Number of miles of main in service in 2018

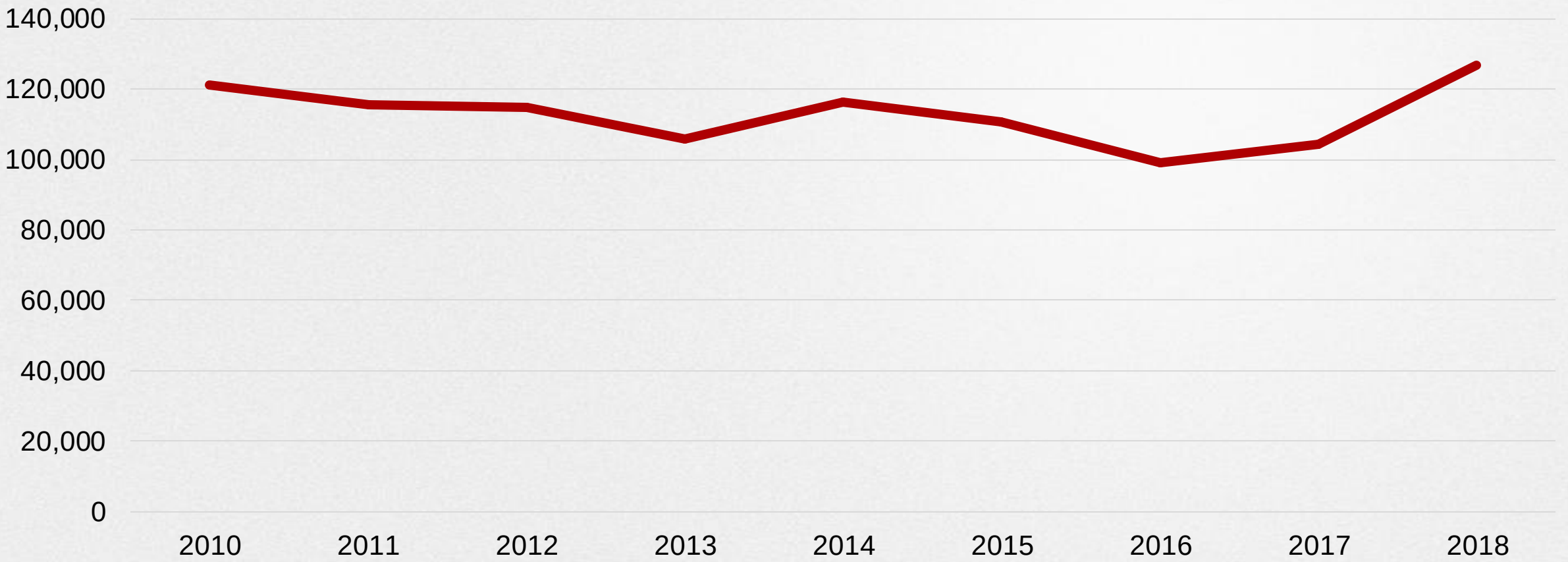


Source: PHMSA 2018

The number of leaks reported in the US gas distribution system has remained around 100,000 per year since 2010

US gas distribution system reported leaks

Annual number of reported leaks, 2010–2018

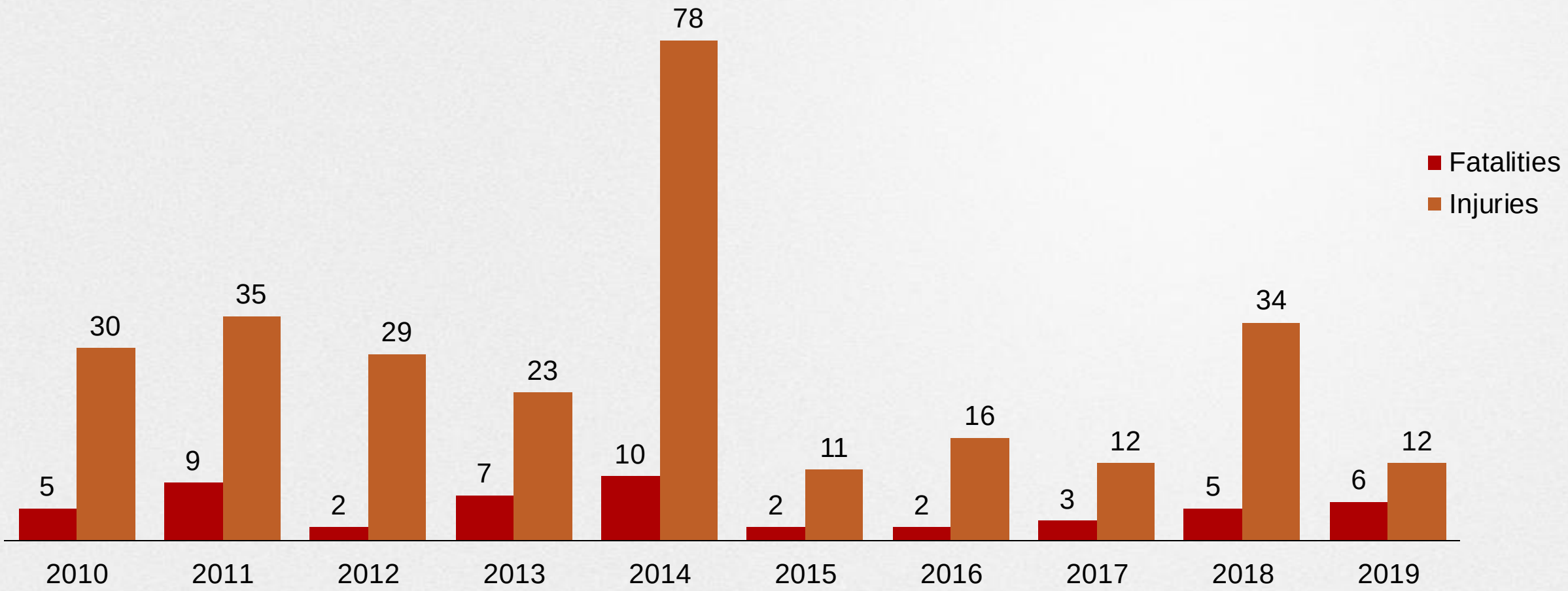


Source: PHMSA 2018

In the past decade, gas pipeline explosions have killed 51 people and injured 280 more

Reported injuries and deaths due to gas distribution pipeline explosions

Number per year, 2010–2019

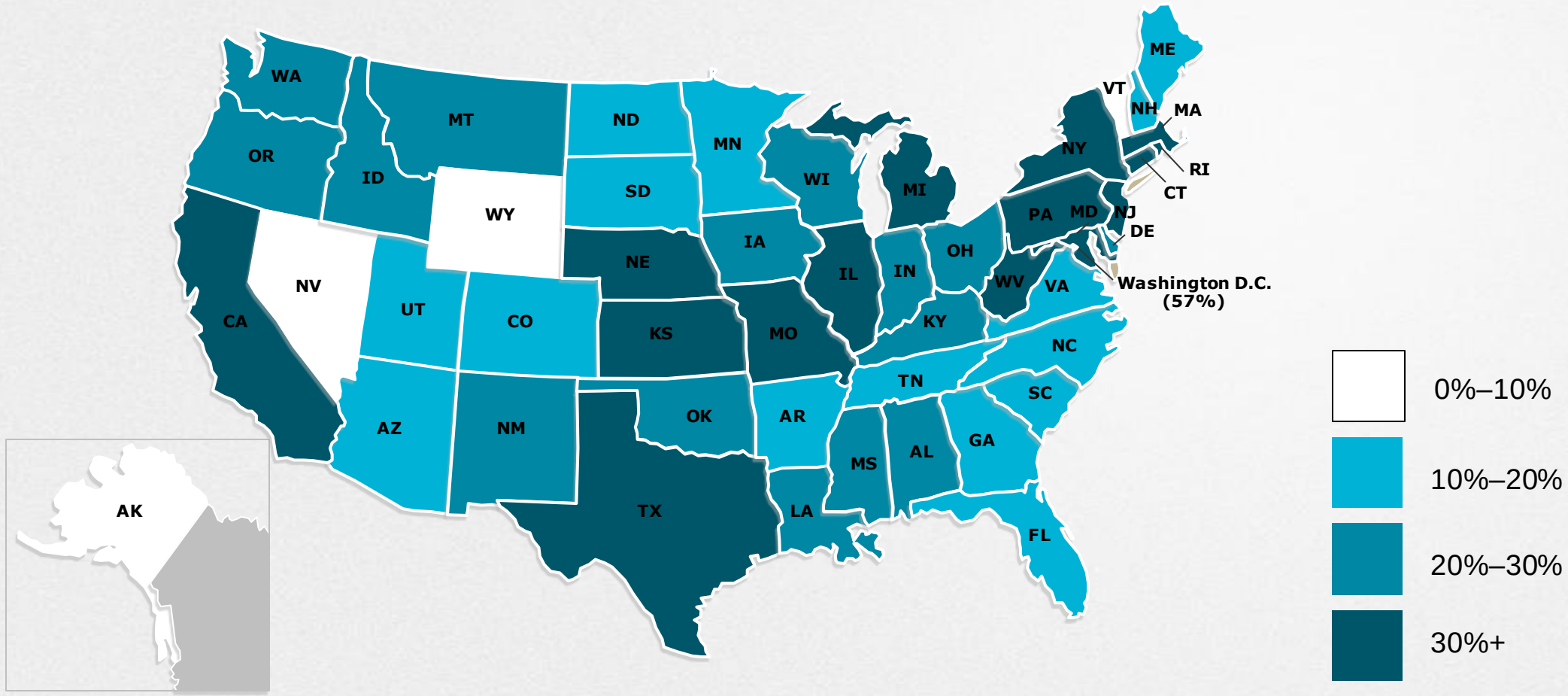


Source: PHMSA 2018

Gas distribution systems are particularly old in California, Texas, and Northeastern and Midwestern states

Proportion of gas distribution mains installed before 1970

% of total miles of main



Source: PHMSA 2018

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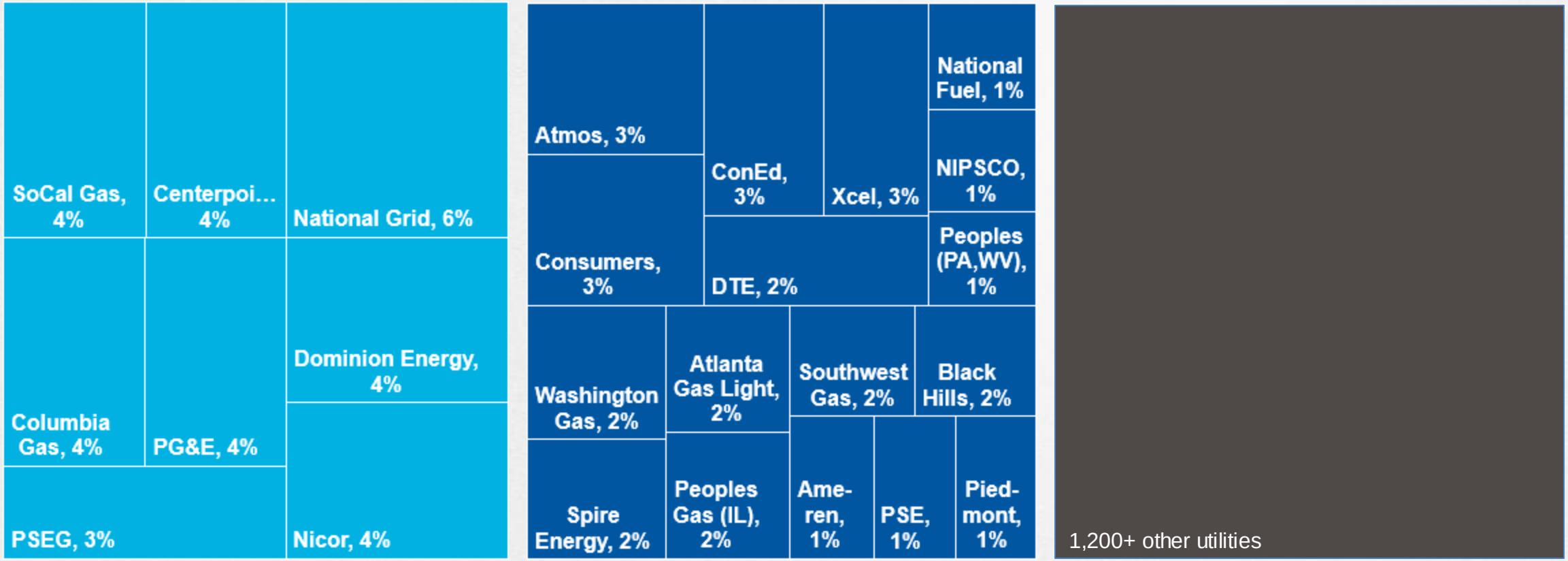
Gas delivery is concentrated, with 25 utilities delivering two-thirds of residential and commercial gas

Residential and commercial gas delivery shares by utility

% of US total, 2017



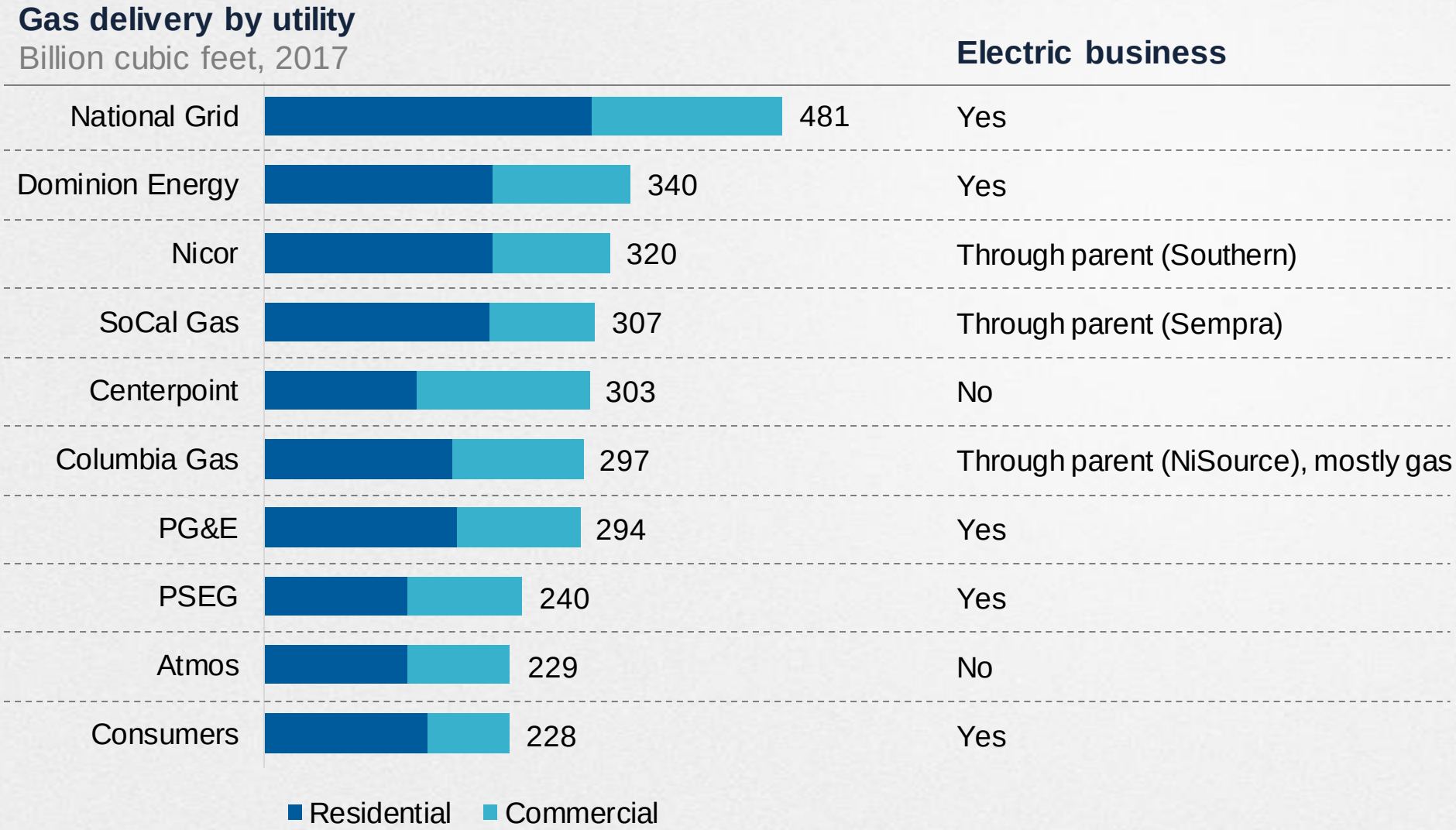
Just eight utilities provide one-third of US residential and commercial gas

Eighteen utilities provide another third of gas use

Over 1,200 smaller utilities provide the remainder

Note: Sales data for multistate utilities that operate under a single brand (e.g., National Grid) have been consolidated.
Source: EIA 2017

Five of the 10 largest gas utilities have combined gas and electricity businesses. Three more are in the same corporate family with electric utilities.



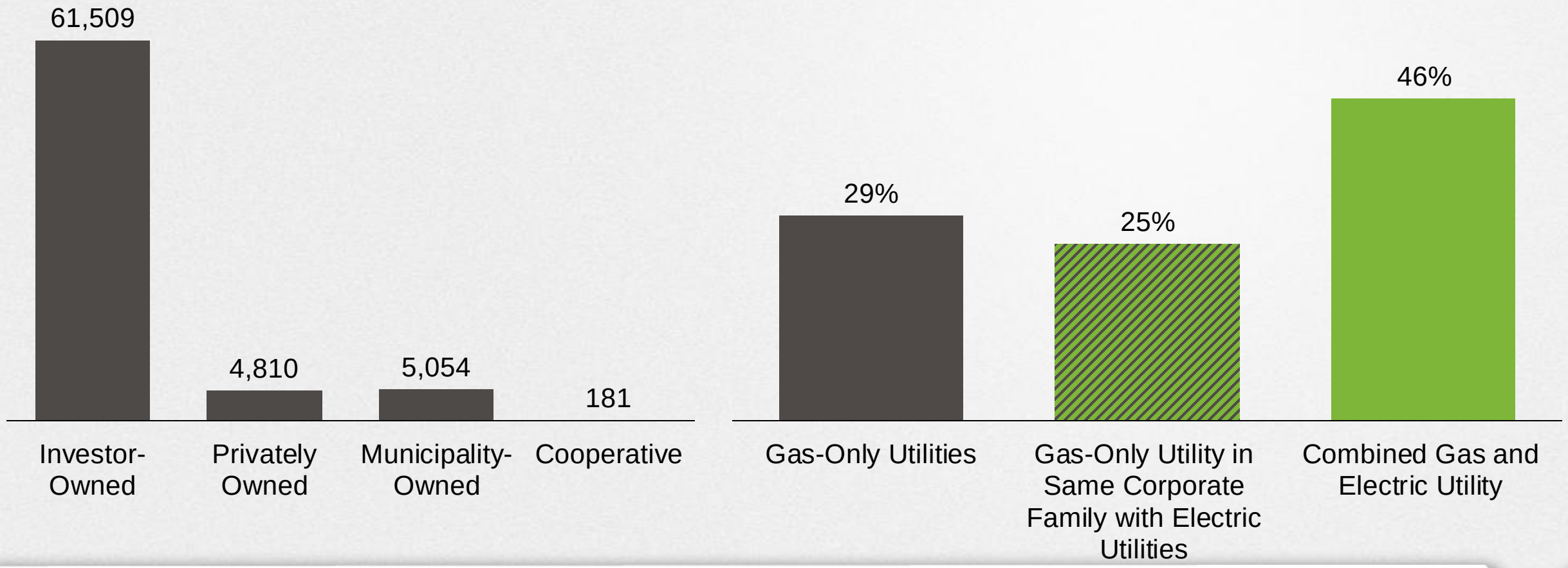
Note: Sales data for multistate utilities that operate under a single brand (e.g., National Grid) have been consolidated.
Source: EIA 2017

Most gas customers in the United States are served by investor-owned utilities

Gas customers by utility ownership structure
Thousands of residential and commercial customers, 2017

Gas volume delivered by utility business structure*
Residential and commercial, %, 2017

*n=61 utilities representing 81% of total volume delivered

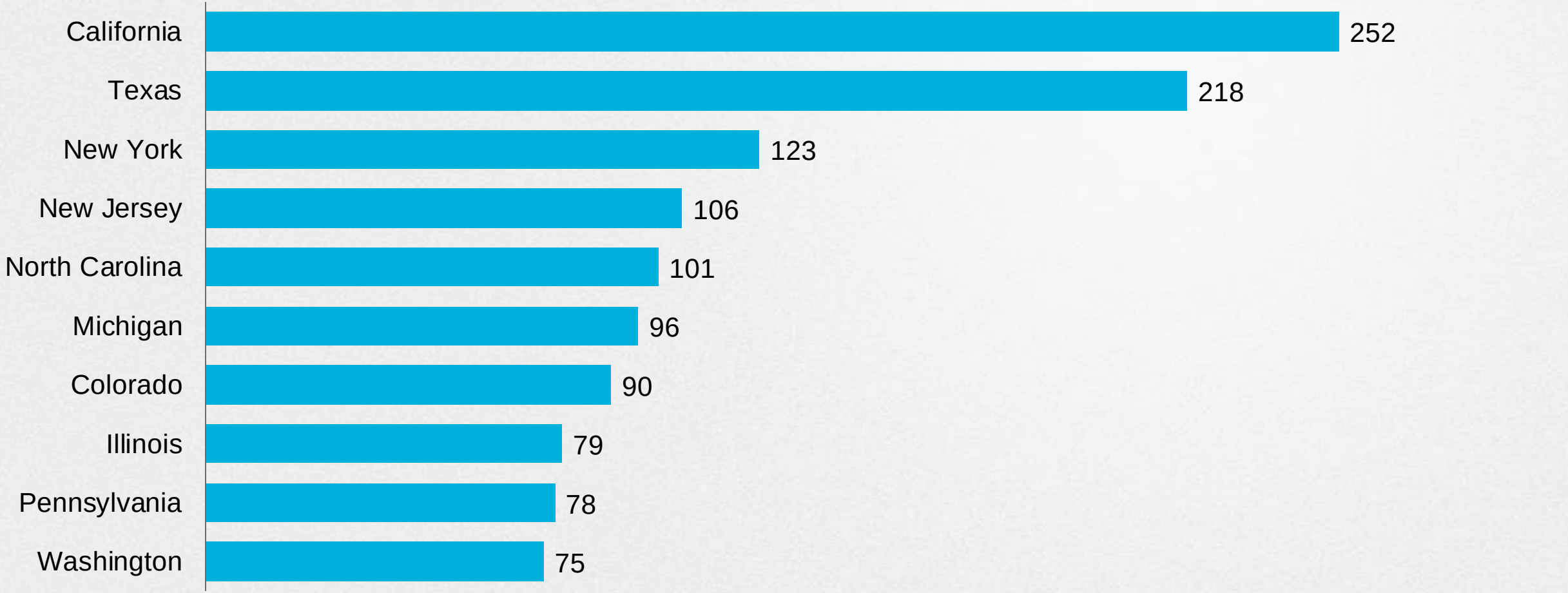


Sources: PHMSA, EIA 2017

10 states account for 52% of all new gas customers from 2013 to 2017

New gas customers, 2013–2017

Thousands of customers, residential and commercial sectors

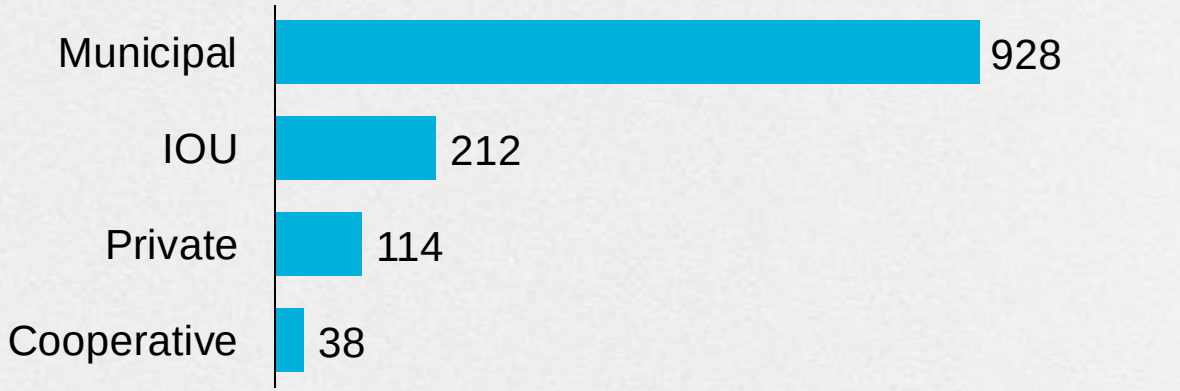


Source: EIA 2017

Although there are many small municipal gas utilities, most carbon emissions are concentrated in a smaller number of investor-owned utilities

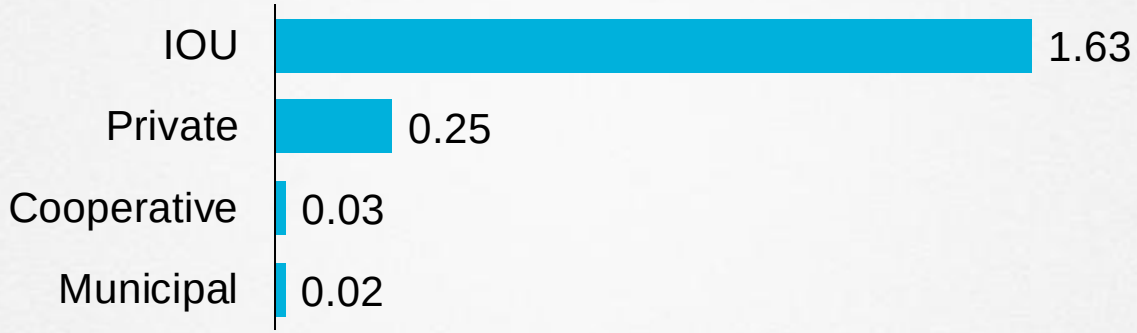
Number of gas companies by ownership model

2017



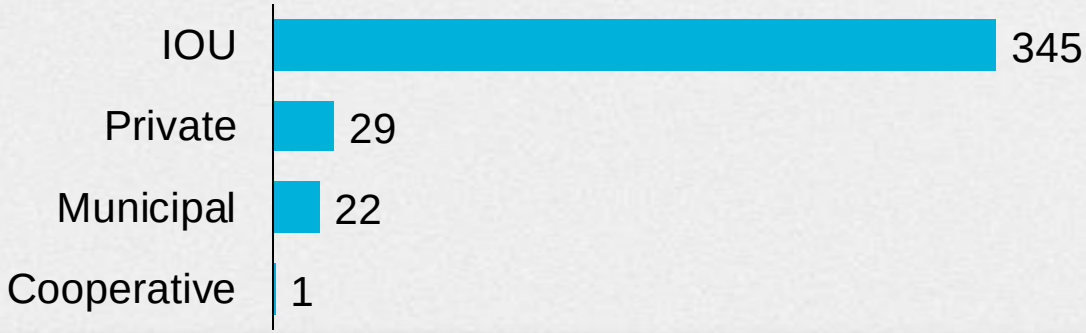
Average total residential and commercial sector carbon emissions from gas by utility type

Million metric tons per utility, 2017



Residential and commercial gas carbon emissions by utility ownership type

Million metric tons, 2017



Average gas carbon emissions per customer by utility type

Metric tons per customer, 2017

Sources: EIA 2017, RMI analysis

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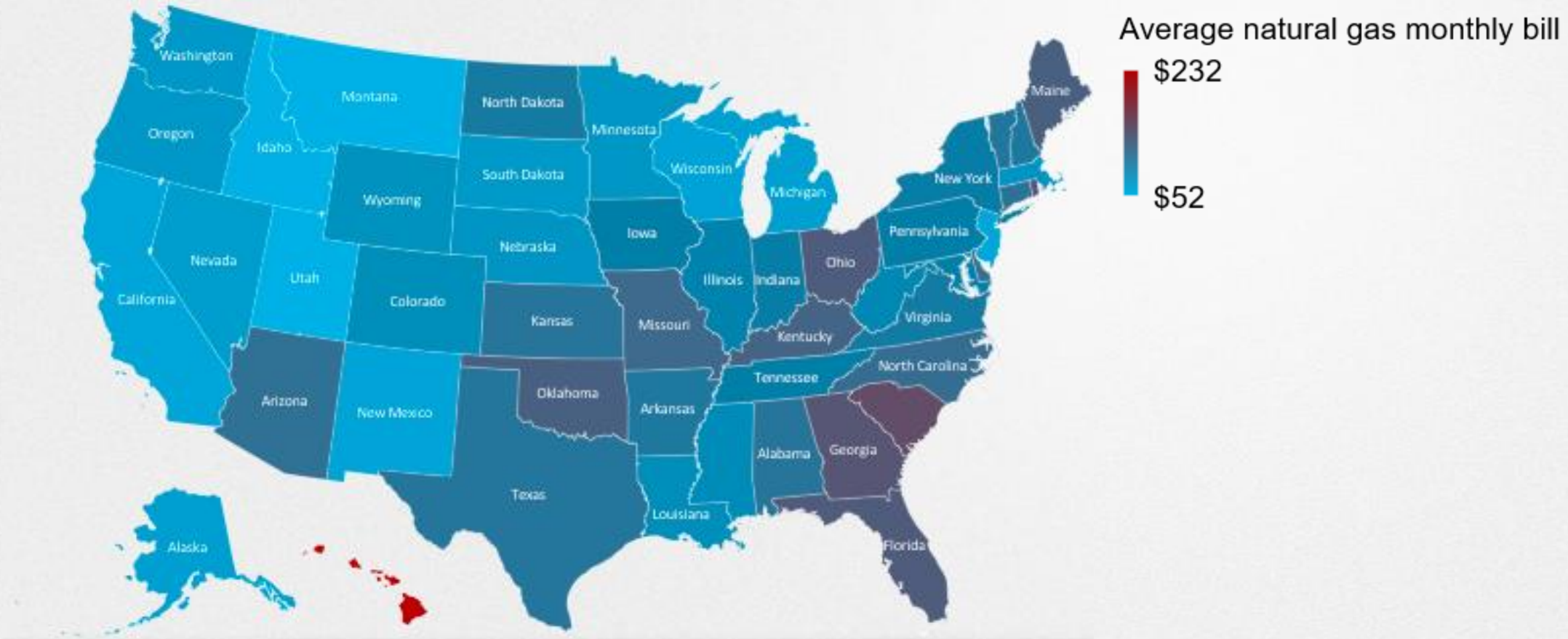
The average monthly home gas bill is $101, with some as high as $230

Average monthly residential gas bill
USD, 2018

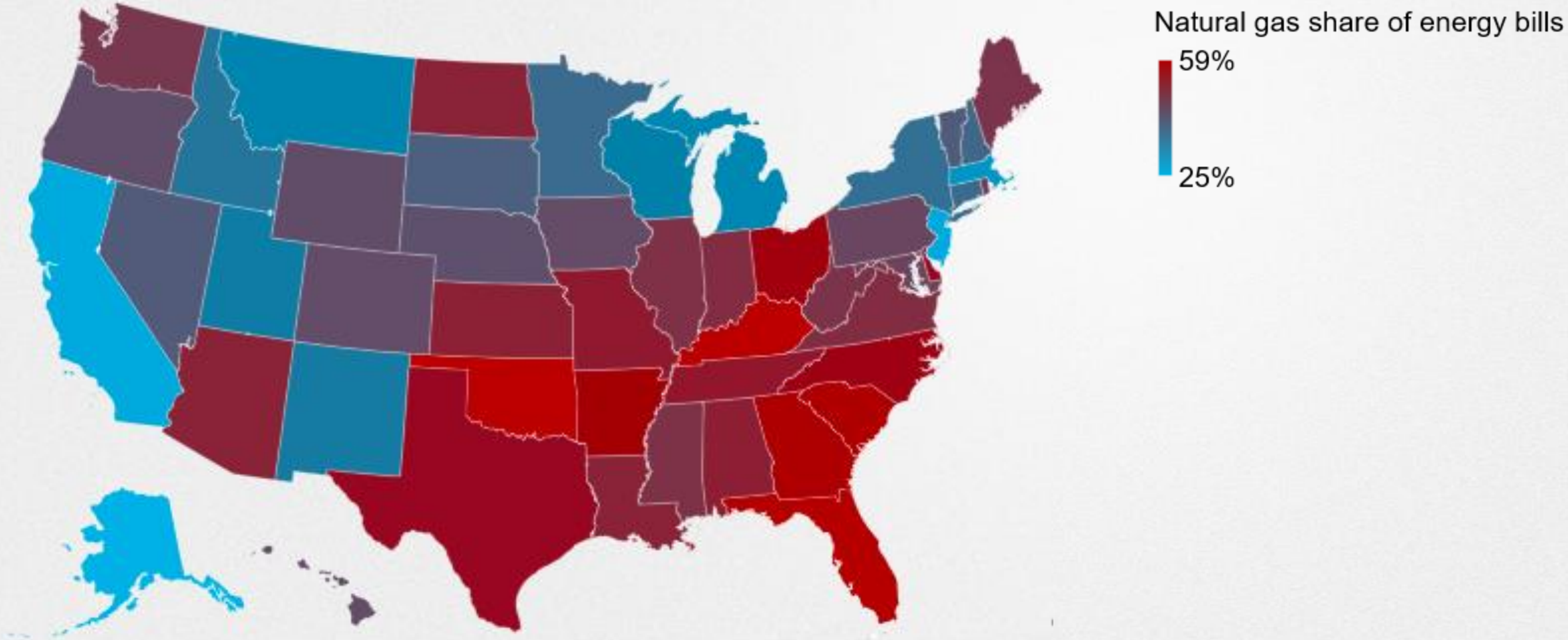


Source: move.org, 2018

In some states, gas bills are more than half of home energy costs

Gas share of home energy costs

USD, 2018

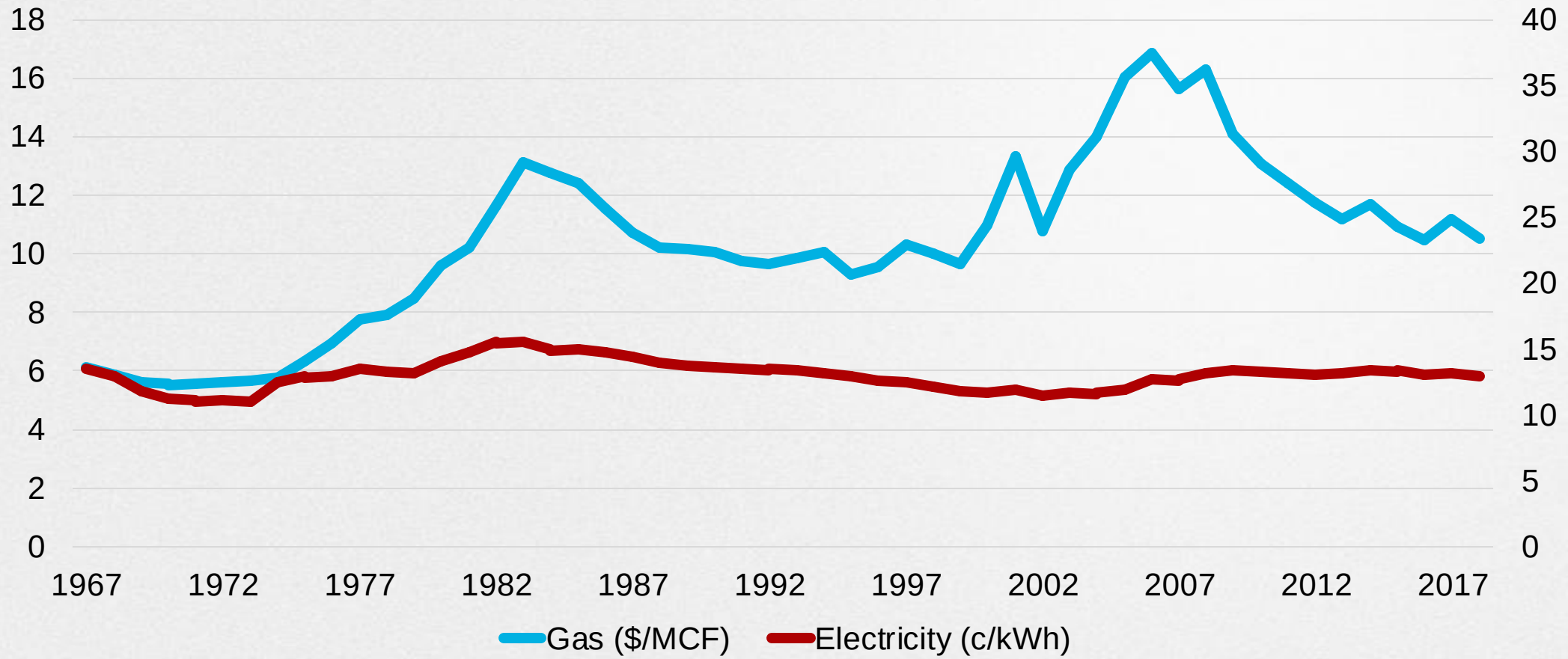


Sources: move.org 2018, RMI analysis

Electricity retail prices are historically much more stable than gas prices and are virtually unchanged in 50 years, adjusted for inflation

US residential price history for gas and electricity

Inflation-adjusted 2018 dollars, 1967–2017



Sources: EIA (retail price history); U.S. Federal Reserve (inflation adjustment factors)

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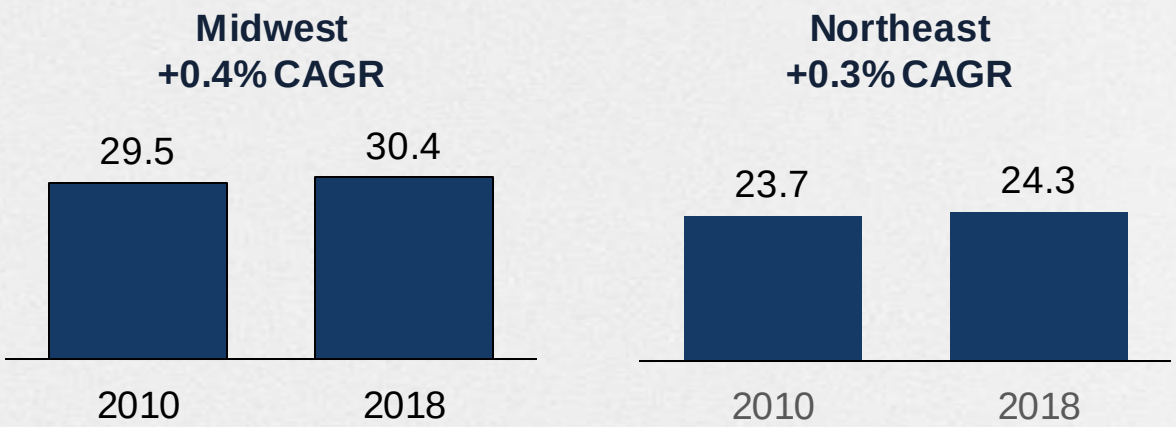
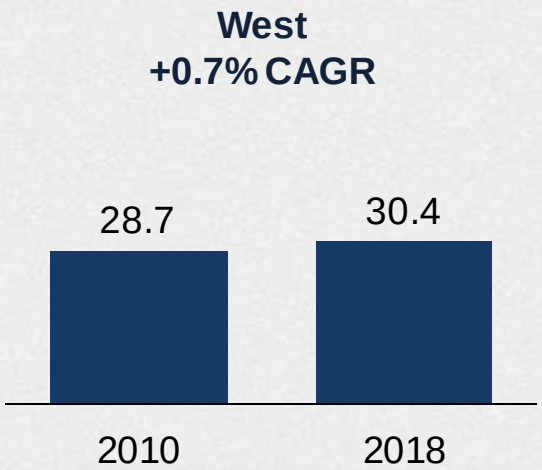
- Emissions and fuel consumption
- Methane leakage
- Gas infrastructure
- Gas utilities
- Gas bills and rates
- Building characteristics
- Appliances
- Air quality and pollution

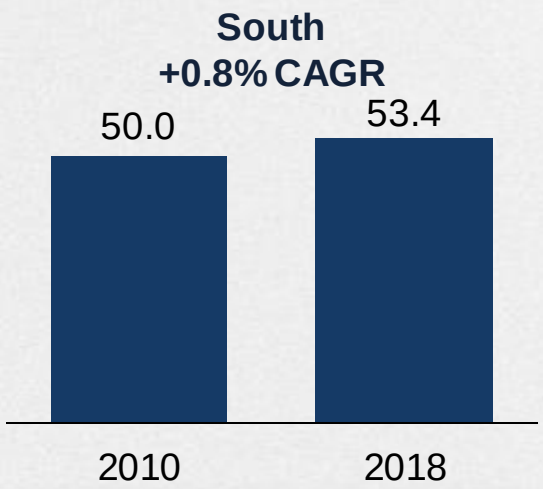
U.S. building stock continues to grow

Residential

Millions of US housing units and 8-year growth

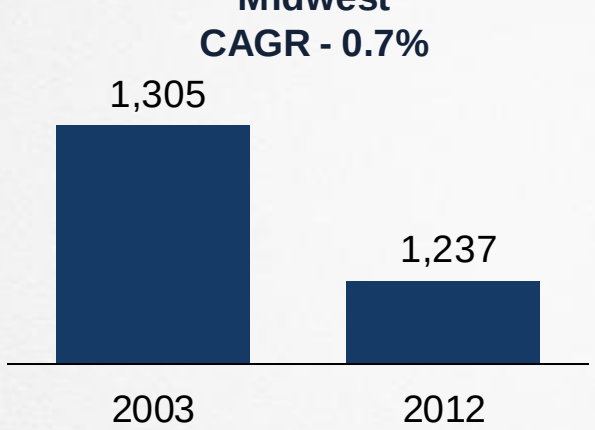


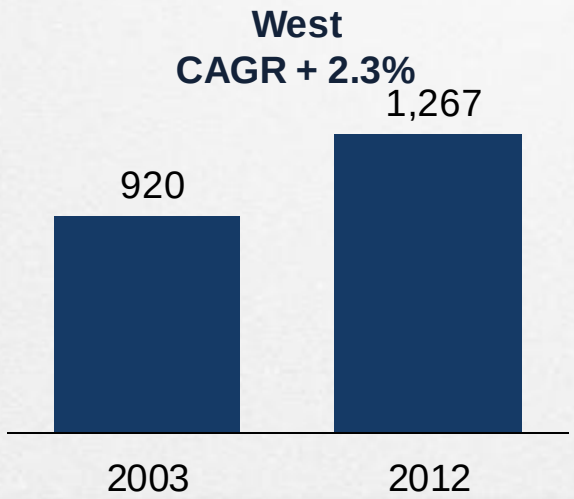


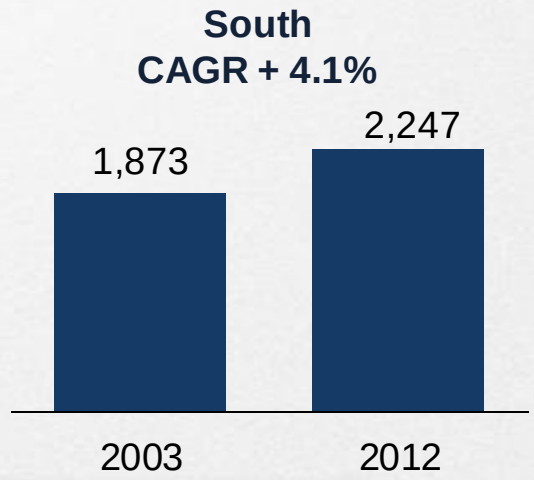


Commercial

Thousands of US buildings and 9-year growth





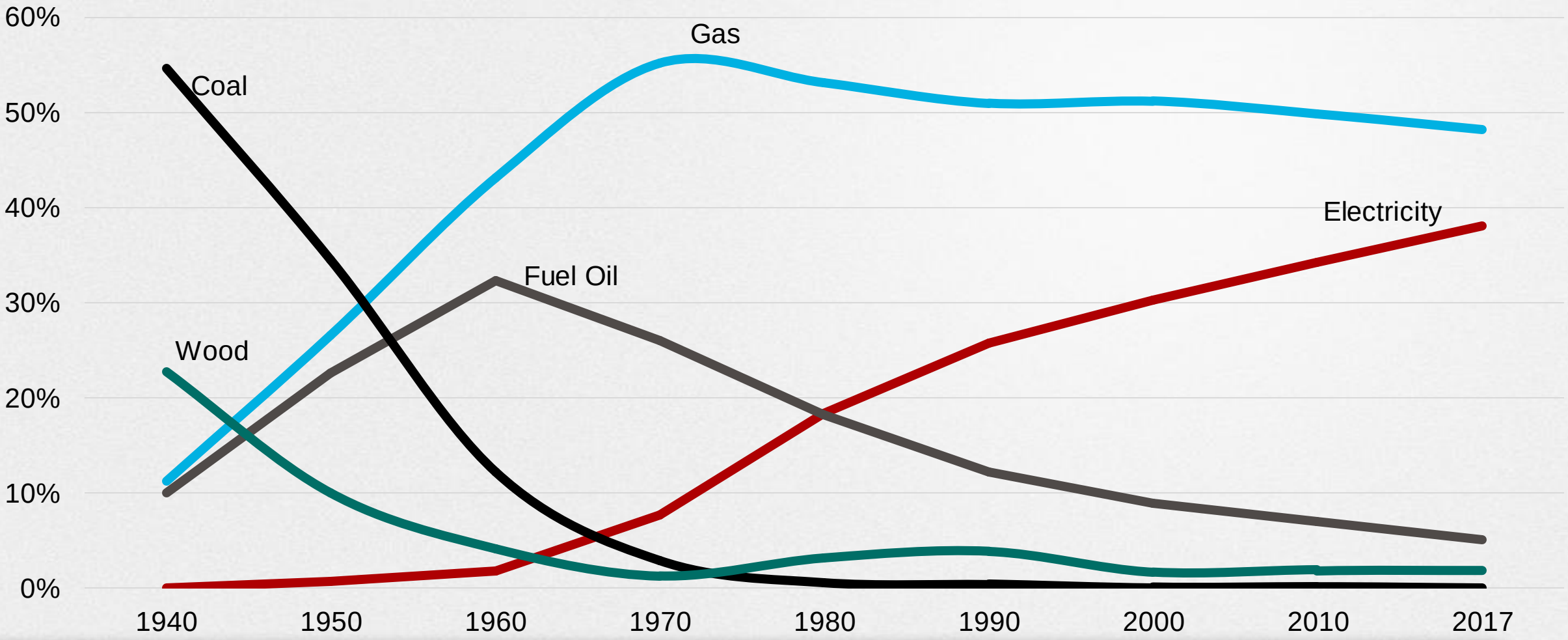


Source: Census American Fact Finder, CBECS

From 1940 through the mid-1950s, coal was the primary source of heating in homes. Forty years later, coal was nearly gone.

Percentage of US households by primary heating fuel

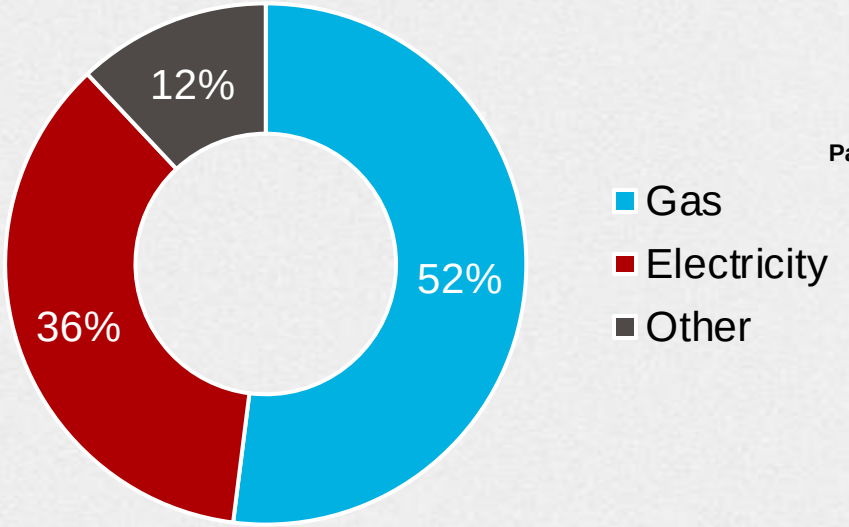
1940–2017



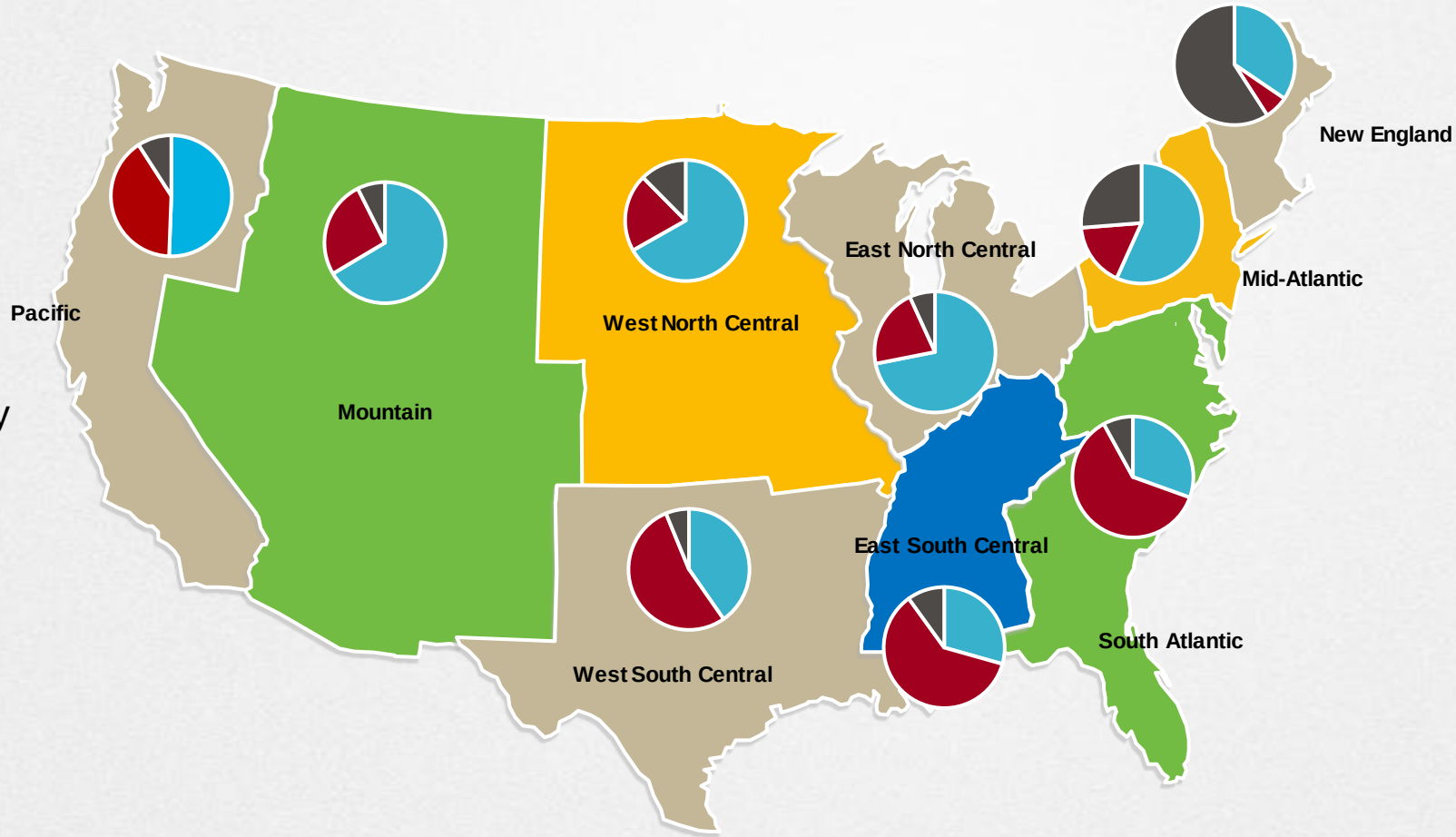
Source: Census Bureau, 2018

Today, more than 60% of homes use gas or other fossil fuels for heating

Primary heating fuel of US residences
2015



Primary heating fuel of residences by Census division
2015

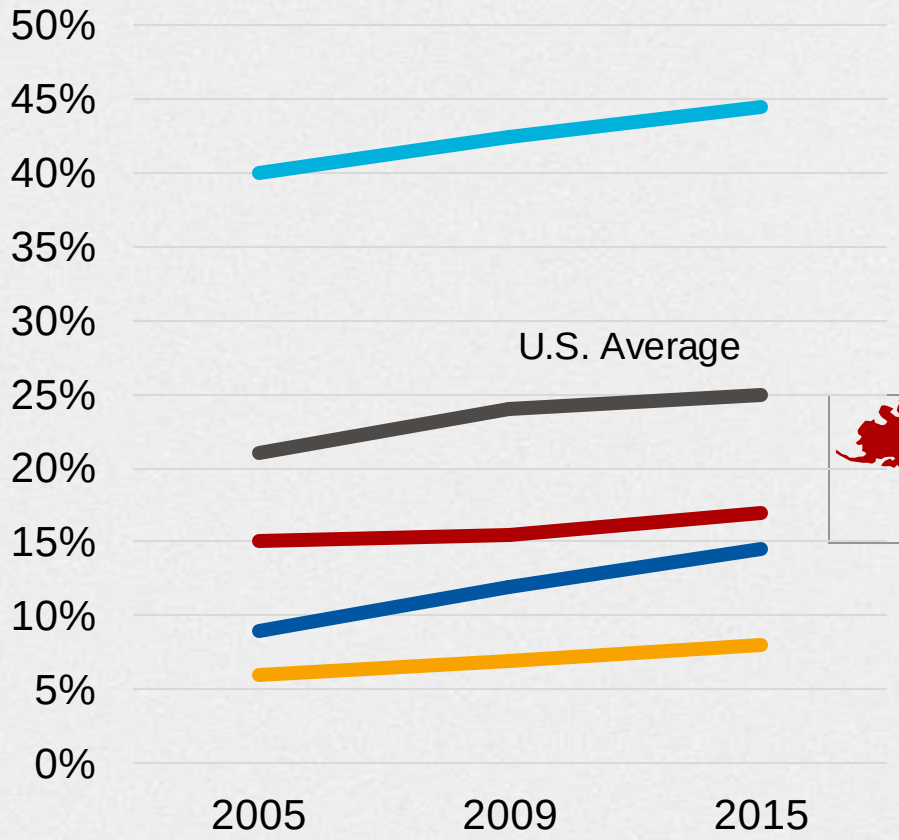


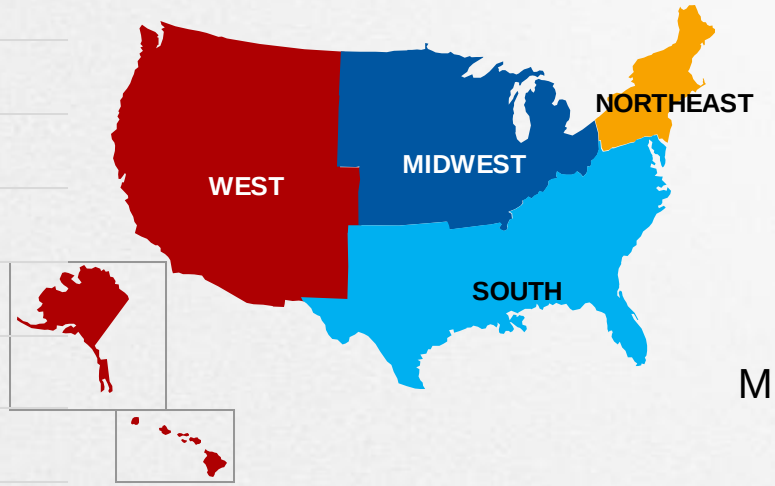
Source: EIA RECS, 2015

One in four US homes is all electric, and that number is growing in all regions

Share of all-electric homes by Census region

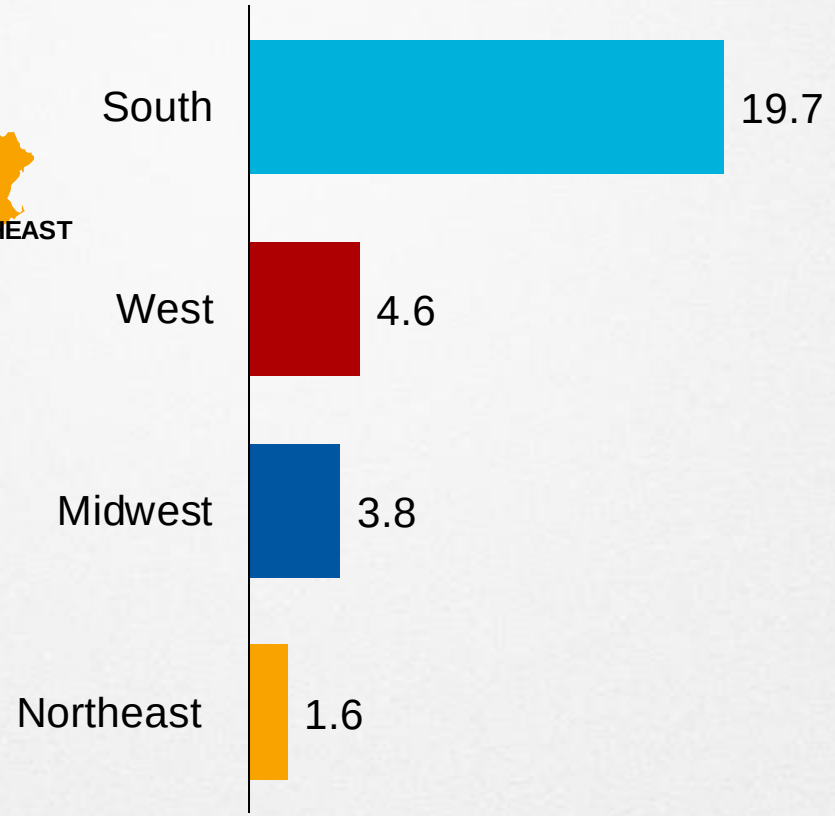
Share of all primary residences





Number of all-electric homes by Census region

Millions of homes, 2015

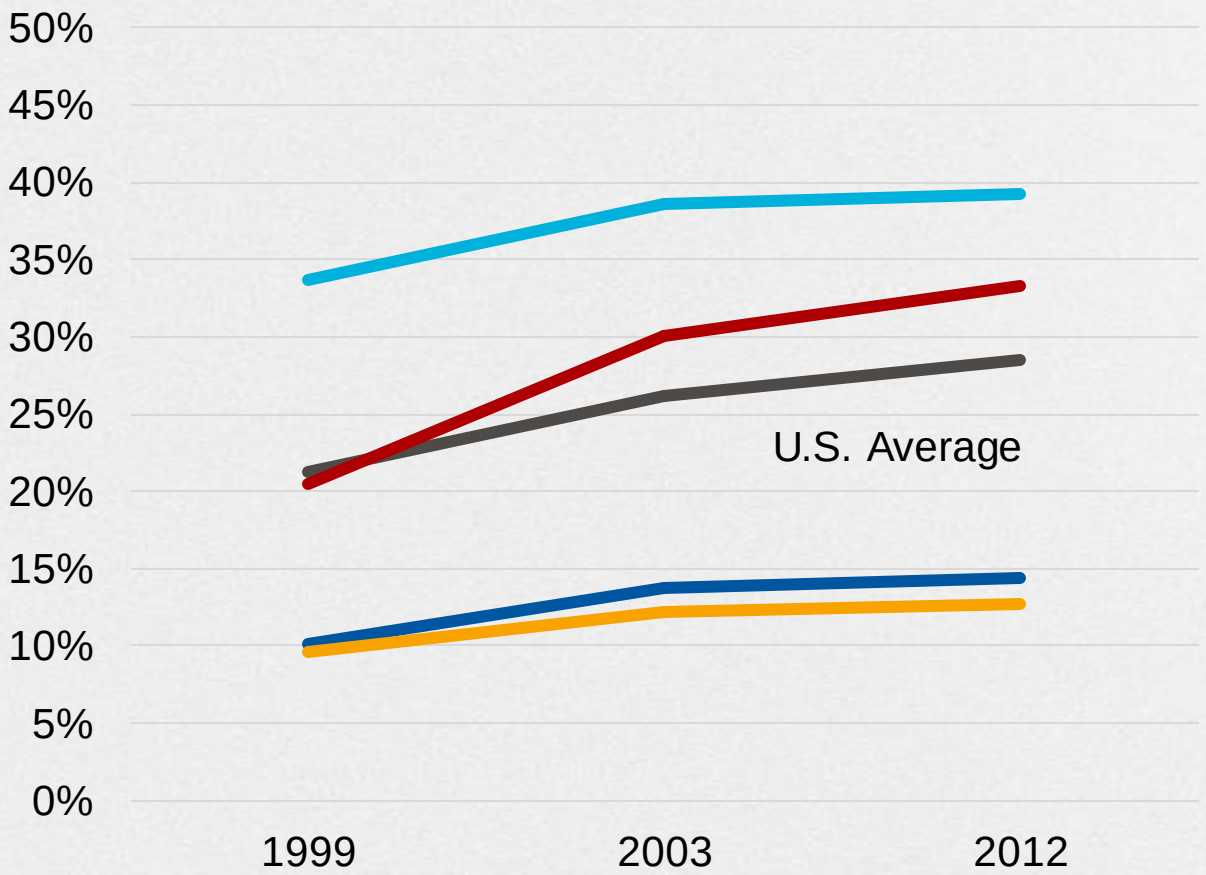


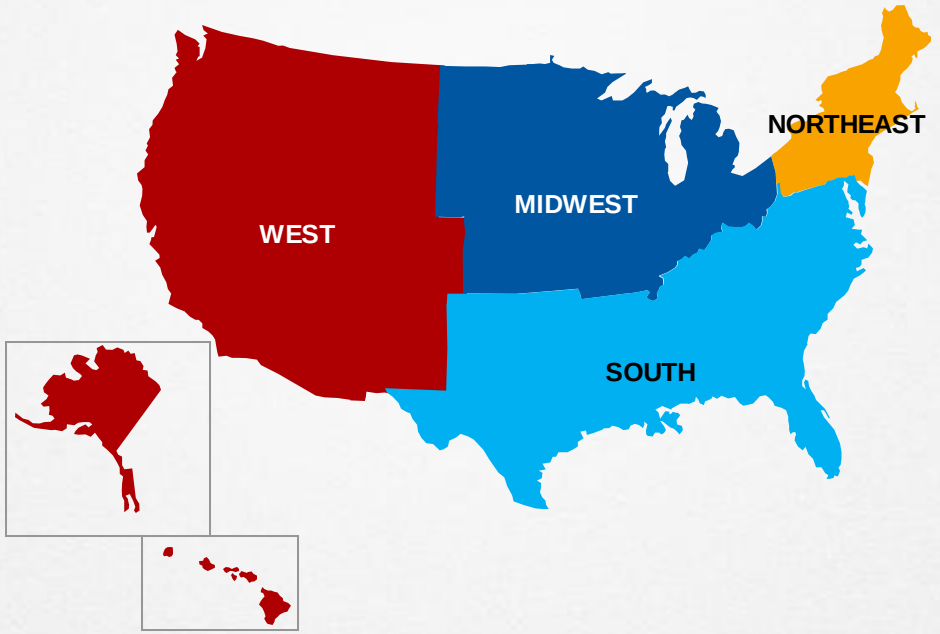
Source: EIA RECS 2005, 2009, and 2015

Likewise, 29% of commercial buildings are all electric, and that number is growing in all regions

Share of all-electric commercial buildings by Census region

Share of all commercial buildings

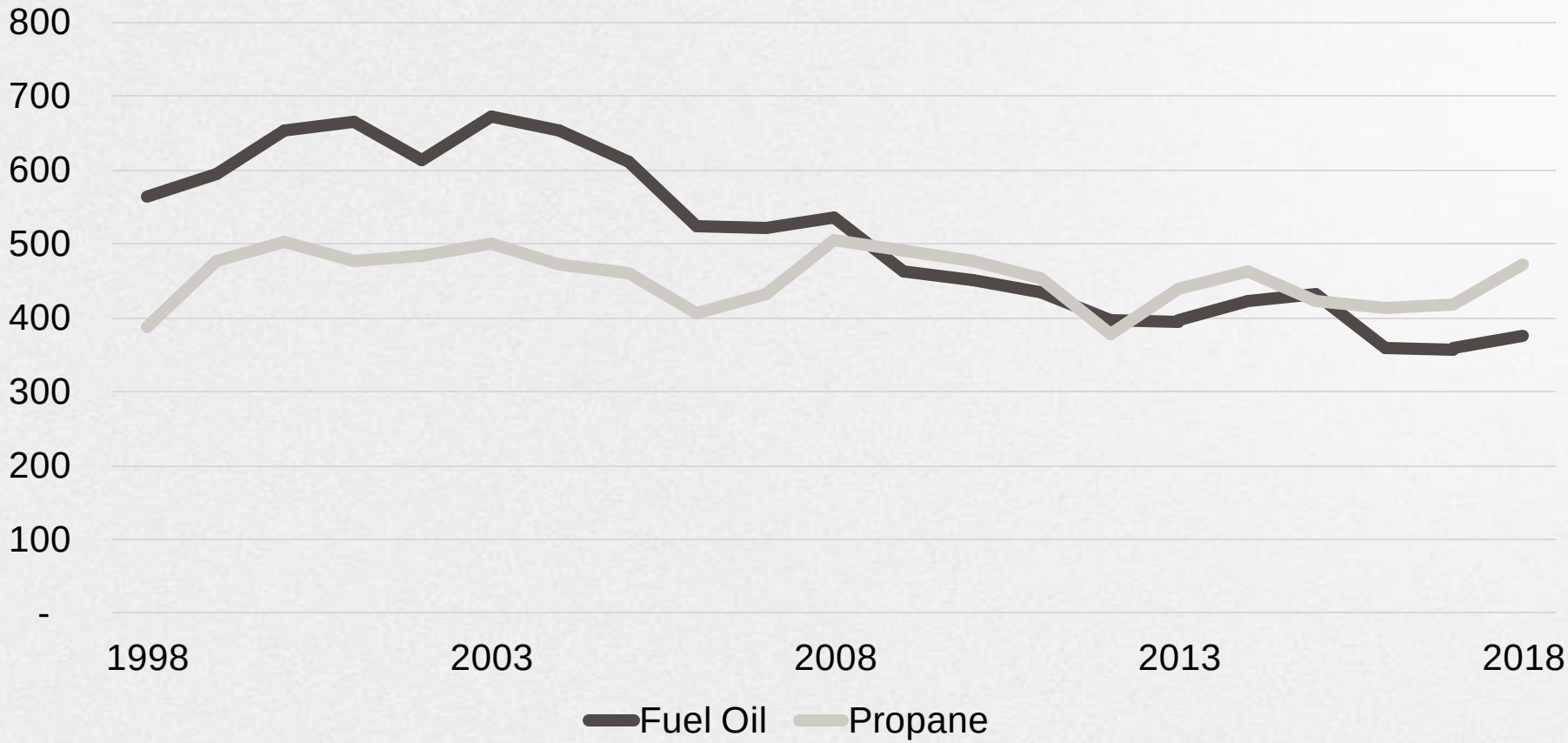




Source: EIA CBECS 1999, 2003, and 2012

Heating oil use has declined as customers switch to gas or electricity

Residential and commercial consumption of fuel oil and propane
Thousand barrels per day, 1998-2018



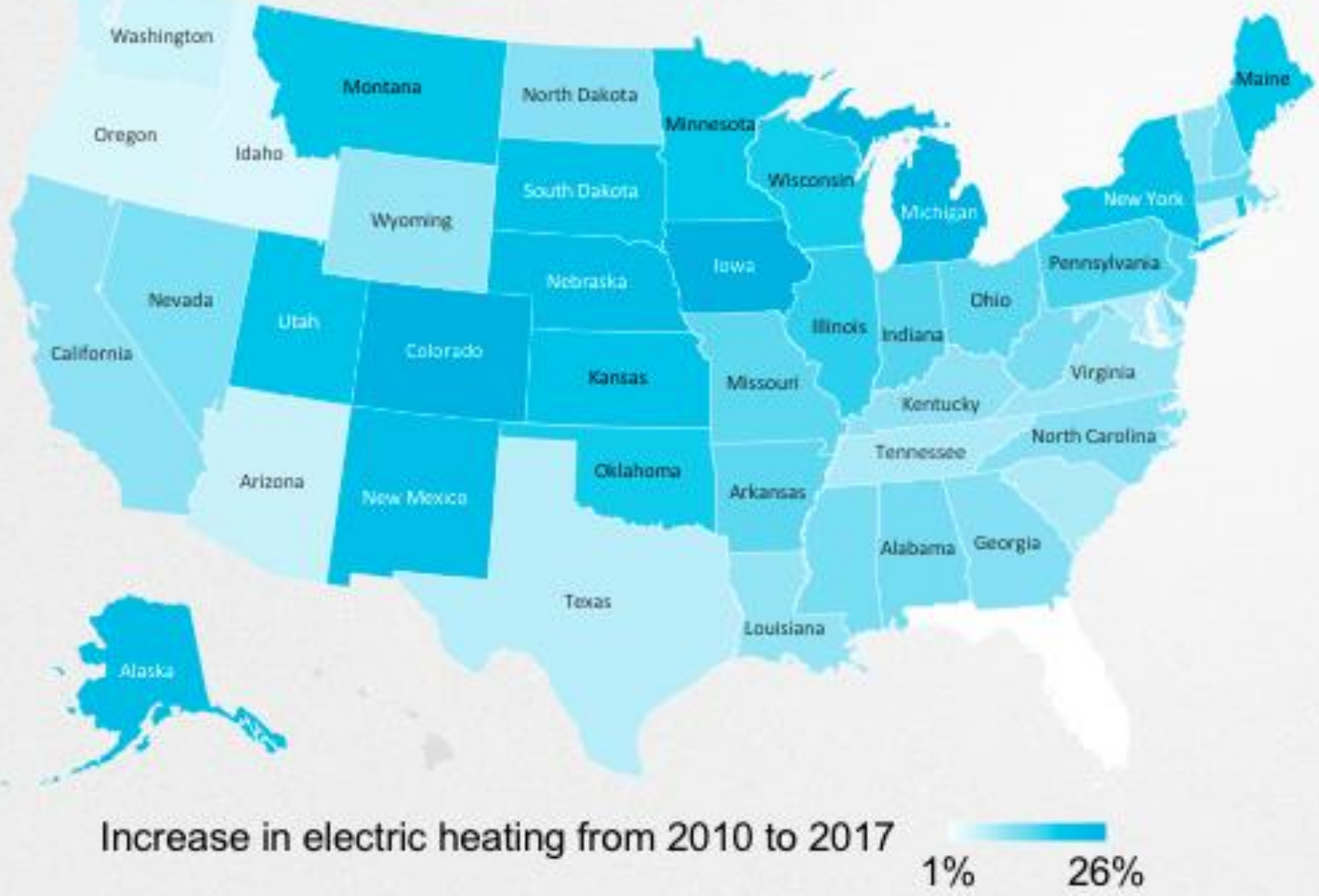
- Oil use declined by a third over the past 20 years
- Propane use is largely flat over the same time period

Source: EIA Monthly Energy Review

Between 2010 and 2017, the number of homes using electricity for heating grew 14% in the United States

Relative increase share of households heating with electricity

Percentage change, 2010–2017

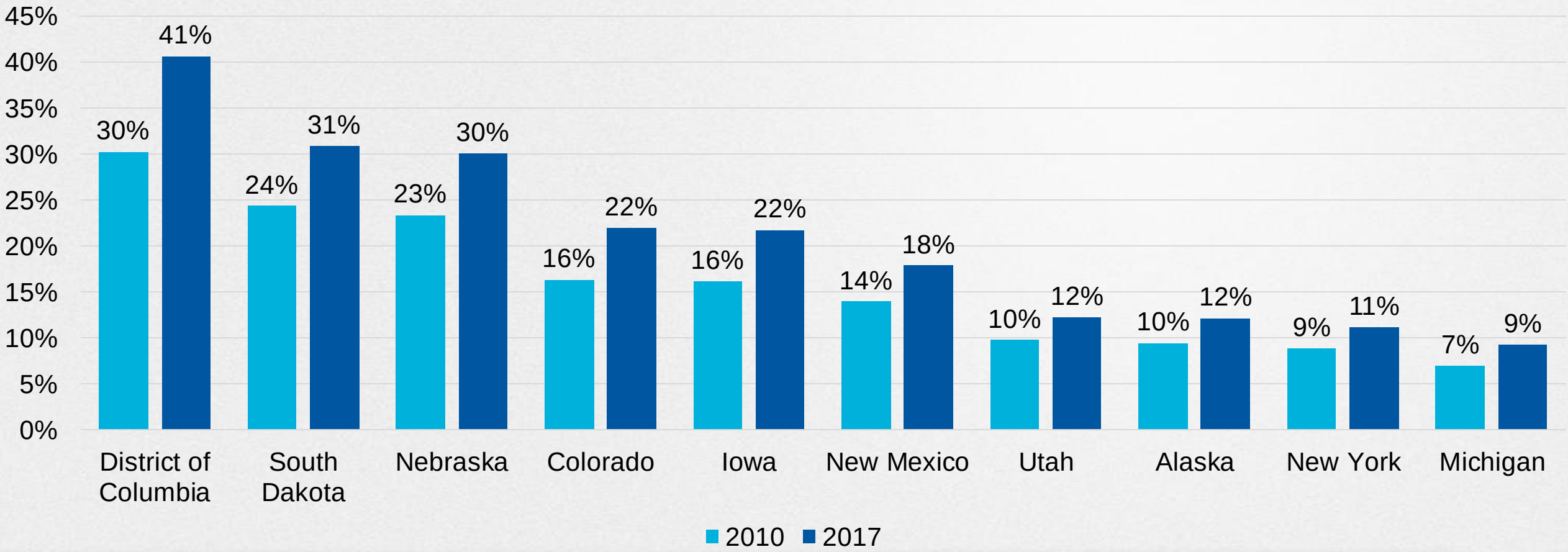


Source: Census Bureau, 2017

The use of electric heating is growing across the United States

New electric heating in American households

Increase in share of households using electric heating, top 10 states by largest increase, 2010–2017

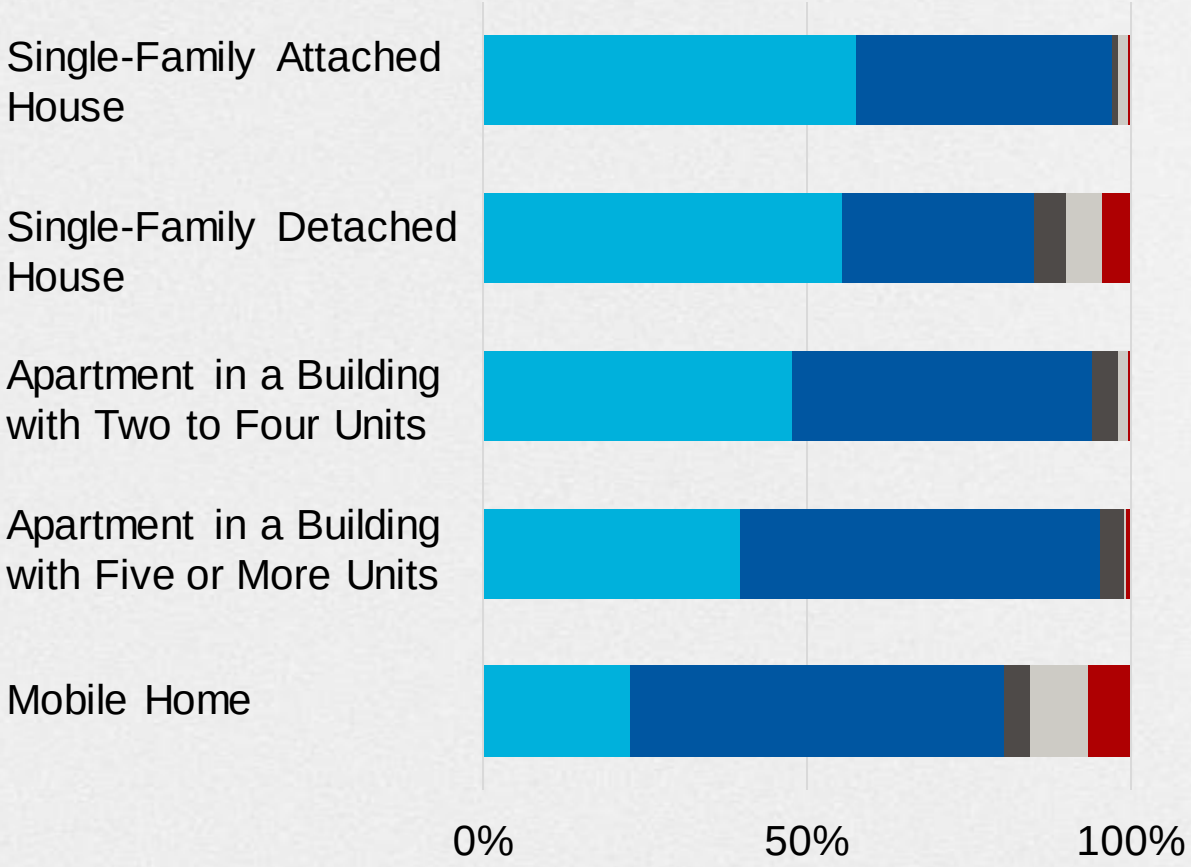


Source: Census Bureau 2010, 2017

While gas is the dominant heating fuel in single-family homes, this is not true for apartment buildings, mobile homes, or the commercial sector

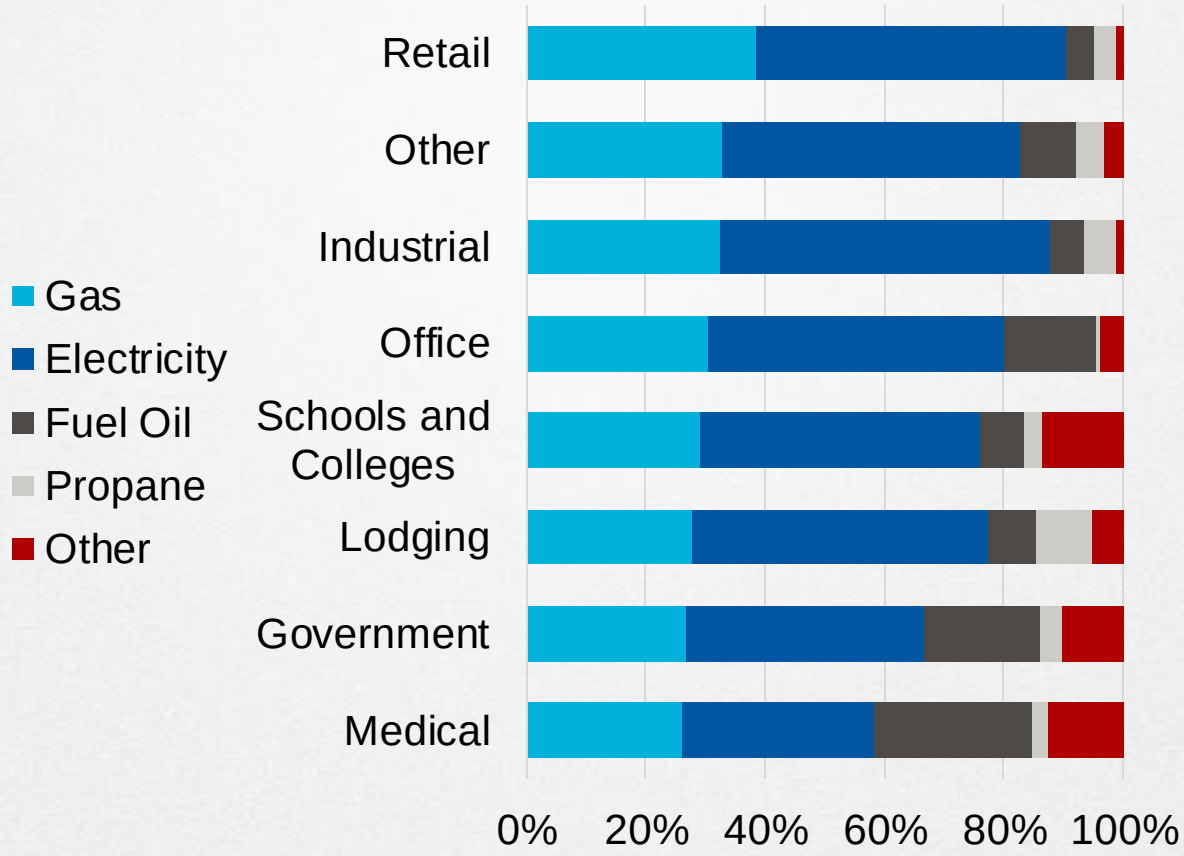
Residential

Share of primary heating fuel by building type



Commercial

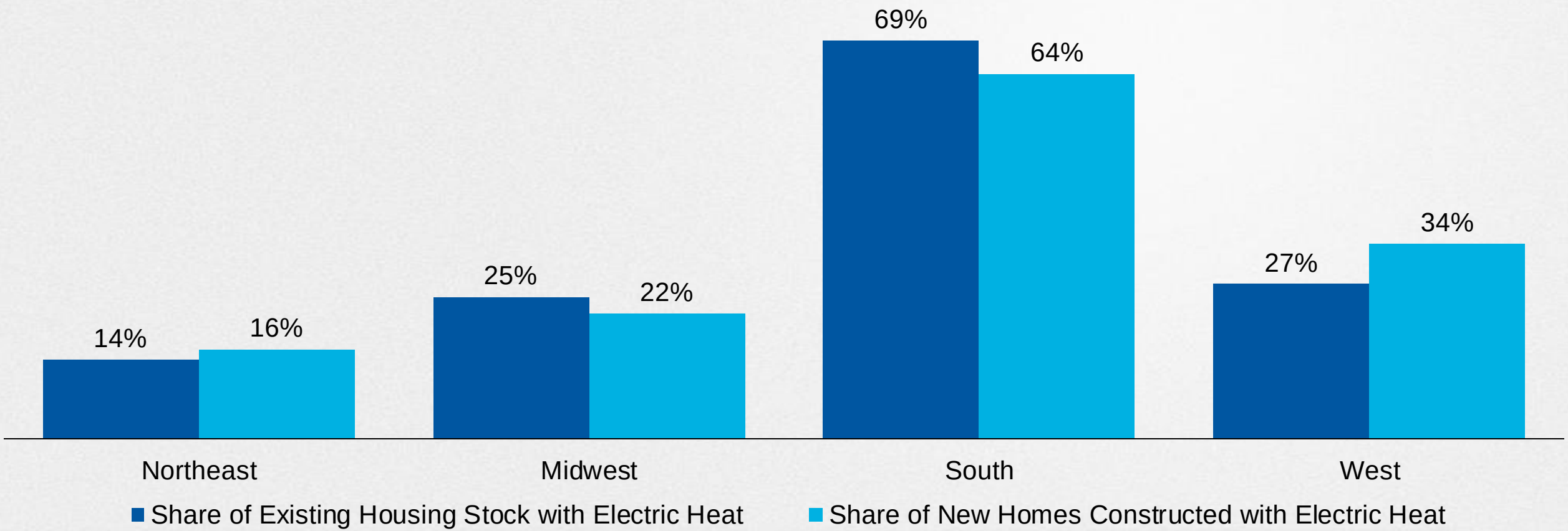
Share of primary heating fuel by building type



Sources: EIA Commercial Buildings Energy Consumption Survey (CBECS), 2012; RECS, 2015

In 2018, newly constructed homes in the West and Northeast had a greater share of electric heating than the existing building stock. In the Midwest and South, electric heat was less common in new construction than existing.

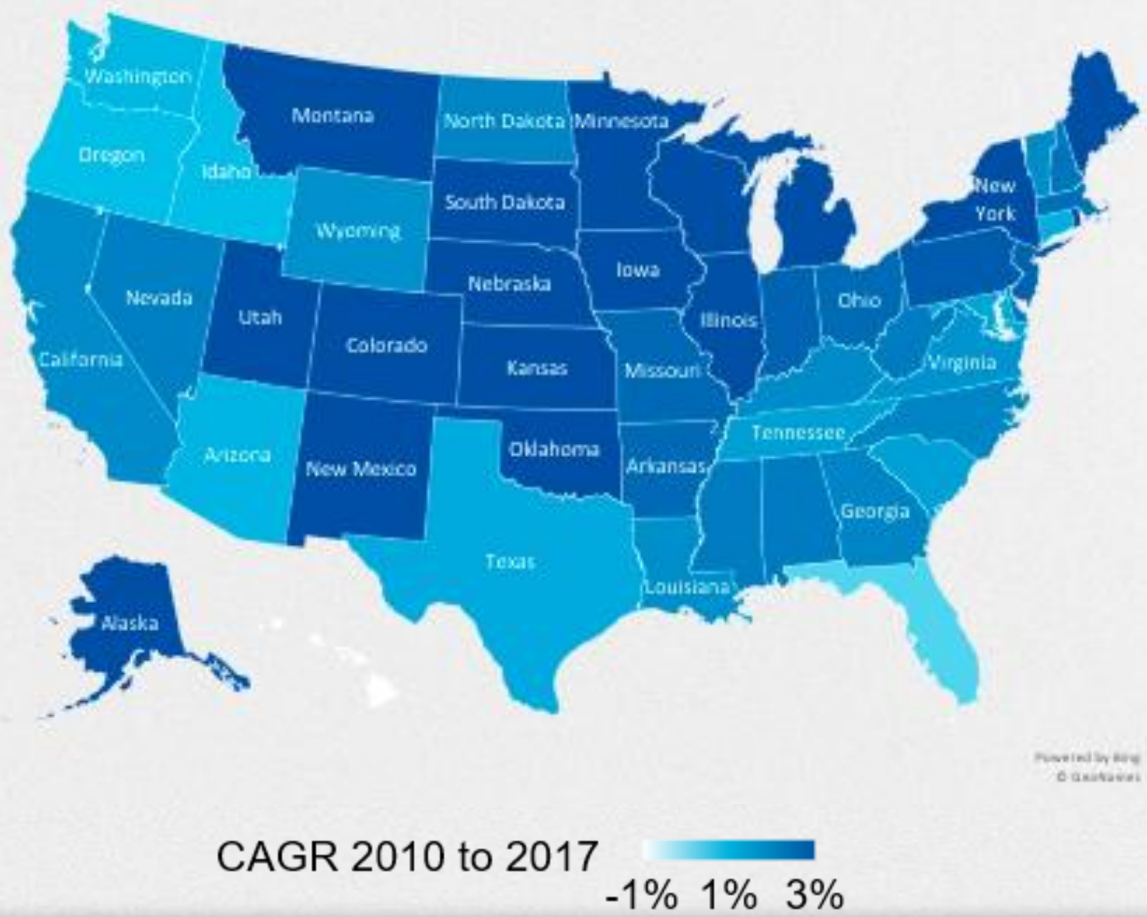
Electric heating in existing single-family homes vs. new construction by Census region
2018 building stock vs. 2018 new construction



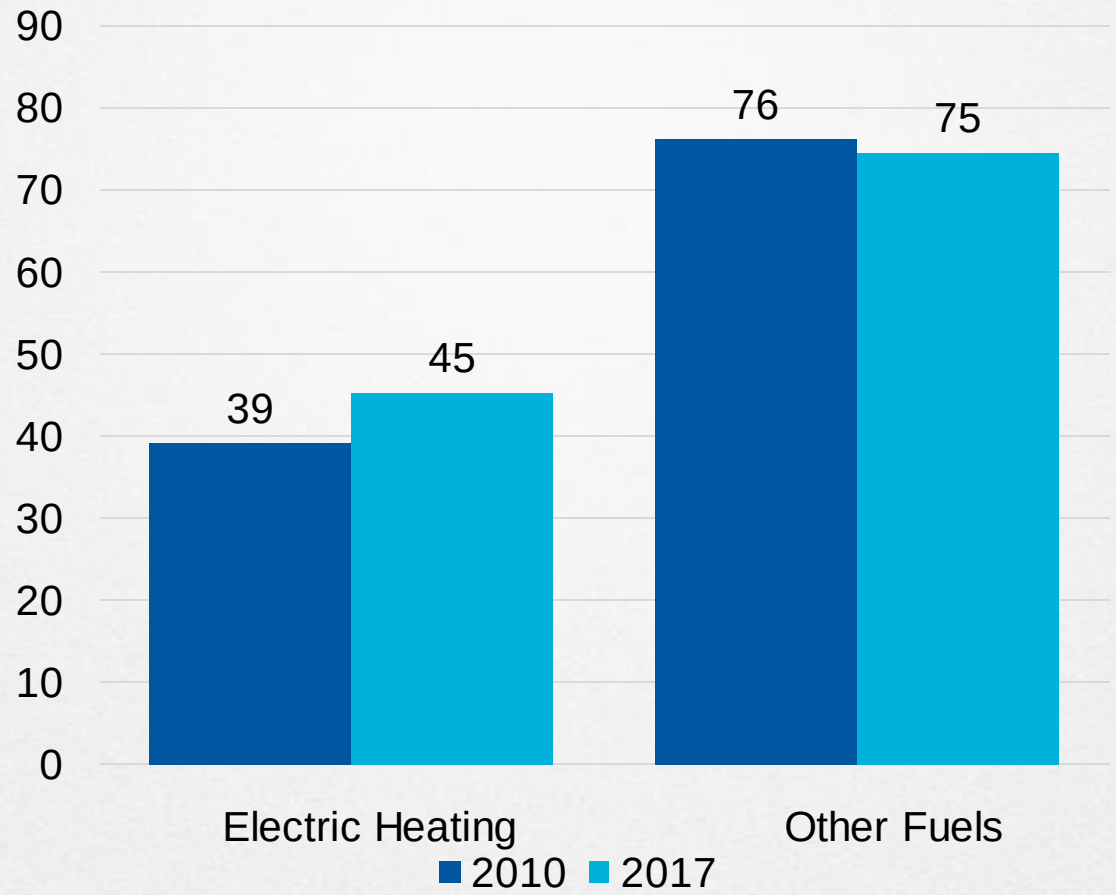
Note: New housing data is for single-family homes and multifamily units; existing housing data is for all occupied households.
Source: Census Bureau, New Residential Construction and American Fact Finder, 2018

From 2010 to 2017, all states (except Hawaii) increased their share of residential customers using electricity for heating

Growth in households using electricity as primary heating fuel Compound annual growth rate (CAGR), 2010–2017



Number of households by primary heating fuel Millions of occupied homes in the United States

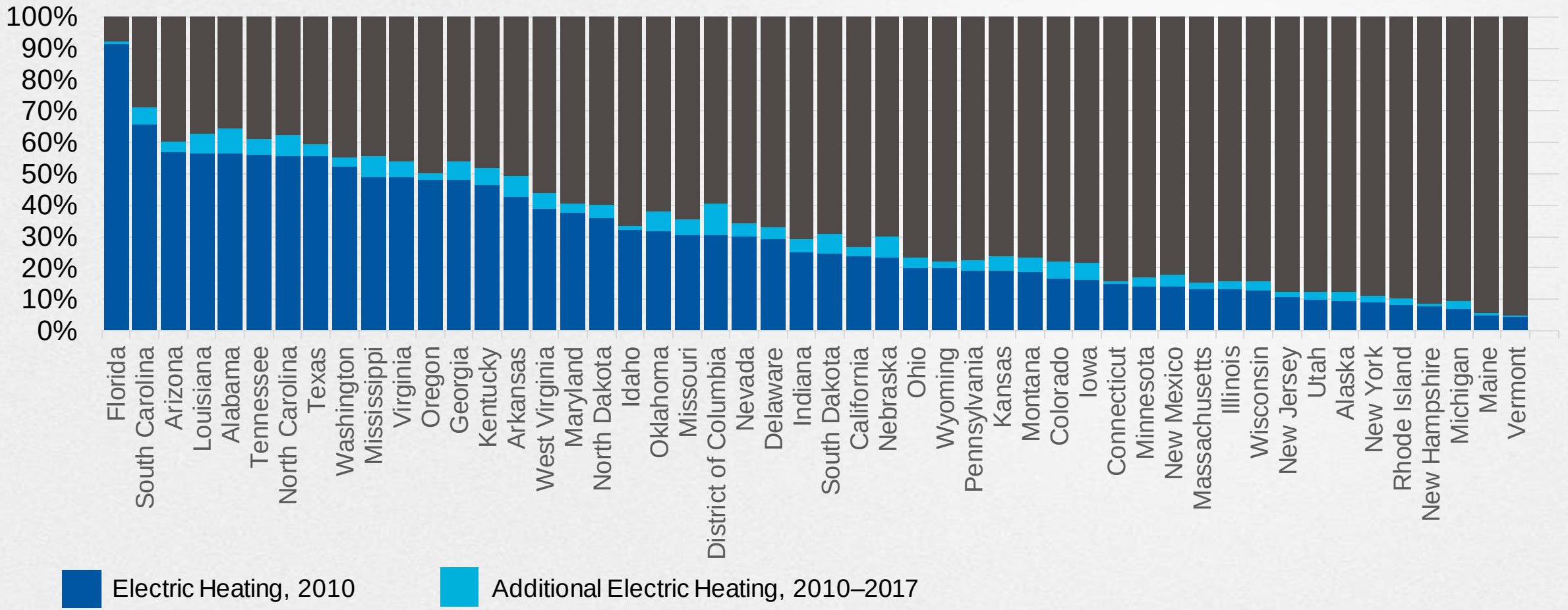


Source: Census Bureau, American Community Survey, 2017

The trend toward electric heating is apparent across the majority of states

Percentage of homes using electric heat across all states

2010–2017

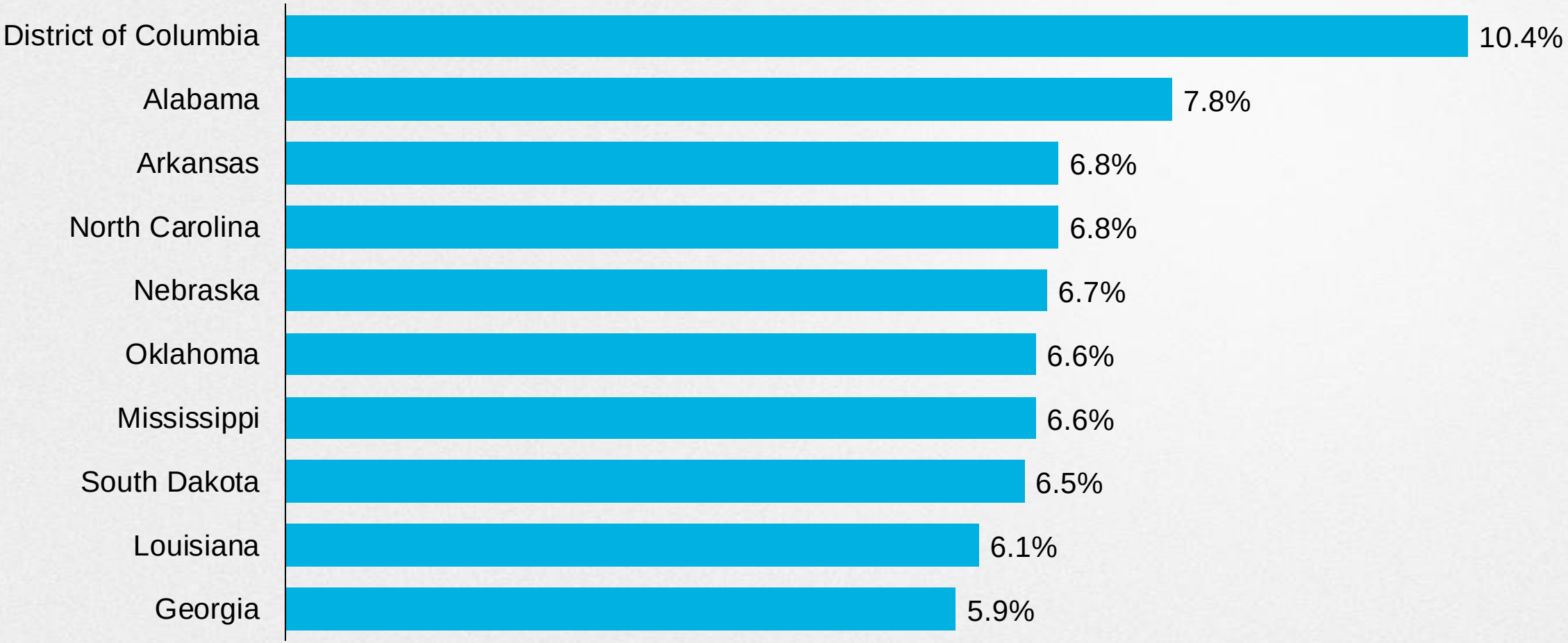


Source: Census Bureau, American Community Survey, 2010, 2017

States that have seen the biggest increase in electric heating in the past decade are predominantly in the South

Increase in electric heat share of total, top 10 states

2010–2017



Source: Census Bureau, American Community Survey,2010, 2017

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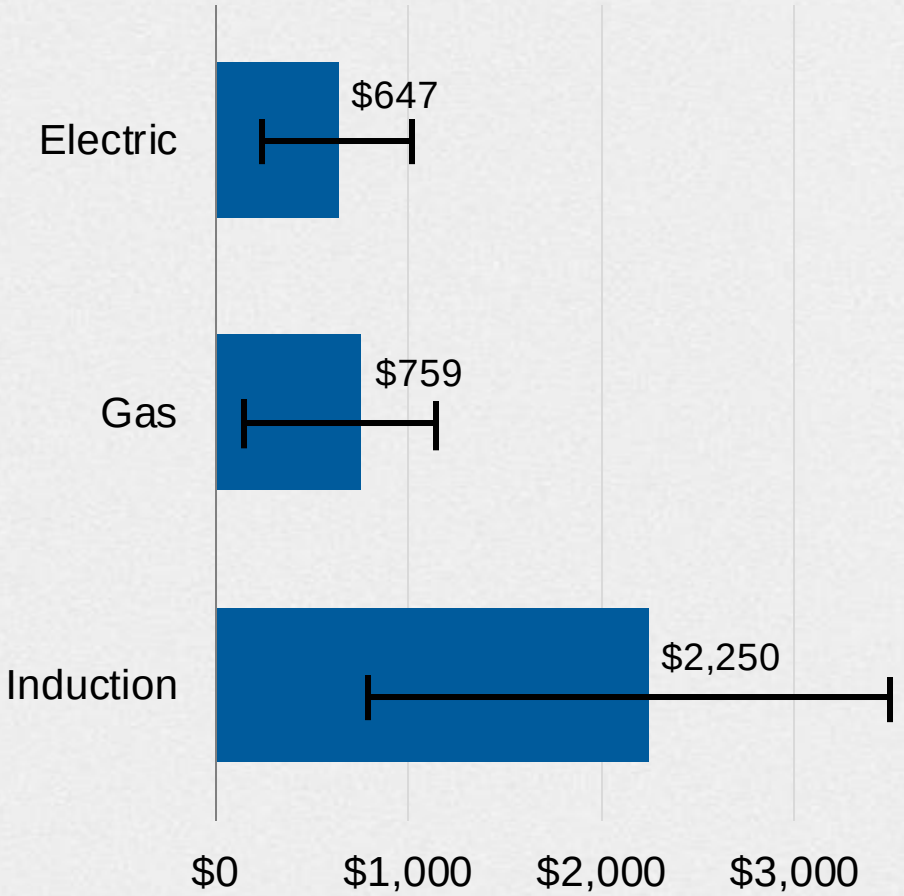
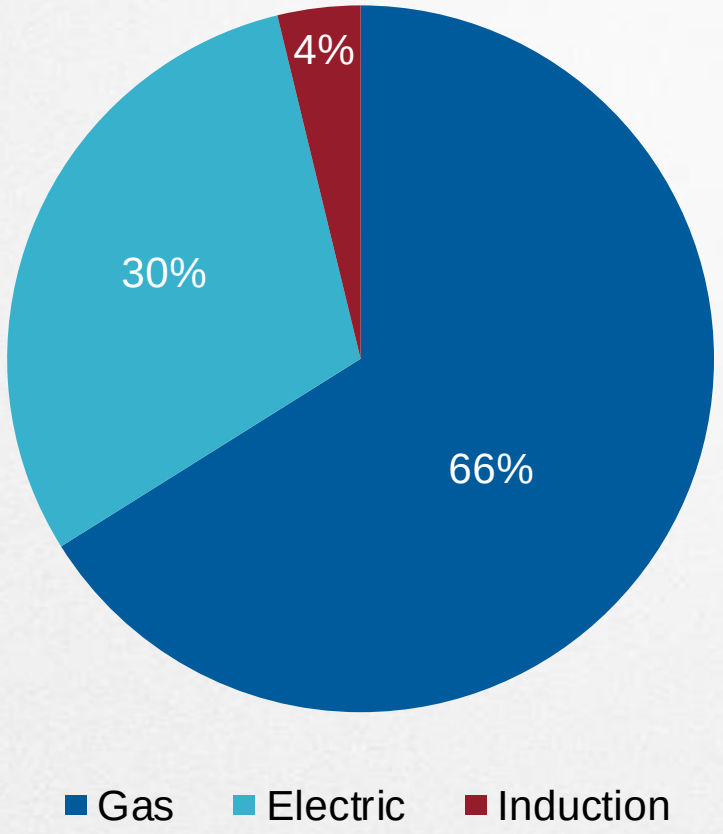
Induction ranges are available but are more costly than gas and electric alternatives in the United States, and there are fewer options available in mainstream retail outlets

Up-front purchase price of ranges by fuel
Mean USD and minimum/maximum price range



Availability of residential ranges by fuel
Products available for sale at The Home Depot

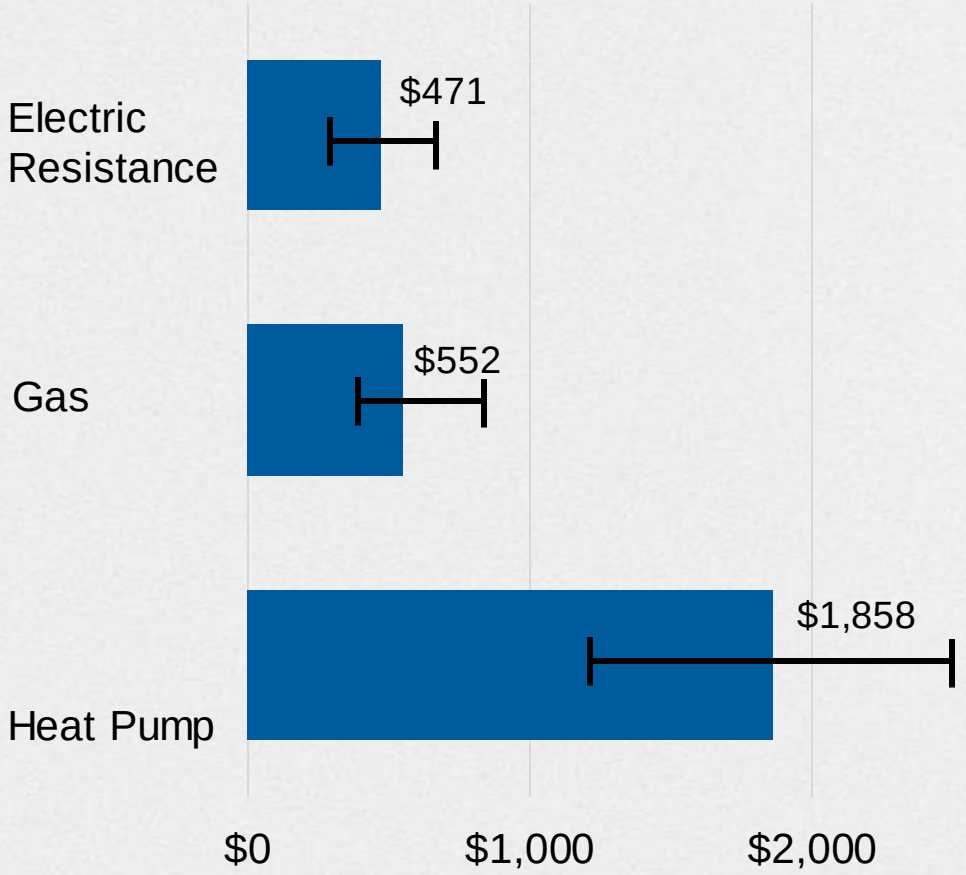


Other countries with greater use of electric appliances (e.g., UK) have seen near-cost-parity and availability for induction hobs.

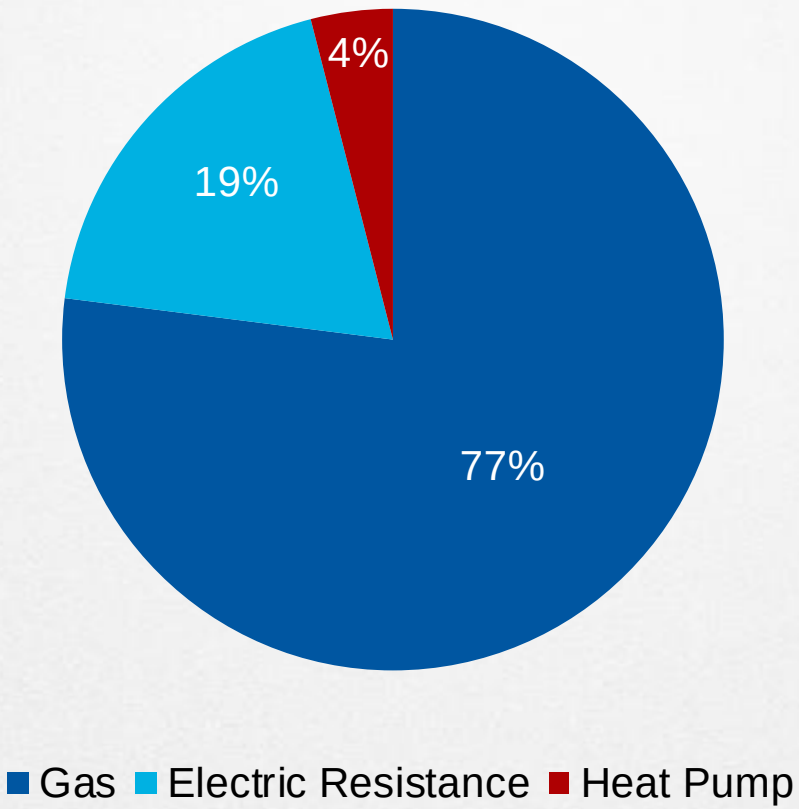
Source: Products available at The Home Depot in 2019, n=581

Heat pump water heaters are less prevalent in the market and come with a retail cost premium

Up-front purchase price of water heaters by fuel
Mean USD and minimum/maximum price range



Availability of residential water heaters by fuel
Products available for sale at The Home Depot

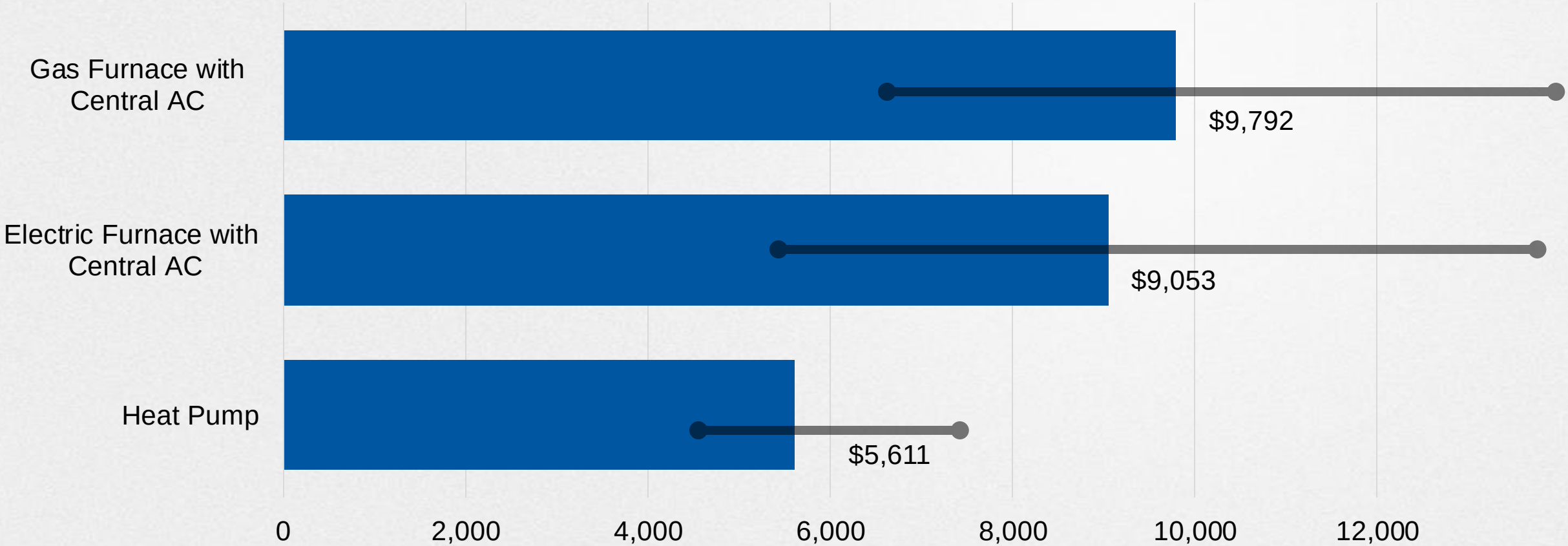


Source: Products available at The Home Depot in 2019, n=137

Up-front costs for heat pumps are lower than for the combination of furnaces and air conditioners

National average of installed cost of home air heating and cooling technology

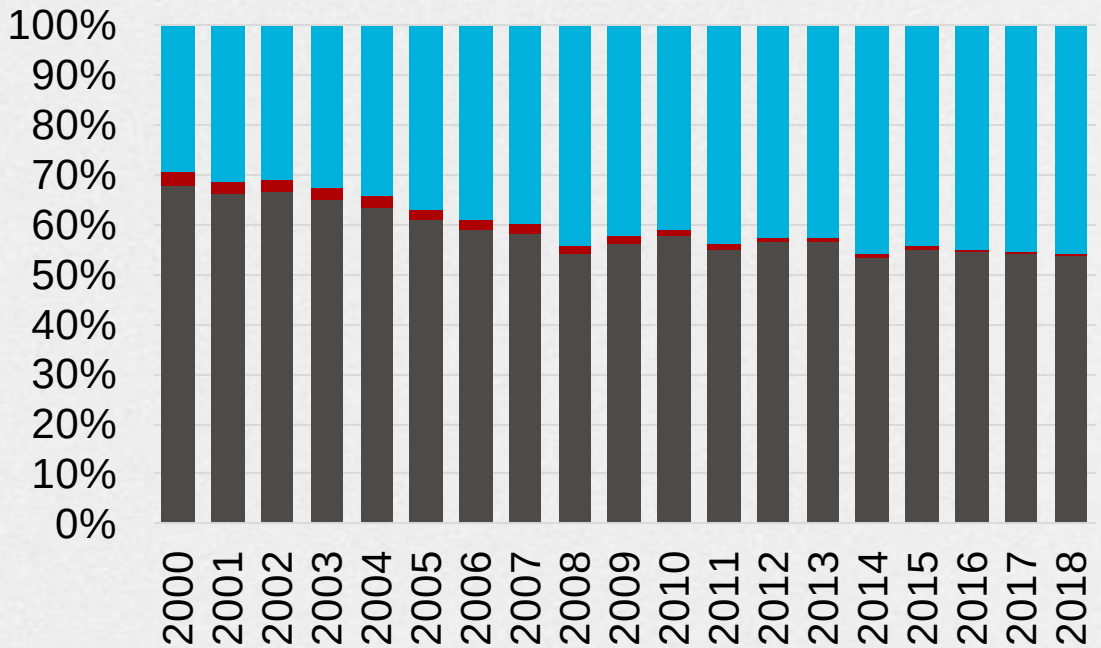
Mean USD, installation and equipment, 2019



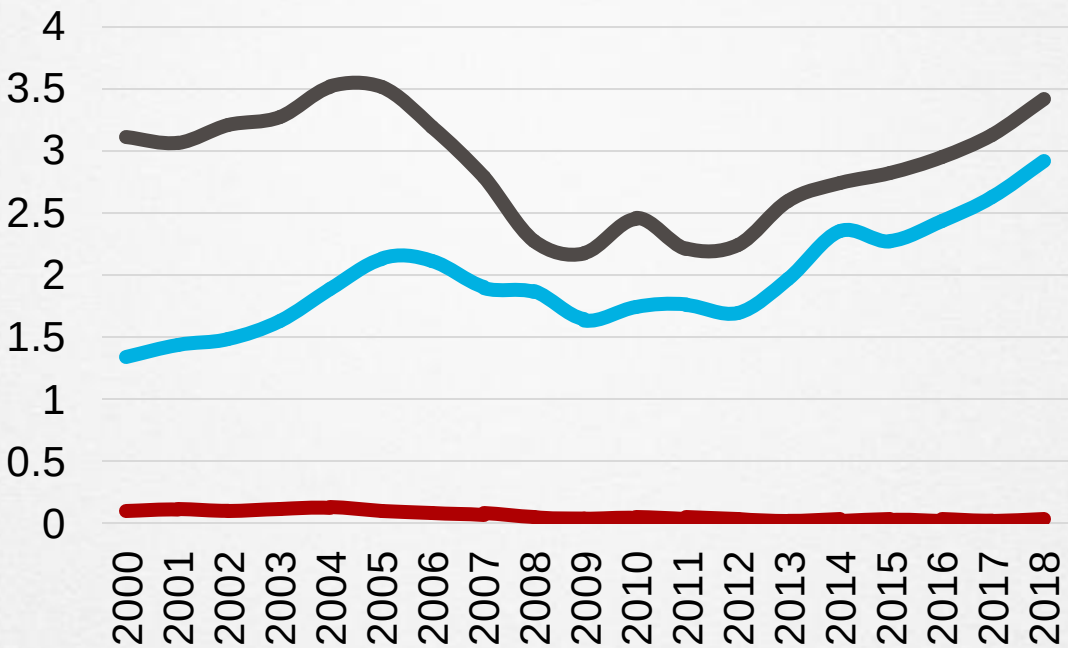
Source: Homeadvisor.com, 2019

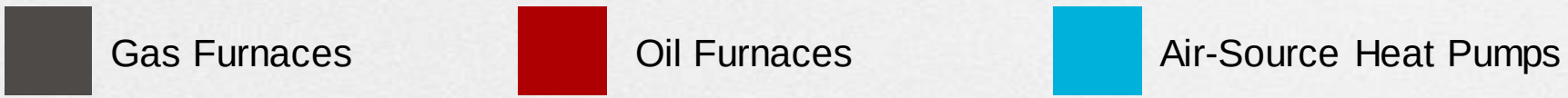
Over the past two decades, heat pump sales have caught up to fossil furnaces. In recent years, the gap between them has not changed.

Market share of fossil fuel furnaces and heat pumps
Percent of annual sales, 2000–2018



Annual sales of fossil fuel furnaces and heat pumps
Millions of units sold, 2000–2018

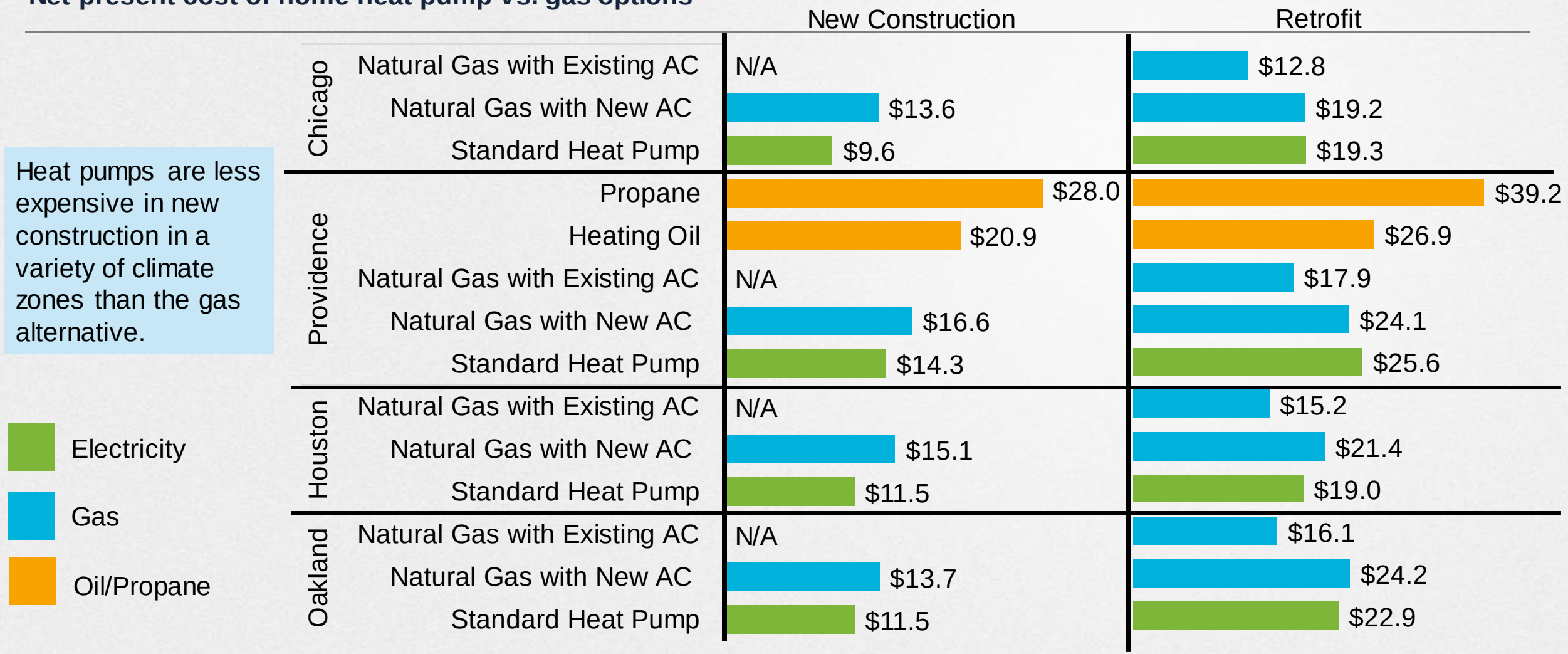




Source: Air Conditioning, Heating, and Refrigeration Institute (AHRI), 2018

Heat pumps are already cost-effective for new construction and, in some cases, for retrofits

Net present cost of home heat pump vs. gas options



Heat pumps are less expensive in new construction in a variety of climate zones than the gas alternative.

Electricity

Gas

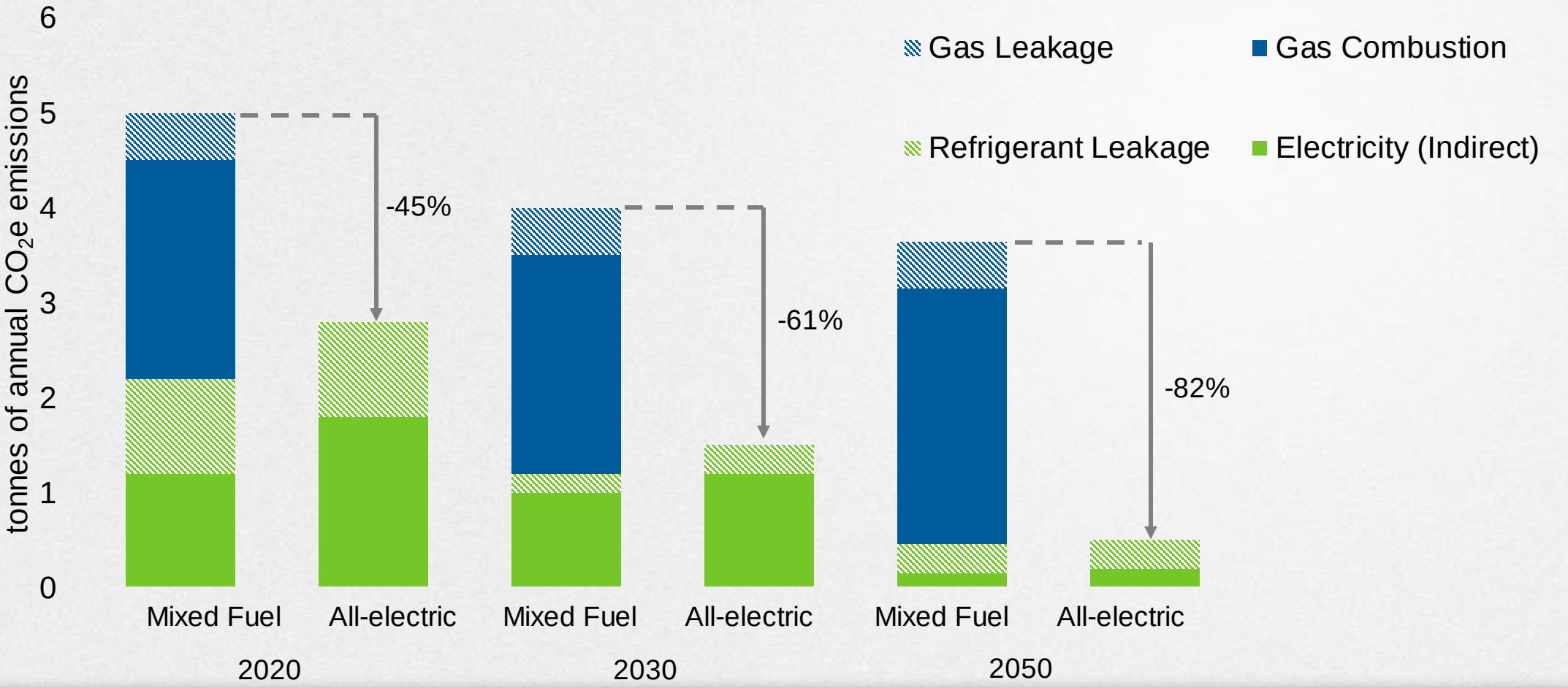
Oil/Propane

Source: RMI analysis, *The Economics of Electrifying Buildings,* 2018

In California, all-electric homes can significantly reduce carbon emissions, and these reductions increase over time ...

Annual greenhouse gas emissions from a mixed-fuel and all-electric 1990s homes in Sacramento

Tonnes of annual CO_2e emissions

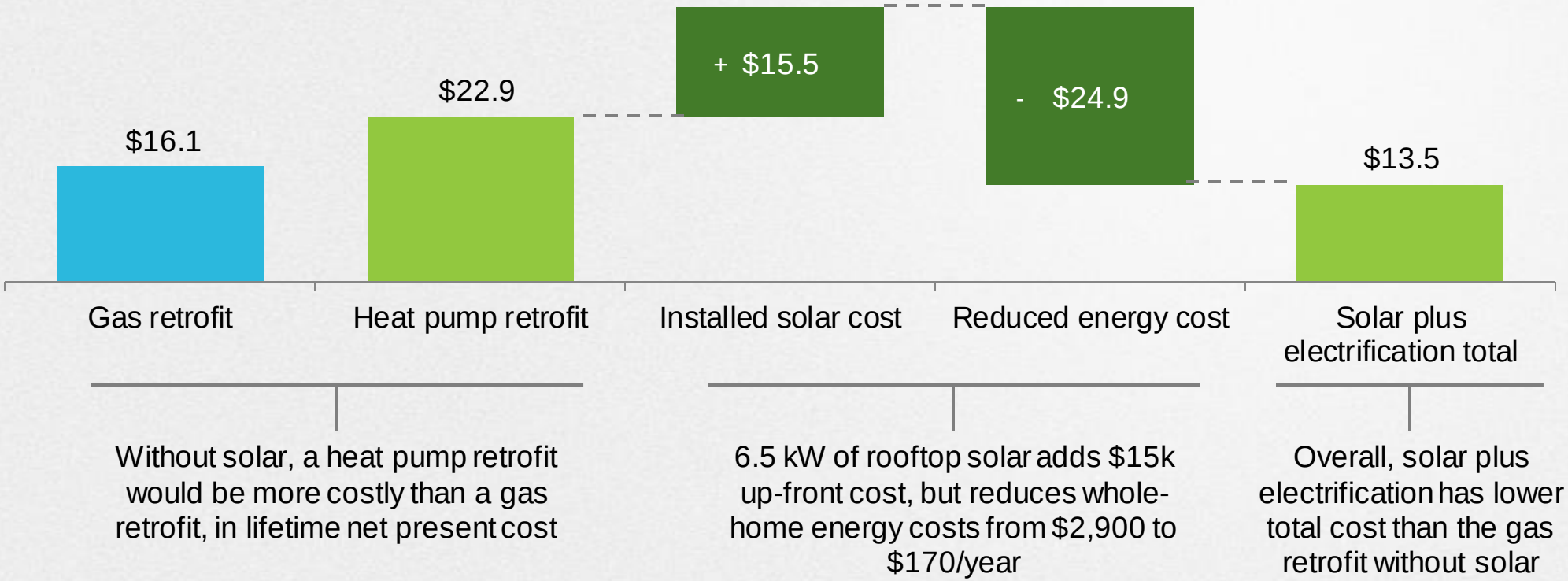


Source: E3, Residential Building Electrification in California, 2019

Adding rooftop solar with net metering makes heat pumps economically attractive

Net present cost of gas compared to solar plus electrification

Oakland single family home retrofit, $000

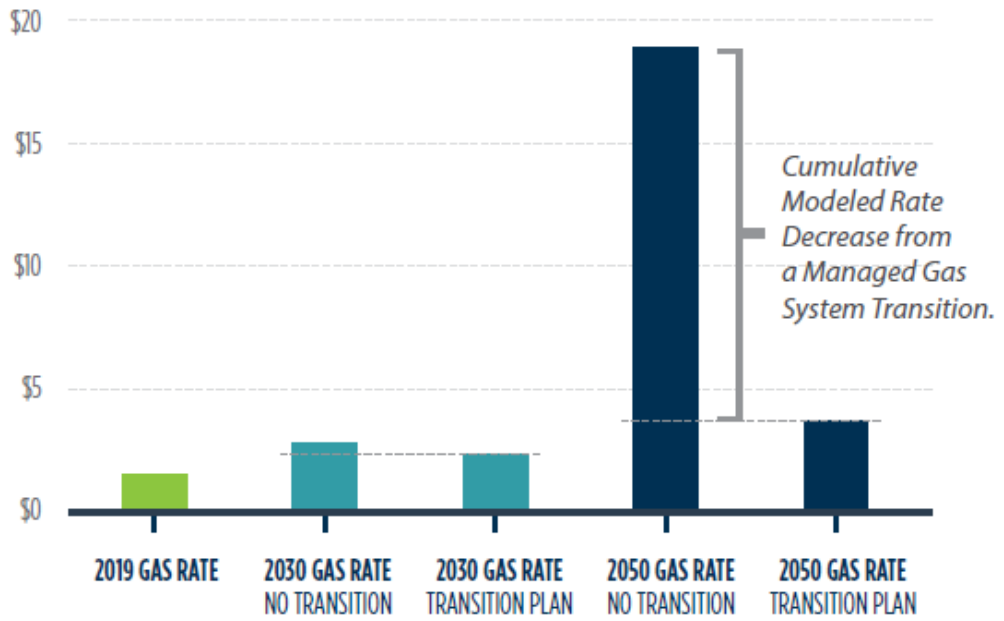


Source: Rocky Mountain Institute, *The Economics of Electrifying Buildings,* 2018

System-level economics: California analysis also concludes that a managed gas system transition will be the most economical and equitable path forward

FIGURE ES1. *2050 Gas Rate Reductions Resulting from Proposed Solutions*

Source: E3



Authors conclude policymakers must start planning the gas system transition now in order to capture rate reduction benefits by 2050, and offer specific recommendations for a managed transition, including:

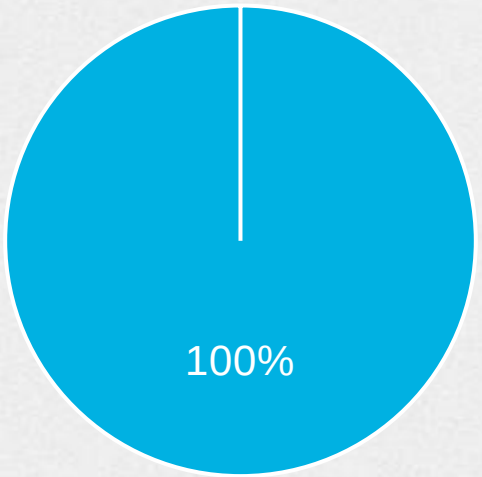
- Initiate pilot projects that decommission segments of the gas distribution system
- Consider requiring all new residential and commercial construction to be all-electric as quickly as possible
- Identify alternatives to significant new investments in the gas delivery system
- Organize a just transition for the gas delivery system workforce
- Consider aligning financial recovery of new investments with time horizons [consistent with state decarbonization goals]

Source: *California's Gas System in Transition,* Gridworks, September 2019

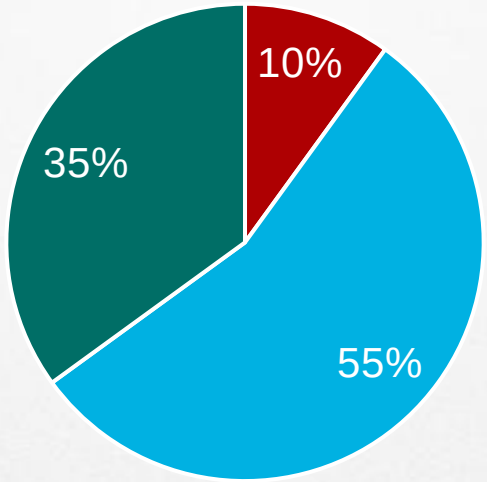
… and most California customers' energy bills would decrease with electrification

Share of simulated single-family households bill savings from adopting electric end uses in California
Pre-1978 and 1990s homes

Retrofit Package (HVAC Heat Pump and Heat Pump Water Heater)



All-Electric New Construction



Bill Increase ≤ $100 Per Year

Bill Increase > $100 Per Year

Bill Savings

Source: E3, Residential Building Electrification in California, 2019

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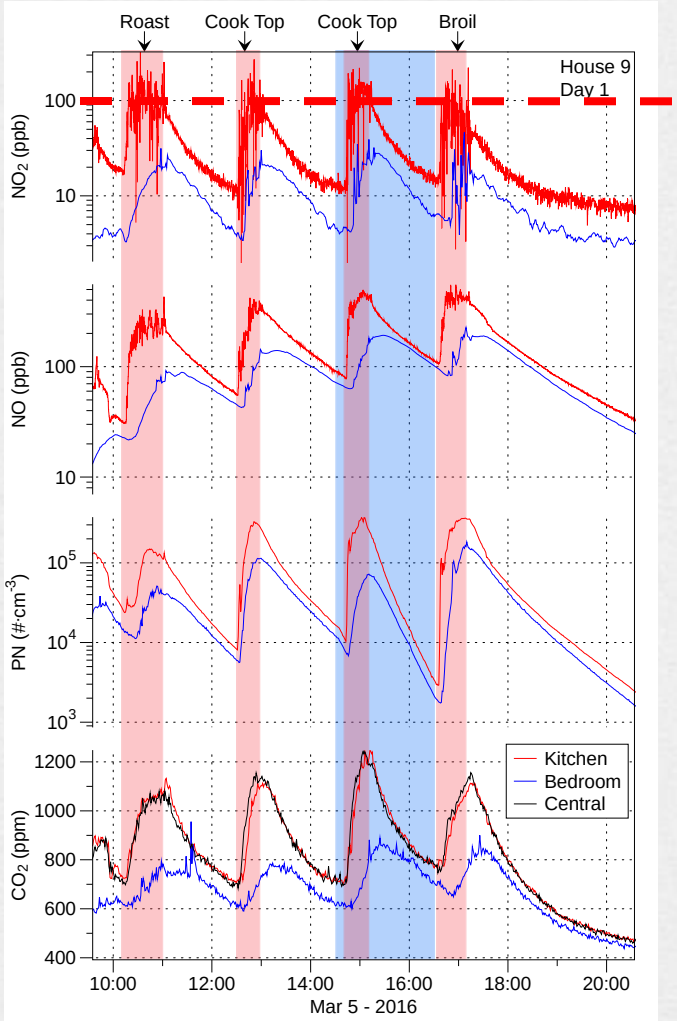
Indoor air quality is often more harmful than outdoor air in most of the United States, primarily due to the combustion of fossil fuels in homes



NO_2 > 100 parts per billion in kitchen

Nitric oxide and nitrogen dioxide (NO_x) pollution released by gas cooking indoors often exceeds EPA ambient outdoor air requirements. NO_x also:

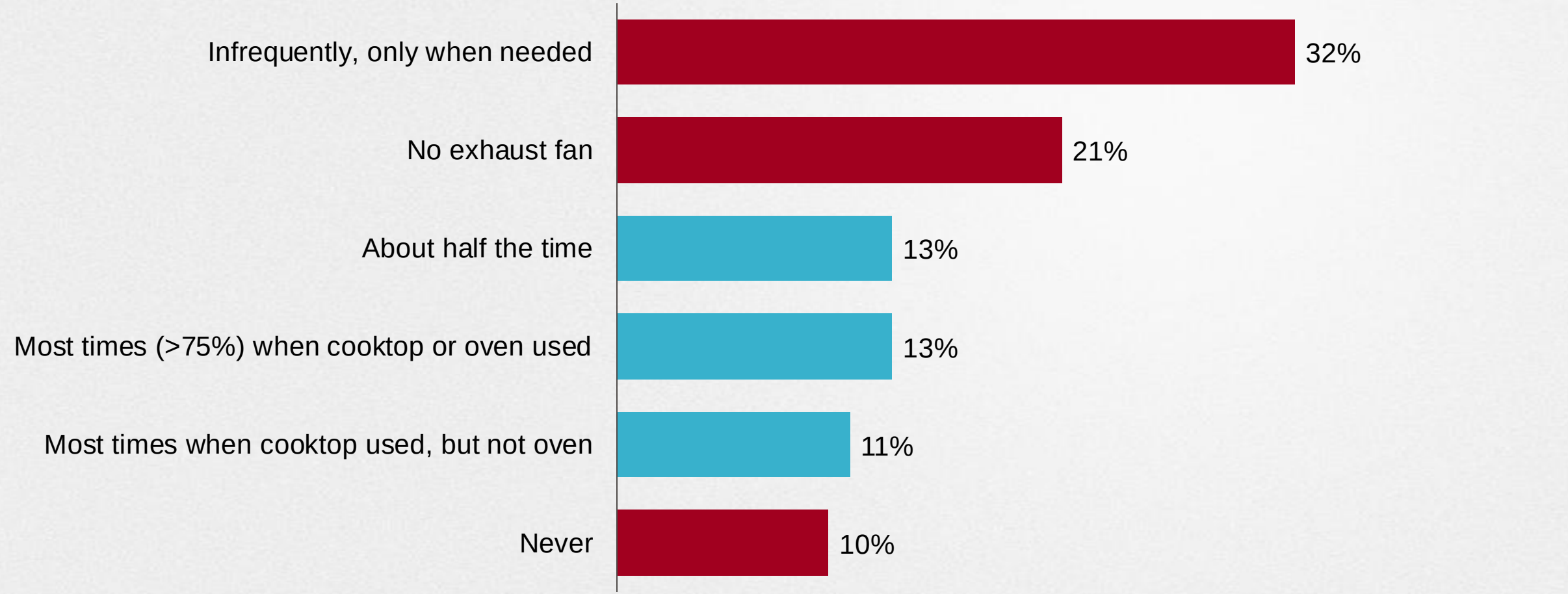
- Is an airway irritant
- Exacerbates asthma and other respiratory diseases
- May cause asthma and increase infections
- Especially affects asthmatics, the elderly, and young children

In addition, gas cooking releases ultrafine particles, particulate matter (PM2.5), and volatile organic compounds (VOCs)

Source: Brett Singer, Lawrence Berkeley National Laboratory (LBNL), 2012

Many of the impacts of indoor gas cooking can be mitigated with proper ventilation. However, more than half the population rarely use vents, or do not have them.

Self-reported use of cooking ventilation
% of respondents, 2012

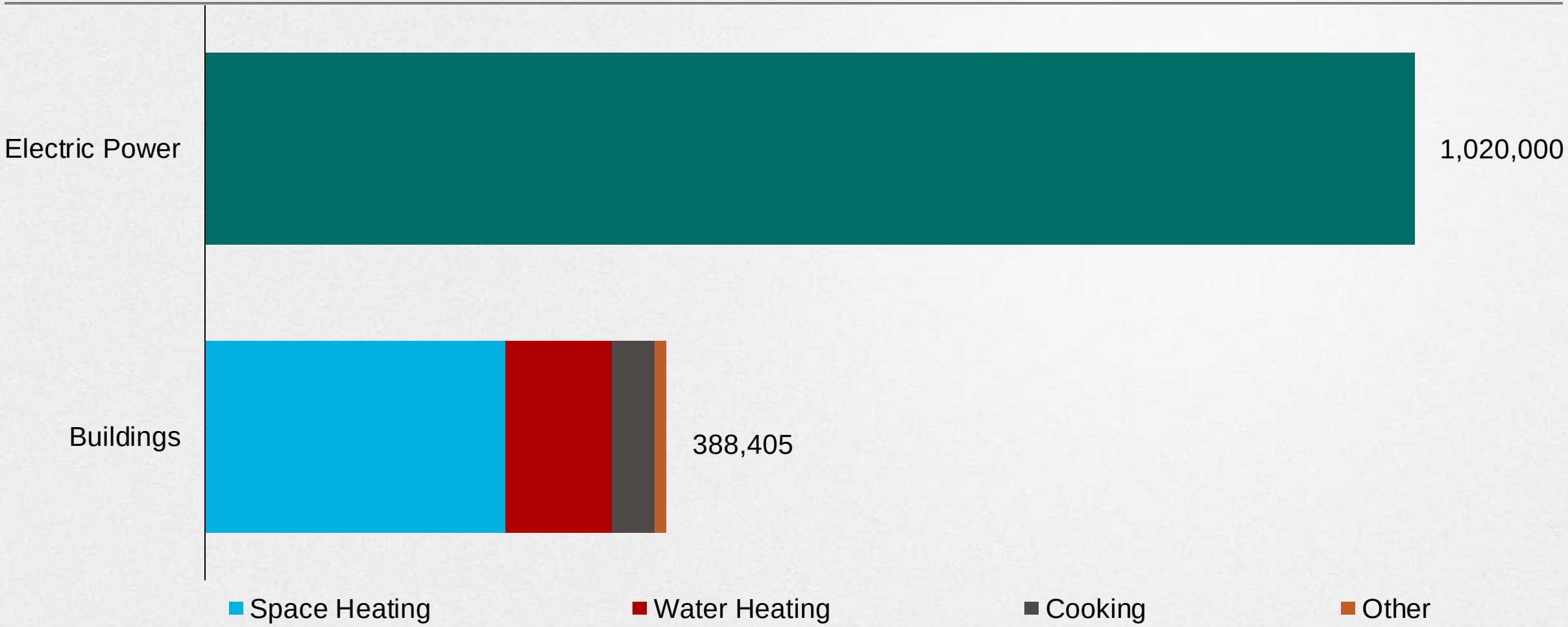


Source: Brett Singer, LBNL; Mullen et al. LBNL-5970E, 2012

Although power plants are the largest source of NOx emissions across the United States, buildings contribute a significant share

Tons of NOx emissions by sector and end use

2018



Sources: EIA 2018, EPA 2018, RMI analysis