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REPORT
GTI ENERGY PROJECT NUMBER 21917

Seasonal Residential Space Heating Opportunities and Challenges

Seasonal Residential Space Heating Opportunities and Challenges:

Report Findings

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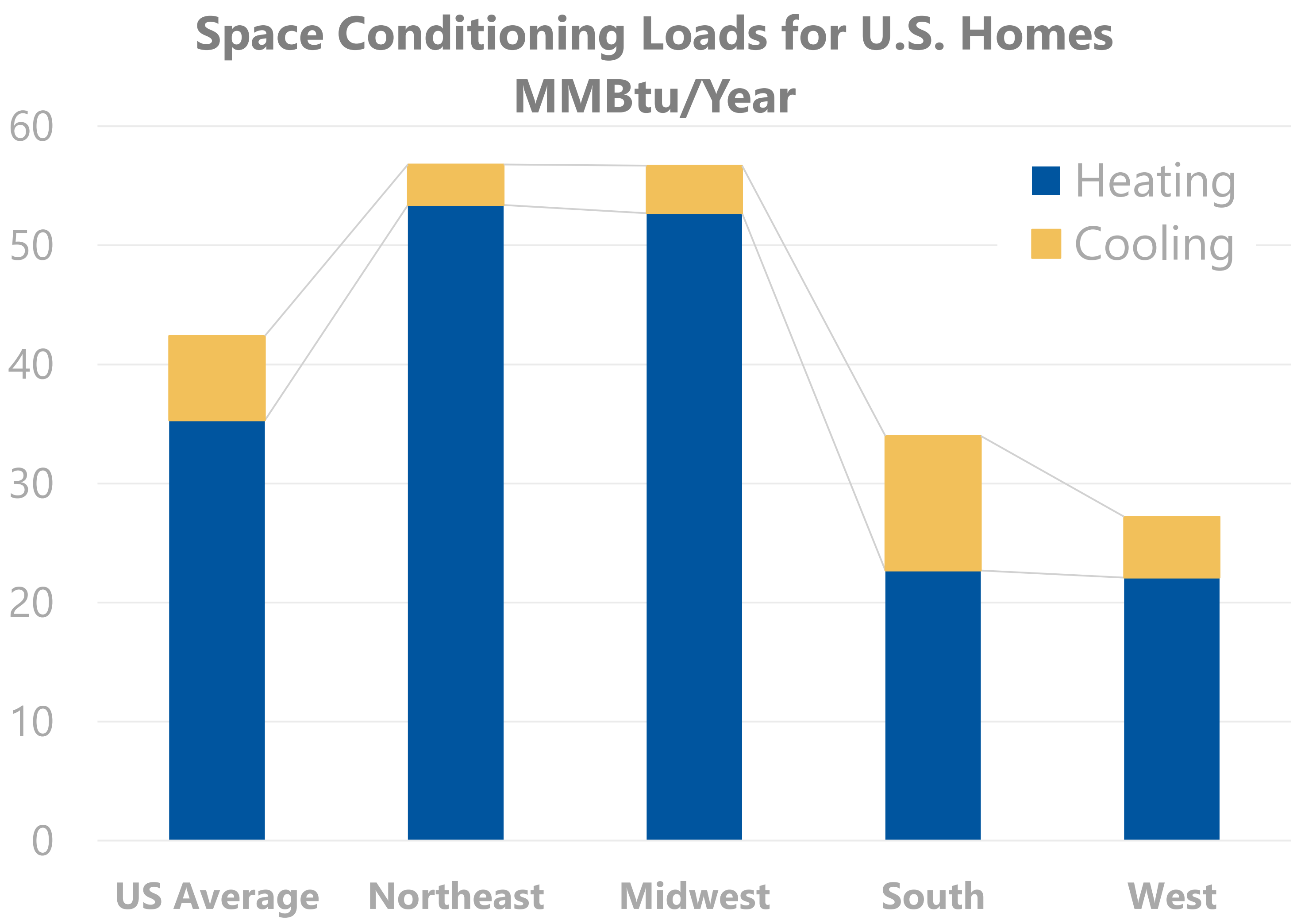
Seasonal Residential Space Heating Opportunities and Challenges

- Presentation reviews opportunities and challenges with natural gas and electricity use in addressing residential space heating loads
- **Challenges:**
  - Intensity of space heating >> space cooling
  - Sensitivity of electric heat pump efficiency to outdoor temperatures
  - Higher CO_2 emission rates from seasonal power generation
  - Current limitations to capturing real-world GHG reductions
- **Solutions:**
  - Hybrid residential natural gas/electric space heating systems
  - Renewable gas blends for residential space heating
  - Decarbonization of dispatchable winter electricity generation

Space Conditioning Energy Use: Heating >> Cooling



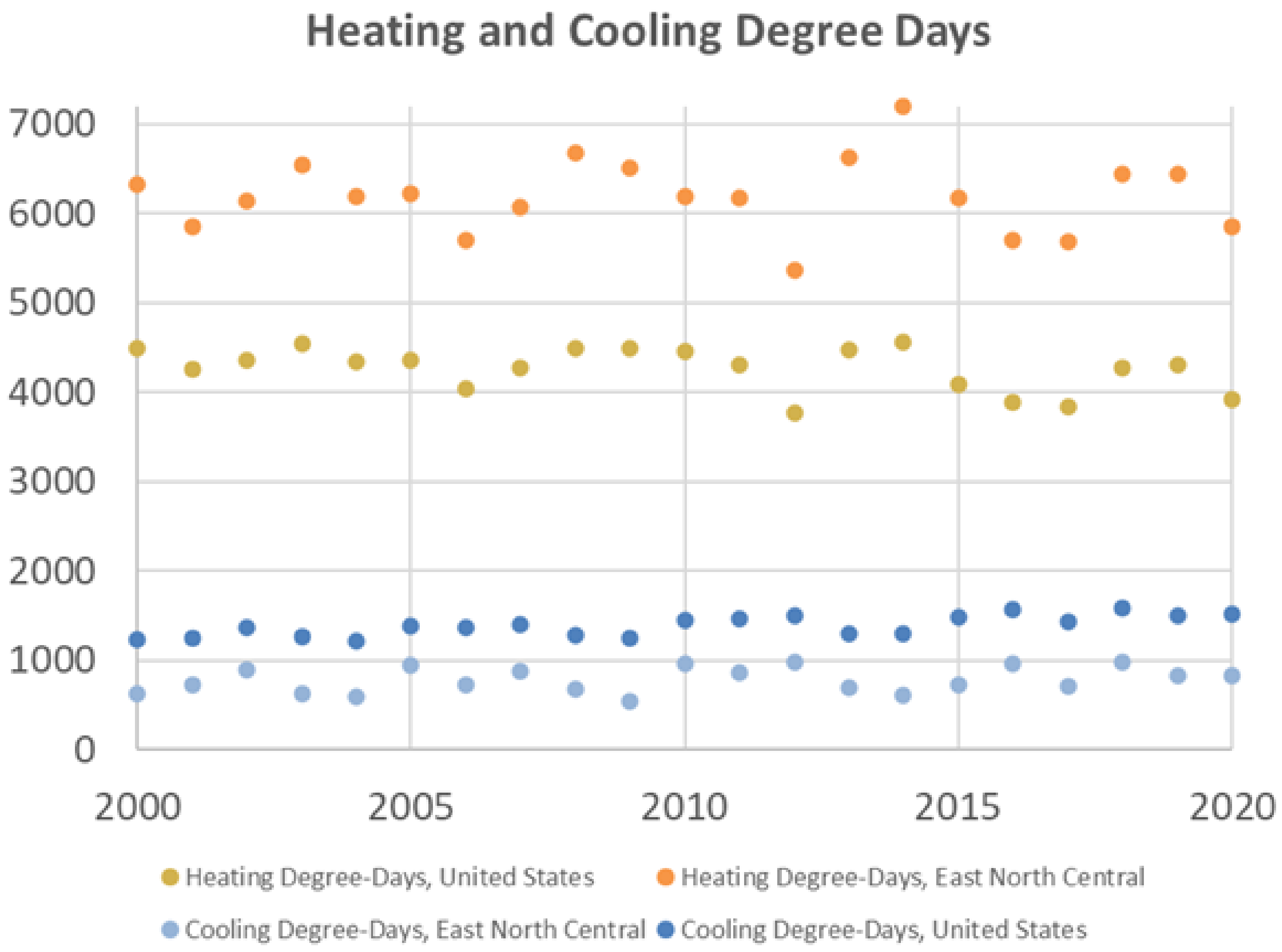
Space heating is the dominant space conditioning load in most regions.

Ratio of heating to cooling is high in northern regions (over 5:1).

Natural gas is main customer choice, particularly in colder climates.

Source: DOE-EIA (RECS, 2015)

Heating >> Cooling



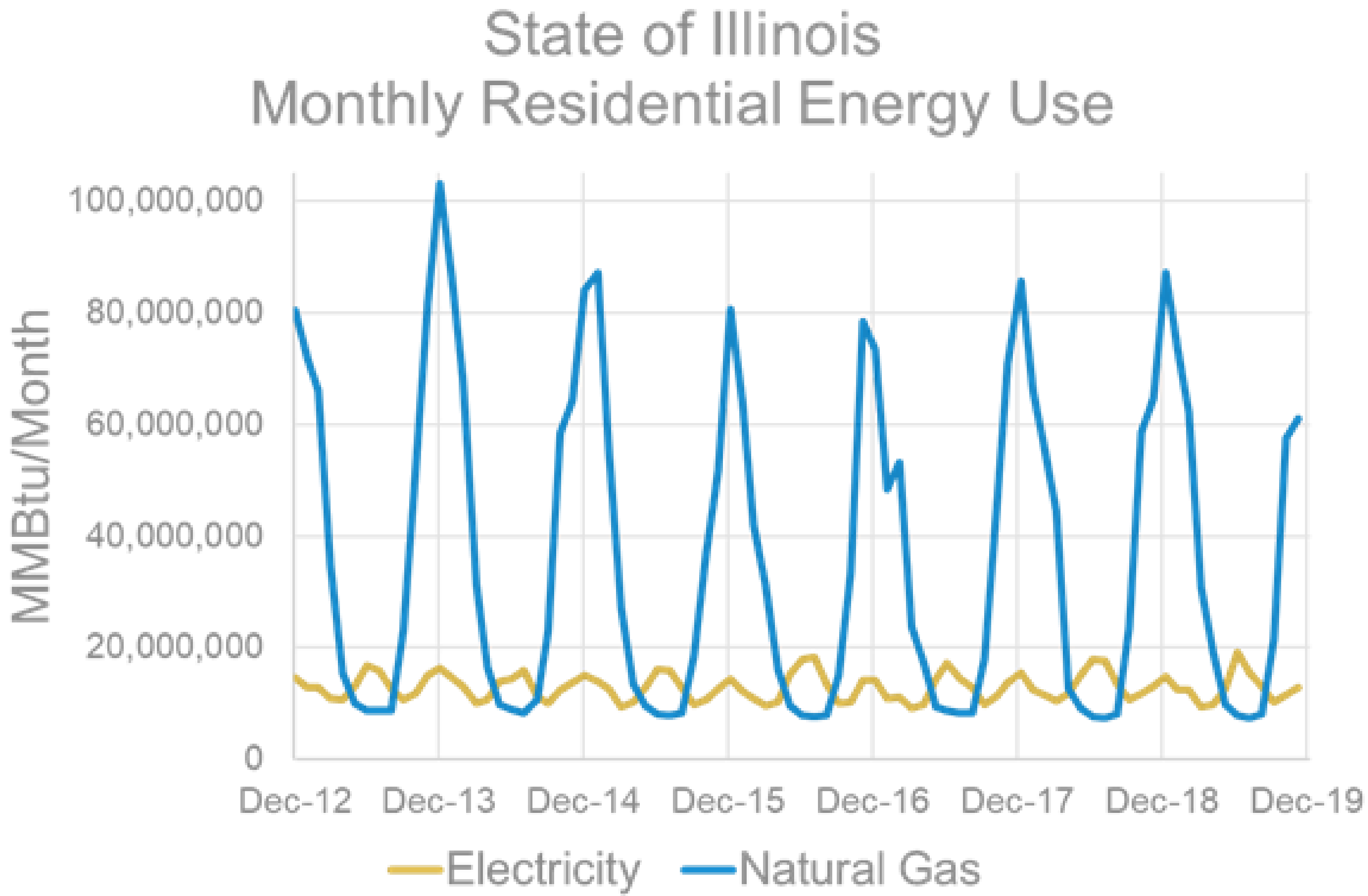
Ratio of heating to cooling is high, notably in northern regions (>5:1).

Shifting from gas to electric in colder weather conditions raises issues:

1. Higher consumer energy costs
2. Large electricity demand peaks (including severe peaks during extremely cold weather)
3. Seasonal electricity demand increases often met with dispatchable power generation having appreciably higher GHG emission rates

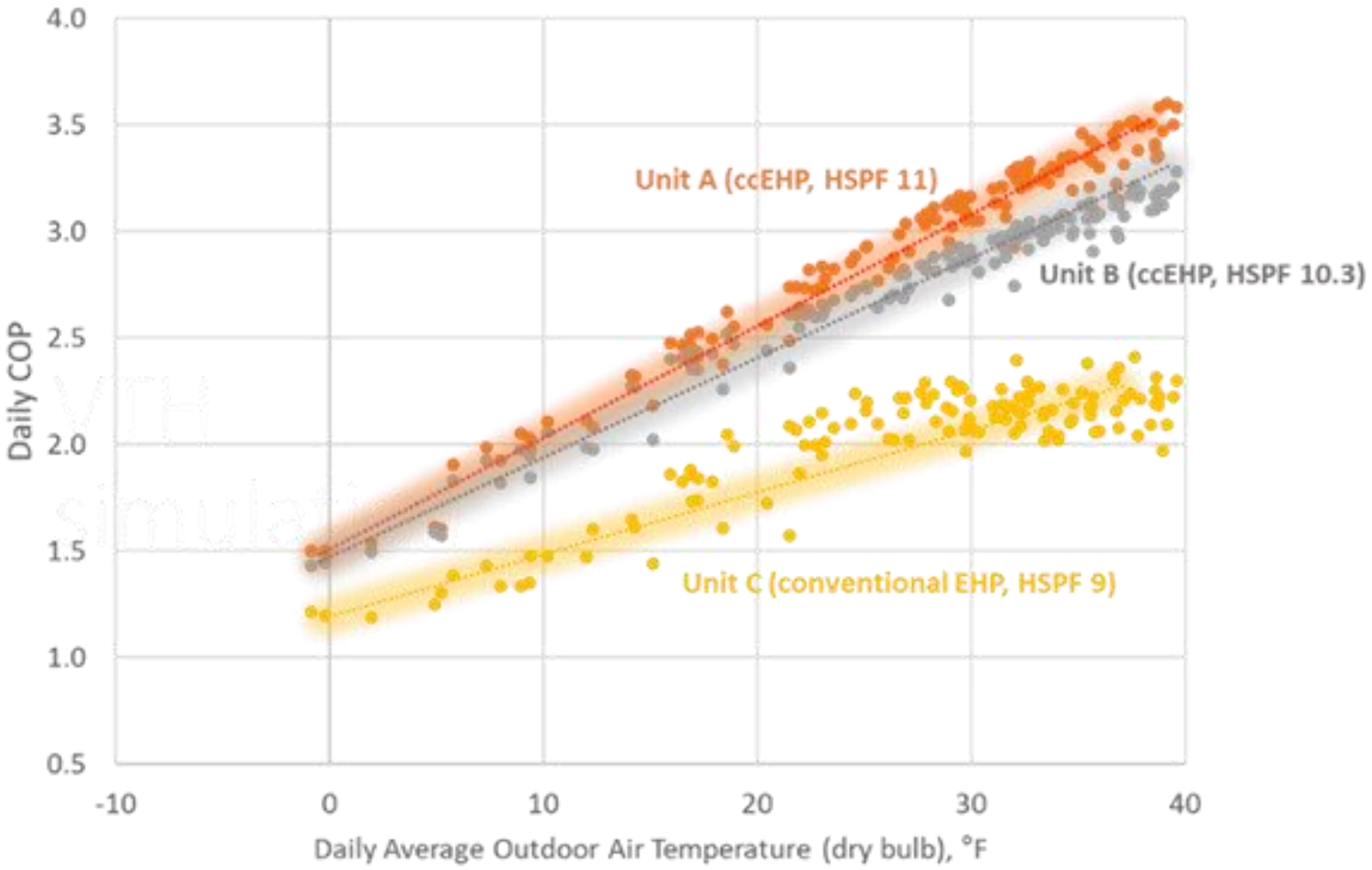
Source: DOE-EIA

Heating >> Cooling



Source: DOE-EIA

Impact of Outdoor Temperatures on Electric Heat Pump Efficiency

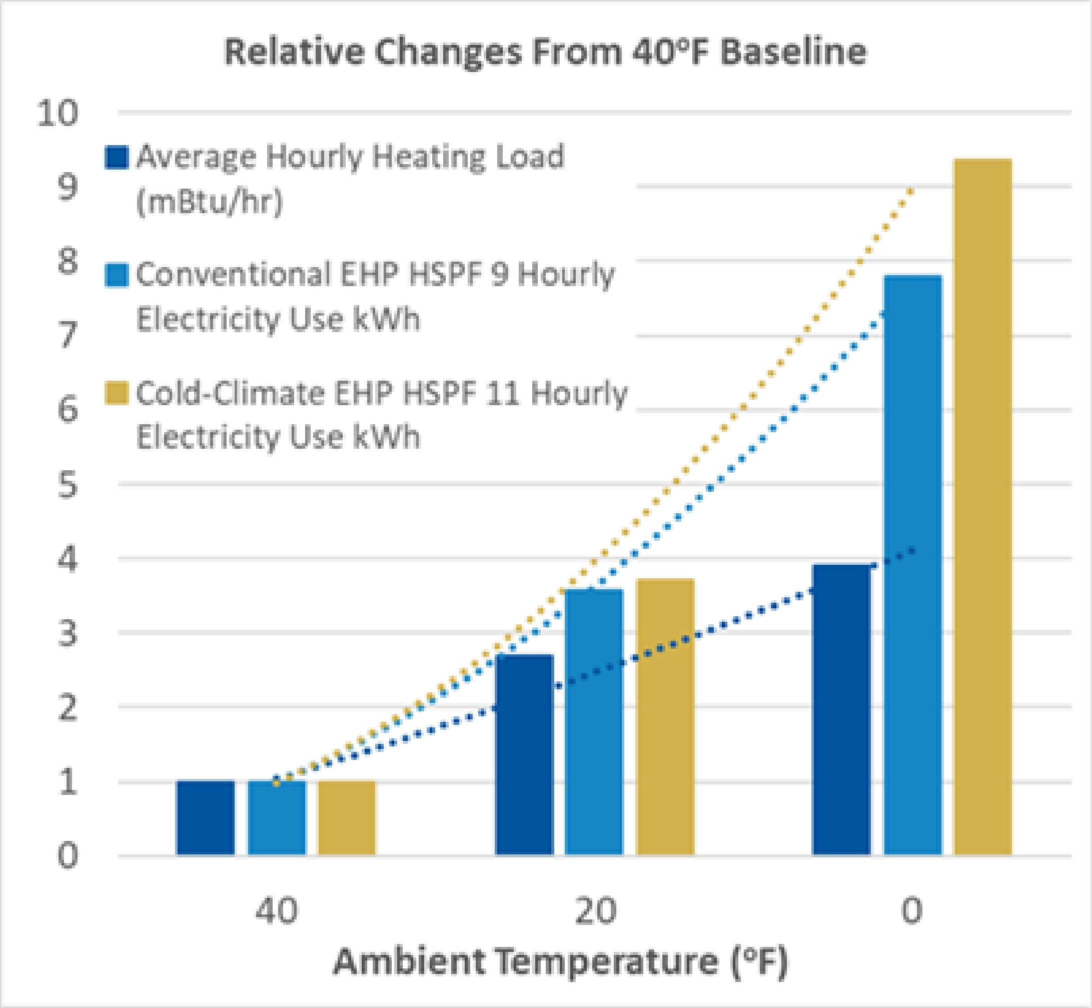


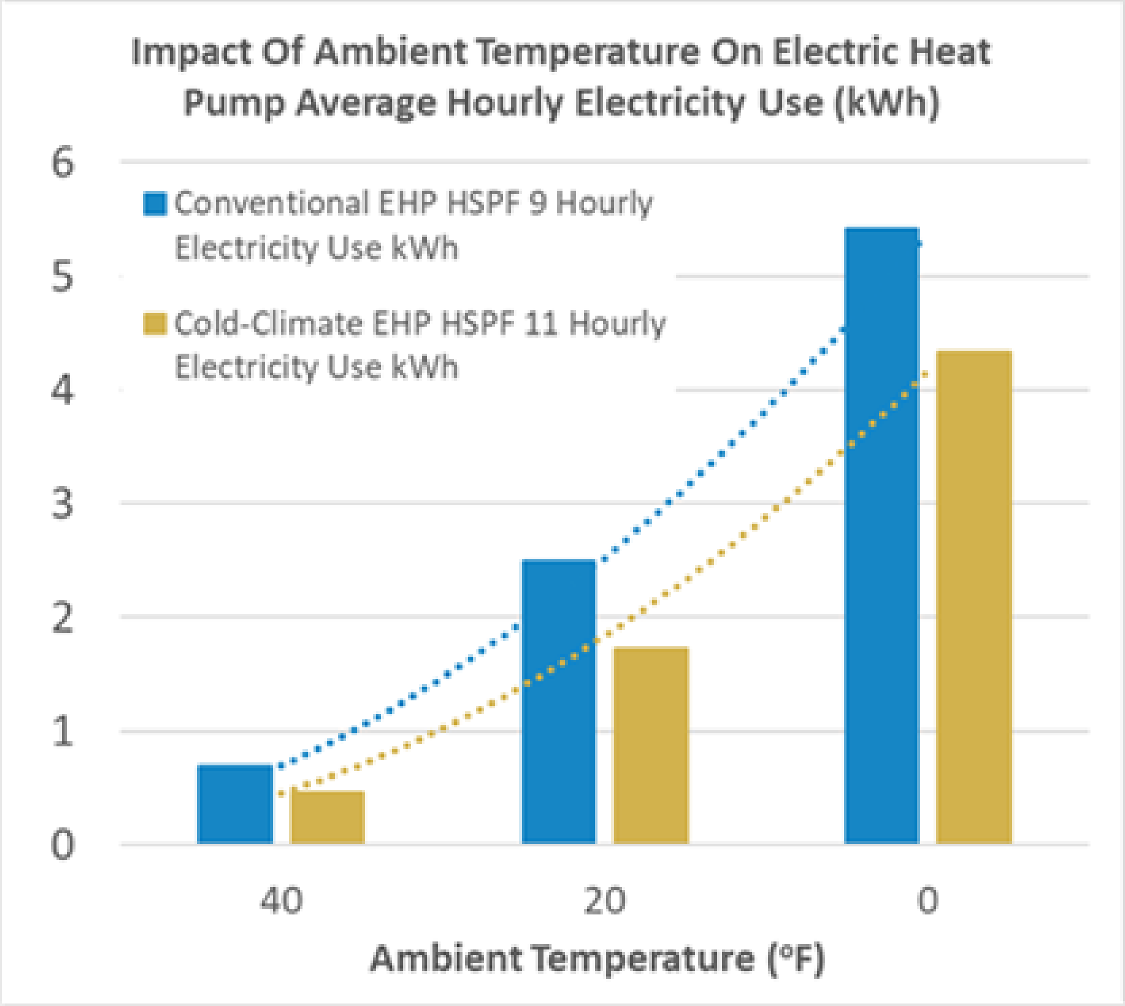
Real-world electric heat pump (EHP) efficiency goes down with temperature

Cold-climate (ccEHP) units an improvement, but still have lower efficiency and higher electricity consumption rates at colder temperatures

COP = Coefficient of Performance, measure of electric heat pump efficiency

Impact of Outdoor Temperatures on Electricity Demand and Electric Heat Pump Efficiency





Residential Seasonal Space Heating Analysis

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- State-level analysis of natural gas and electric space heating options
  - Gas furnace with 95% efficiency; electric heat pump with HSPF 9.0 rating
  - Single-family homes with about 1600-2000 ft^2 of living space
- Metrics analyzed:
  - Consumer source energy use and annual space heating costs
  - GHG emissions (winter marginal and winter average)
  - Projected state-wide future winter residential peak month electricity use with widespread residential electrification
- Results incorporated into a final report and an online website with interactive state-level data viewer

https://www.gti.energy/residential-space-heating/

Single-Family Home Space Heating Cost Changes

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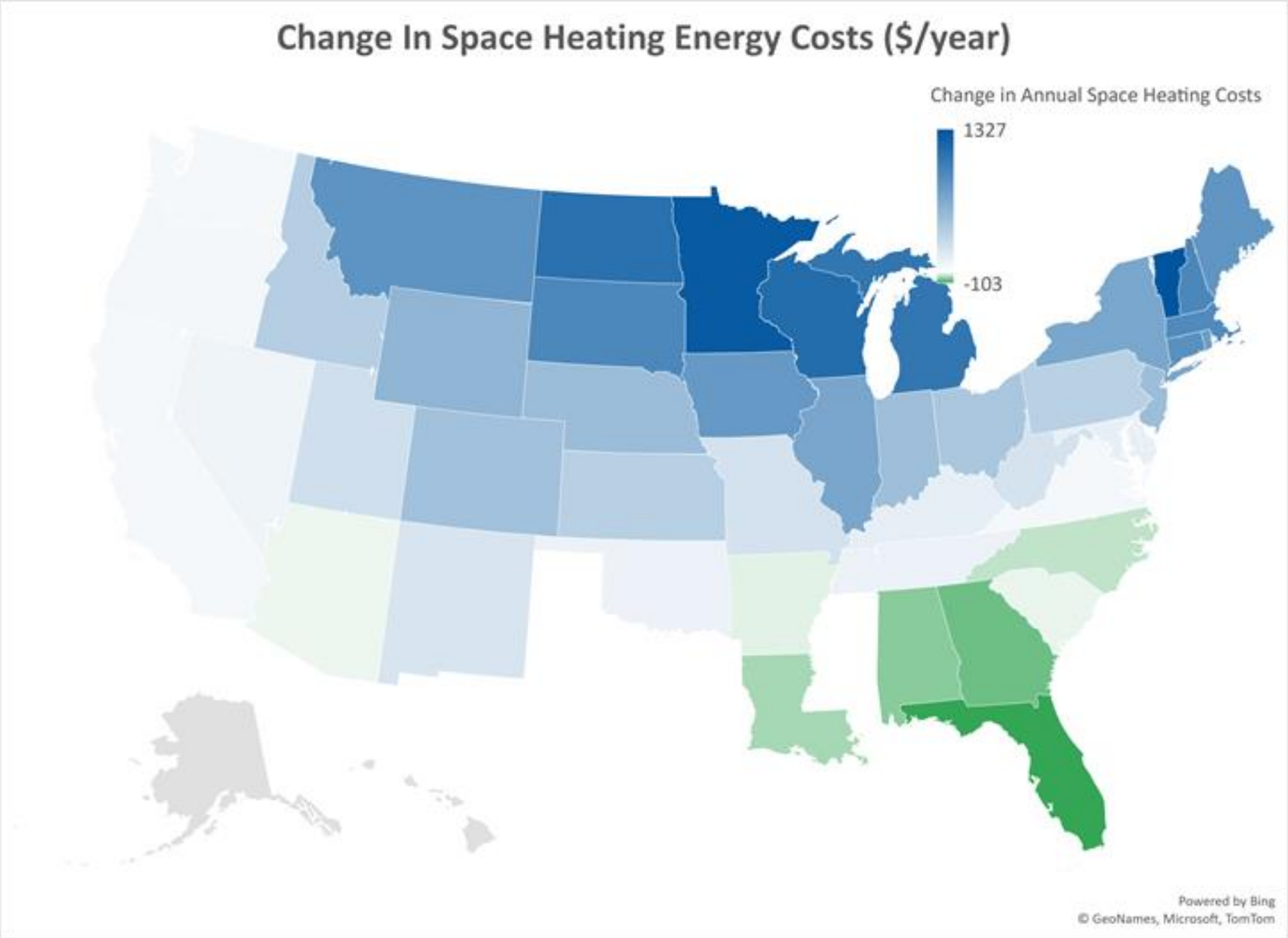
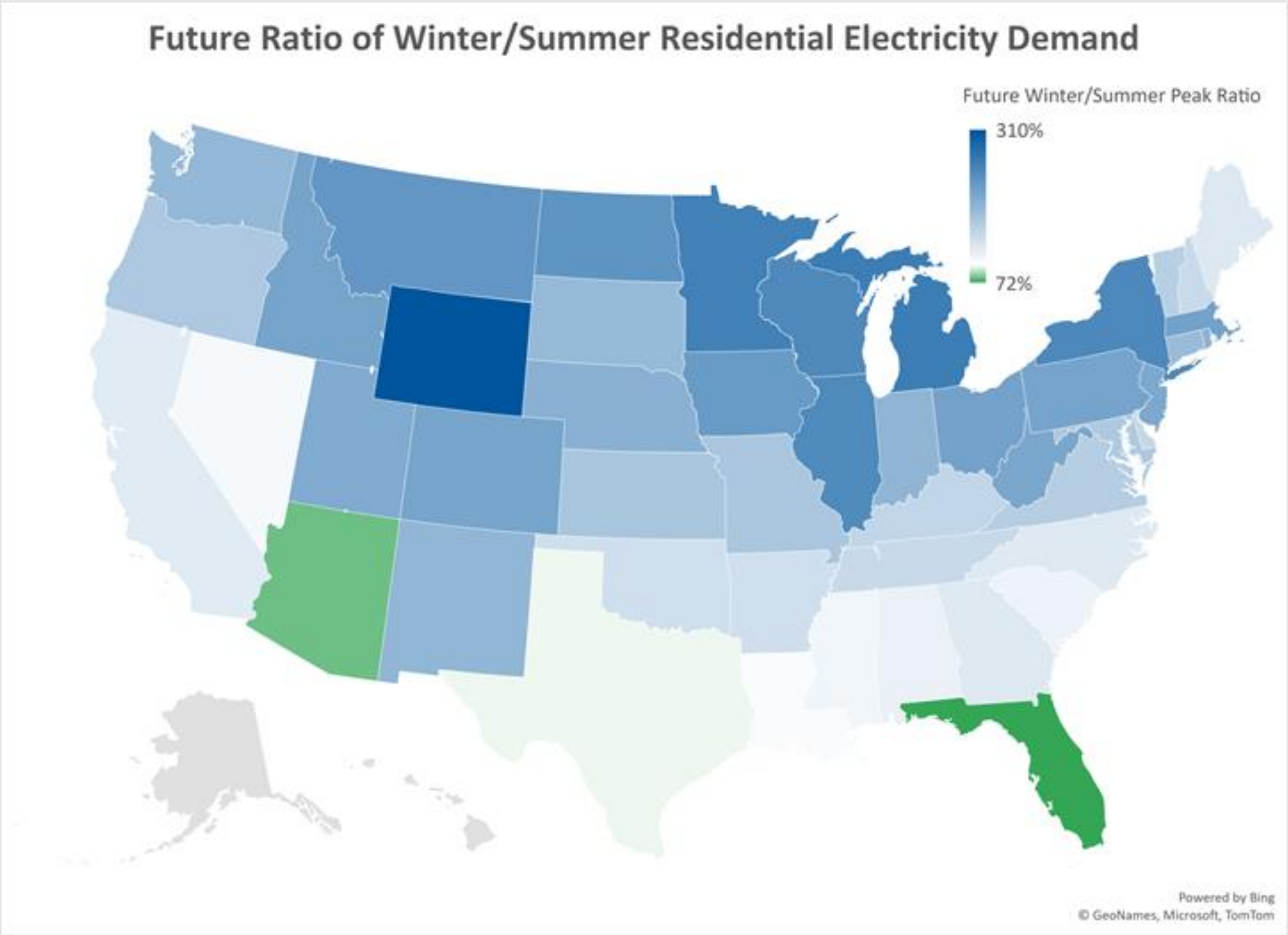


On average, a shift from natural gas to electric space heating for a typical single-family home (1600-2000 ft^2) resulted in an average annual increase of $411 (66% increase)

Space heating costs would increase in 38 of the 48 states (79%)

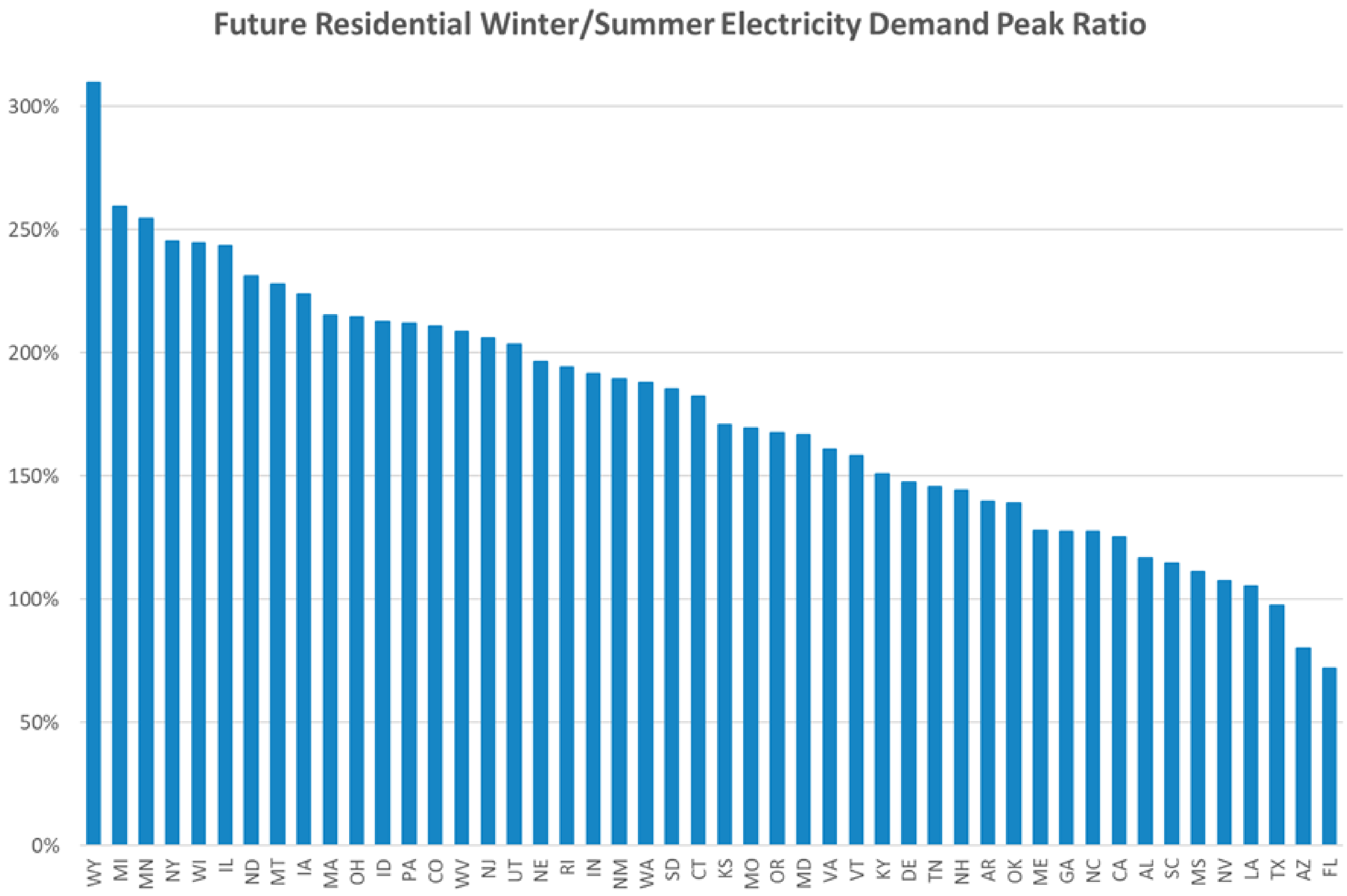
Impact on Peak Winter Residential Electricity Demand (Compared To New Summer Peaks)



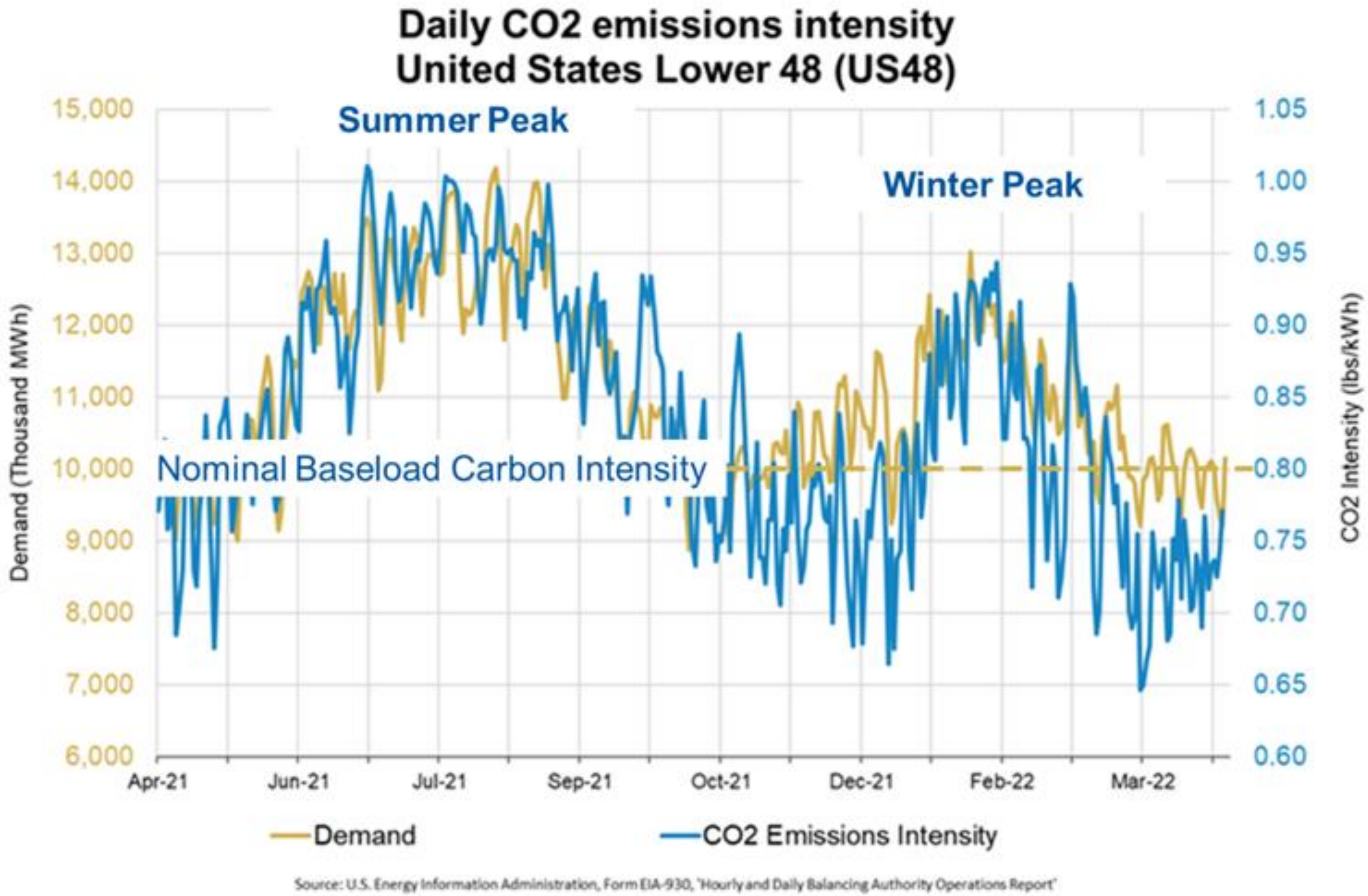
Across these forty-eight states, the winter peak for residential electricity would be 175% of the future summer peak

Winter peaks would occur in 45 of the 48 states (94%)

Impact on Projected Peak Winter Electricity Demand
Compared To Summer Peaks



Changes In U.S. Power Generation Carbon Intensity From Seasonal Space Conditioning Loads



Seasonal use of electricity for space conditioning (heating or cooling) results in a higher emission rate compared to baseload periods such as spring and fall months.

Results vary by state, but the pattern exists in overwhelming number of states and regions.

Seasonal Generation For Space Conditioning: U.S. Overall Market

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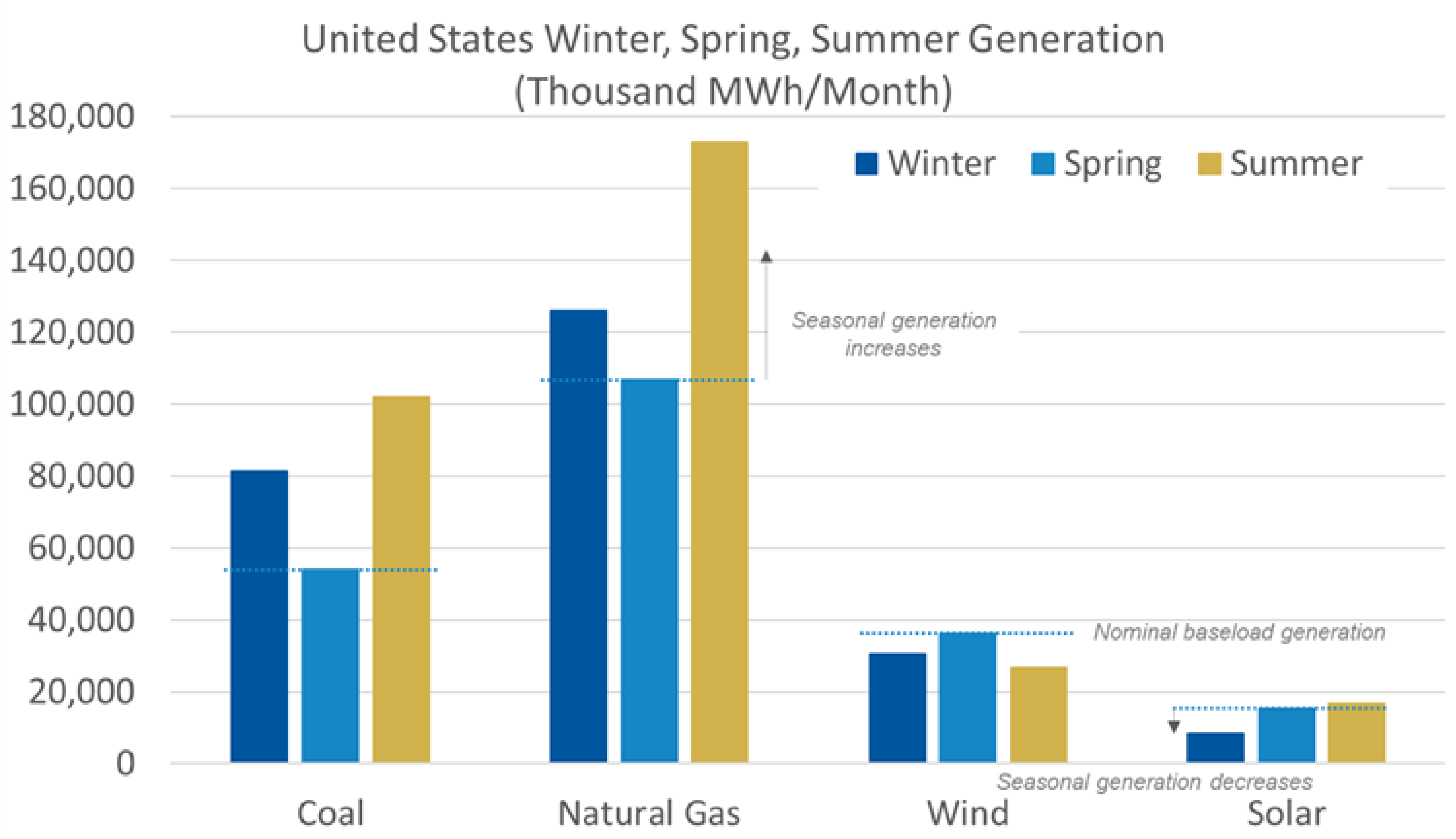

Across the U.S. (and in most states) winter heating and summer cooling loads mainly met by dispatchable natural gas or coal generation

Both wind and solar generation typically decline in January (especially solar generation) – which necessitates even more gas or coal generation to meet winter heating demand

Source: DOE-EIA (2021 data)

U.S. Generation, Power Sector CO_2 Emissions, and Seasonal Marginal Emission Rates

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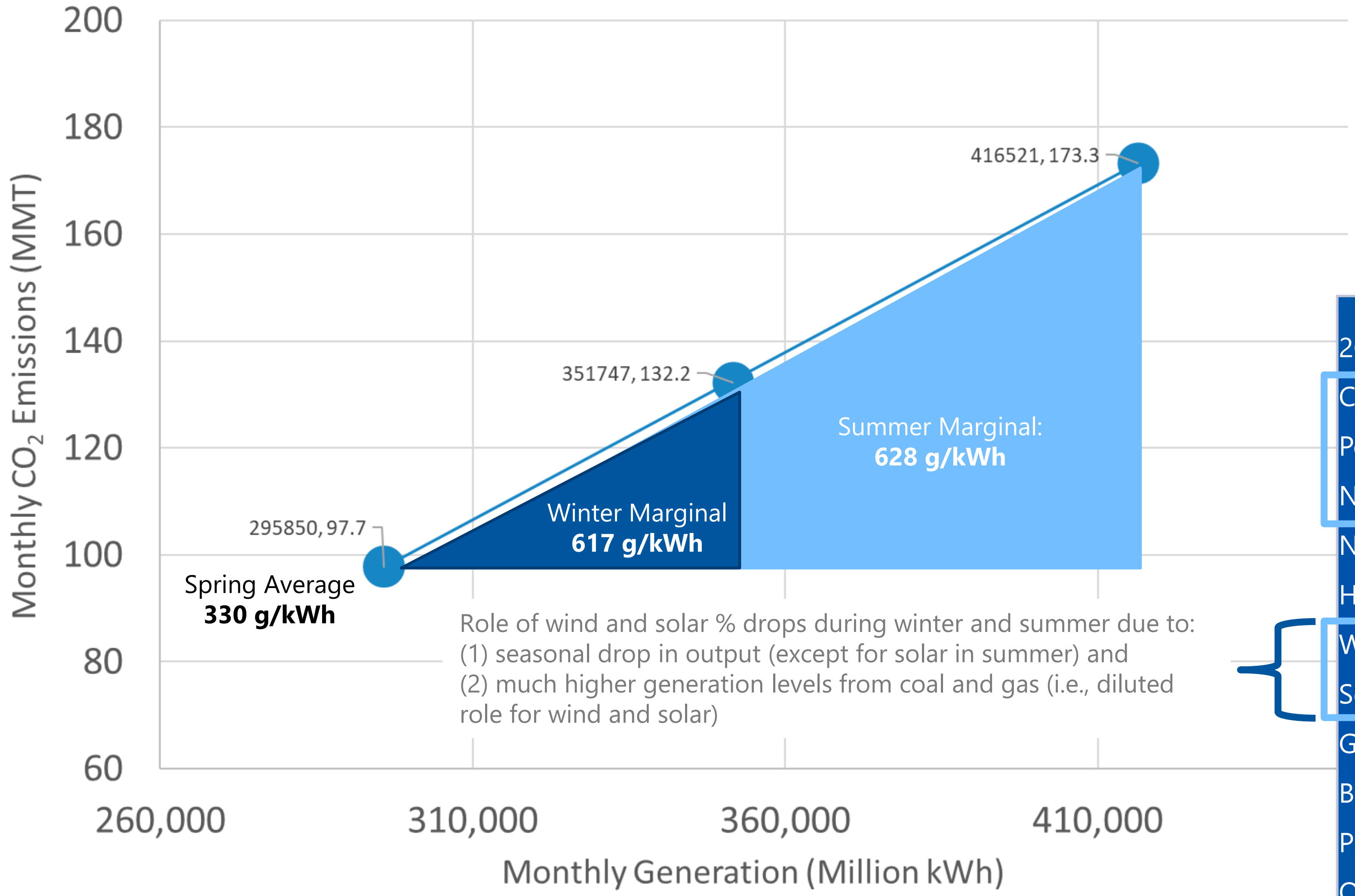


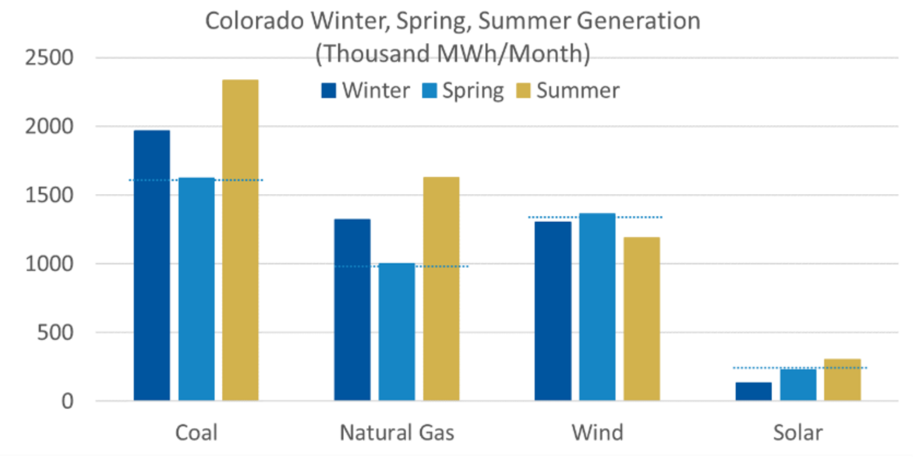
Seasonal Marginal CO_2 Emissions Generation Rate (g CO_2/kWh)

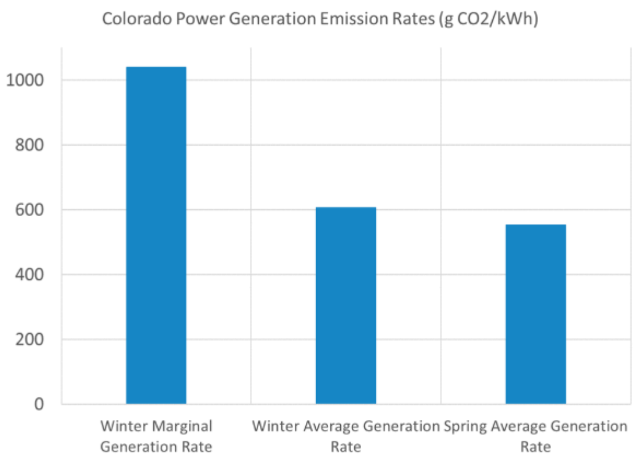
$$= \frac{\Delta CO2\ Emissions}{\Delta\ Generation}$$

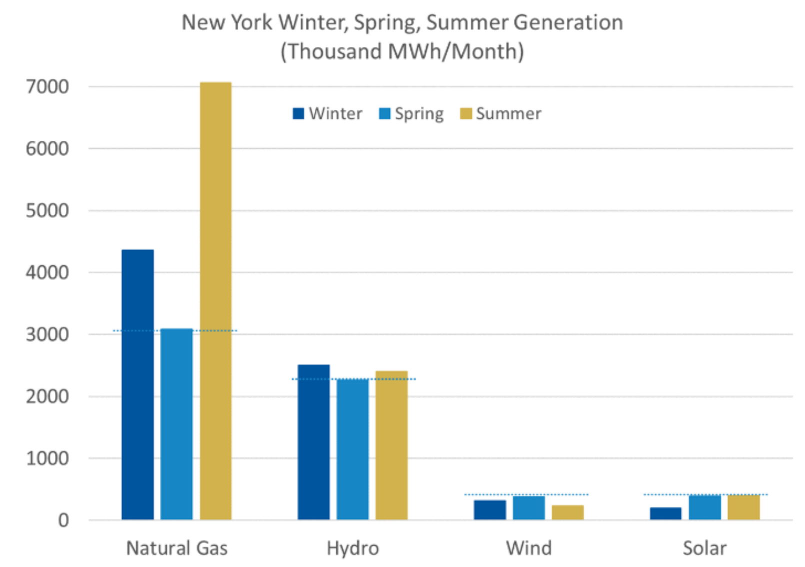
2021 U.S. Generation	Spring Apr-21	Winter Jan-21	Summer Aug-21
Coal	18.2%	23.2%	24.5%
Petroleum liquids	0.3%	0.3%	0.3%
Natural gas	36.1%	35.8%	41.5%
Nuclear	19.3%	20.4%	16.7%
Hydroelectric	6.5%	7.3%	5.0%
Wind	12.2%	8.7%	6.4%
Solar	5.2%	2.4%	4.0%
Geothermal	0.4%	0.4%	0.3%
Biomass	1.4%	1.4%	1.2%
Pumped hydro storage	-0.1%	-0.1%	-0.2%
Other	0.3%	0.3%	0.2%

Source: DOE-EIA (2021 data)

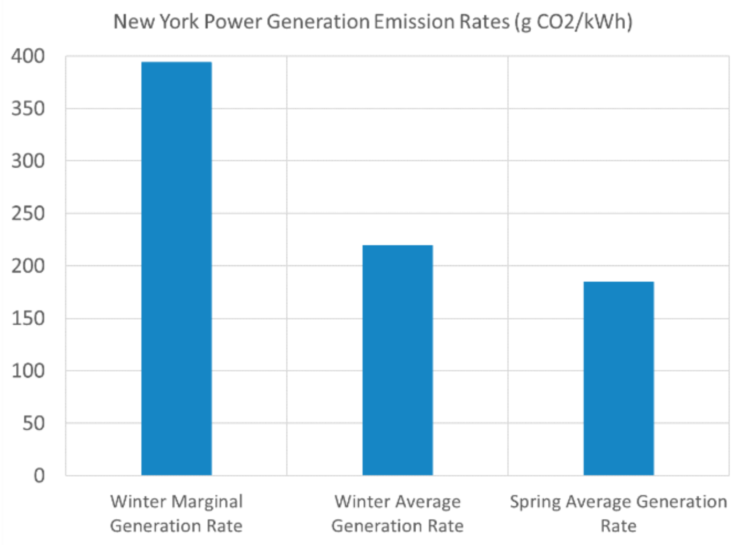
Seasonal Generation For Space Conditioning: State-Level Examples







DOE-EIA 2021 data.



Over 80% of states show a pattern of ramping up gas or coal generation to meet winter peak electricity demand

Adding winter loads results in a marginal emissions rate that is considerably higher than average Spring levels

U.S. Average and Marginal Generation Rate (gCO_2/kWh) Trends

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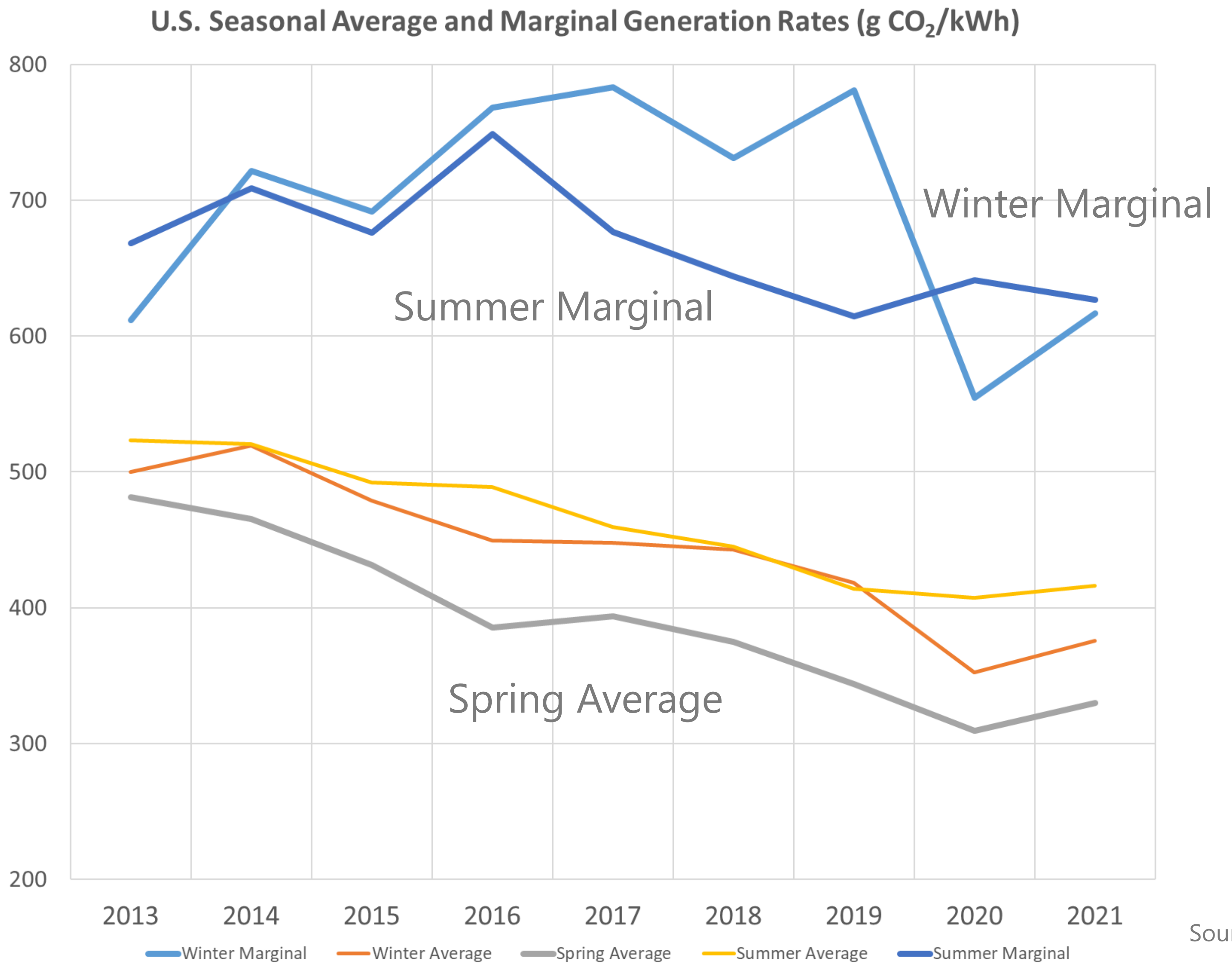


Spring Average CO_2 emission generation rates are trending downward

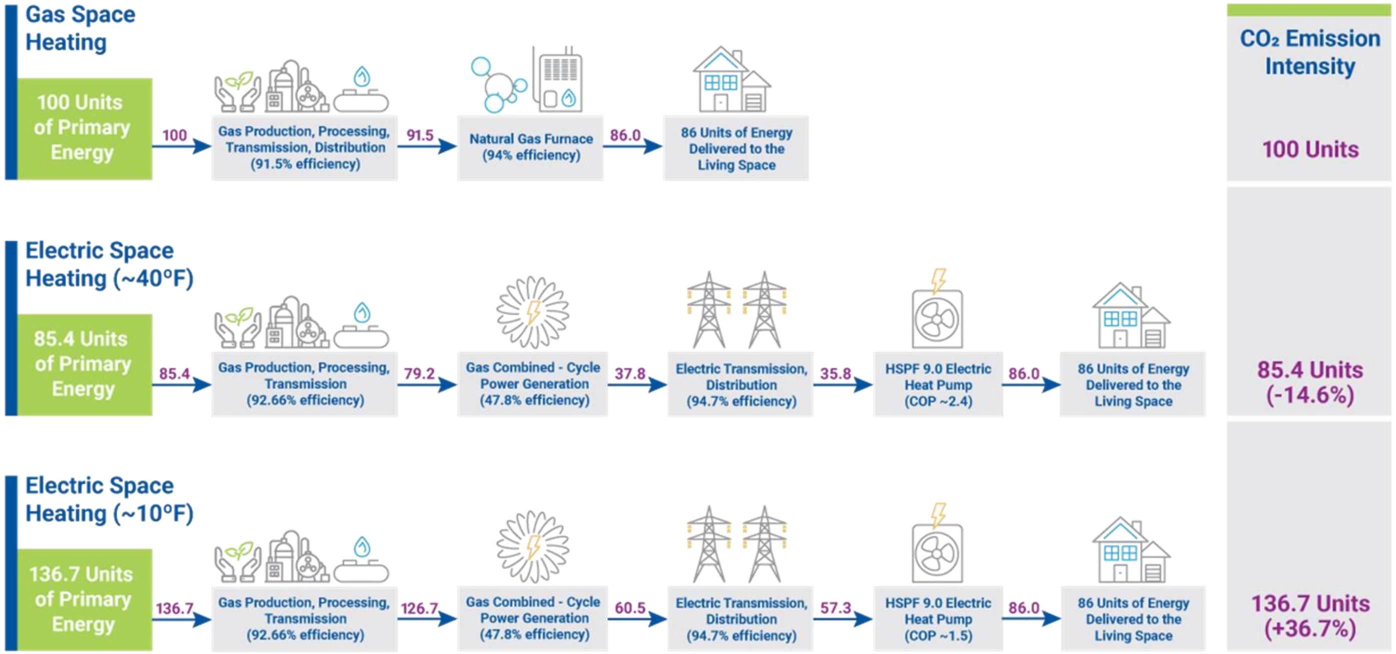
Winter and Summer Marginal CO_2 emission generation rates are considerably higher with relatively smaller changes

More effort needed to decarbonize summer and winter seasonal generation

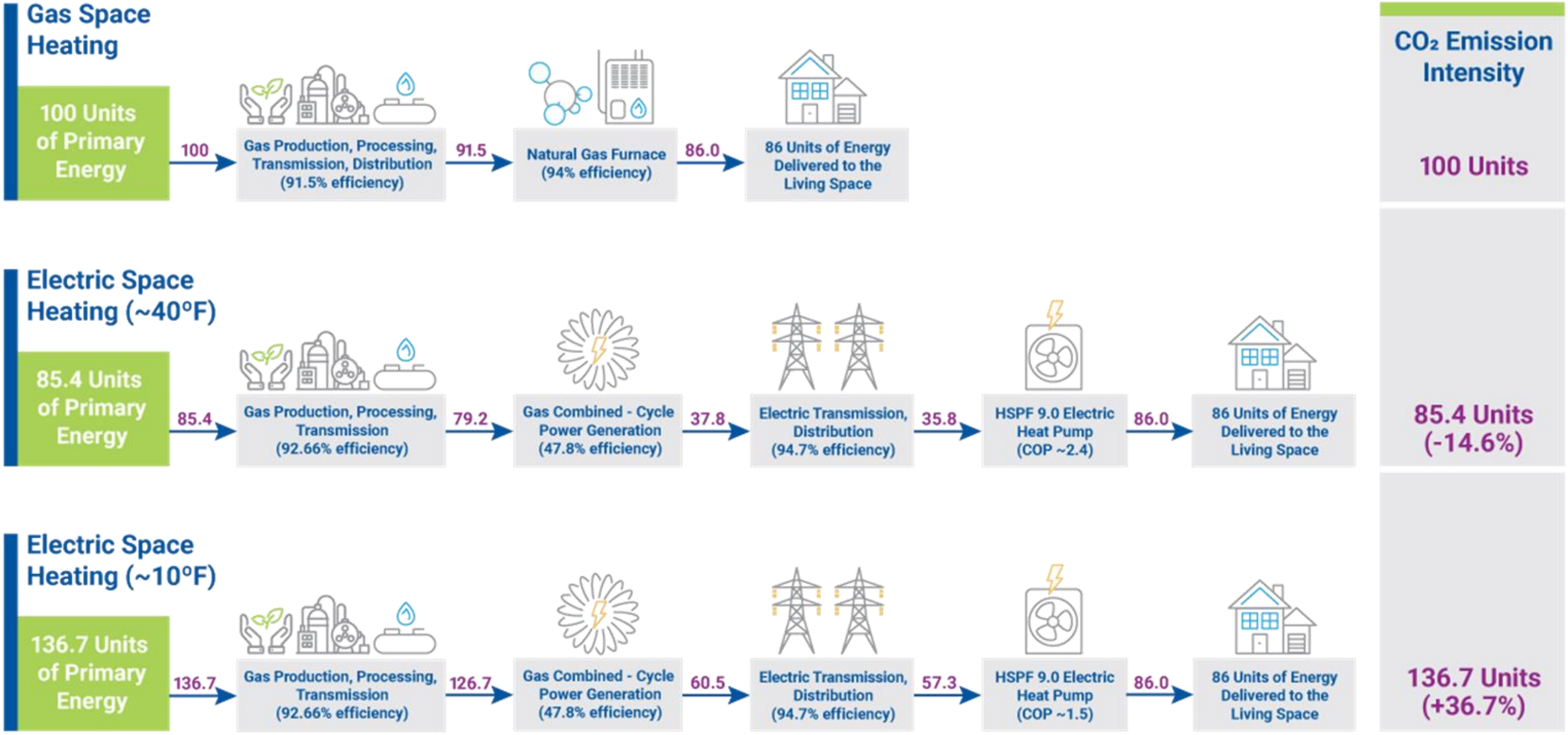
Source: DOE-EIA

Full-Cycle Energy and CO_2 Emissions Comparison

- In practice, electric space heating will in many cases result in smaller GHG emission reduction benefits than anticipated (or increases in some states and temperature conditions)
  - This is particularly true when colder temperatures descend on a region and dispatchable resources such as natural gas combined-cycle plants are used to meet space heating (non-baseload) seasonal demands
- Impact is compounded by the typical drop-off of wind and solar generation during winter months
  - Severe decline in winter solar generation occurs in most regions



Full-Cycle Energy and CO_2 Emissions Comparison



Energy Planning Analysis Tool http://epat.gastechnology.org/

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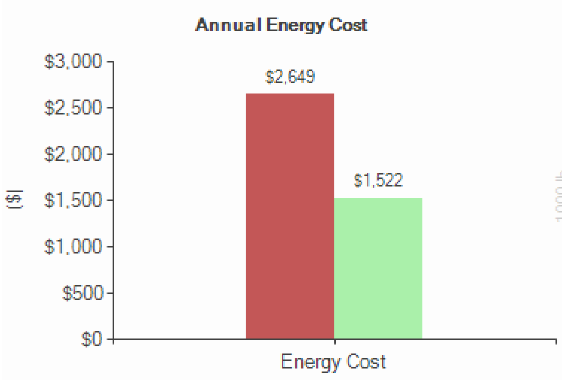
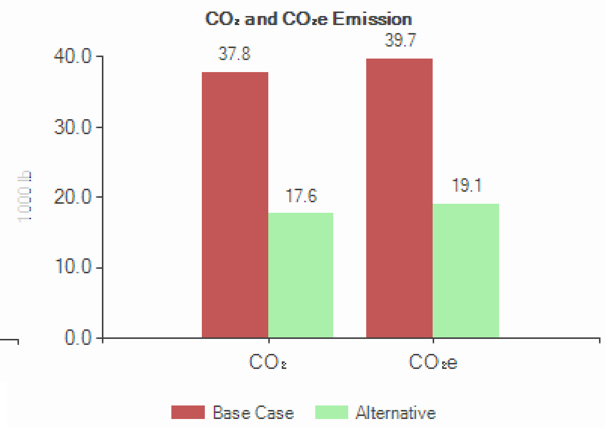
- State level analysis was performed using GTI Energy's **Energy Planning Analysis Tool (EPAT)** developed with support from the Carbon Management Information Center (CMIC) and AGA/APGA/NPGA
- EPAT allows comparison of consumer energy costs, **full-fuel-cycle** energy consumption, and greenhouse gas emissions for comparable residential technology options for building energy services using electricity, natural gas, and propane
  - Public domain web-based tool
  - Evaluations at state and city level
  - "Current Year" annual energy and equipment costs or multi-year analysis through 2050
  - User-inputs available for all variables

Energy	Source energy
Environment	GHG and criteria pollutant emissions
Economics	Annual energy cost, simple payback, NPV





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Energy Planning Analysis Tool: Data Sources

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EPAT uses public databases for determining cost, emissions and source energy factors…

Energy and emissions from upstream fuel production	Argonne National Lab GREET® model, EPA GHGI
Regional electric grid mix	US EPA eGRID2020, EIA Annual Energy Outlook 2020
Residential electricity and fuel prices by state	US EIA
Installed equipment costs	NREL NREM 3.1.0
Average residential home size and number by state	US EIA Residential Energy Consumption Survey

…and GTI Energy generated information for building energy use.

Regional heating/cooling load	Building energy models
Annual site energy use for emerging technologies	Reduced order correlations from research

EPAT workflow

User selects location, house size, and equipment for baseline and alternative house

↓

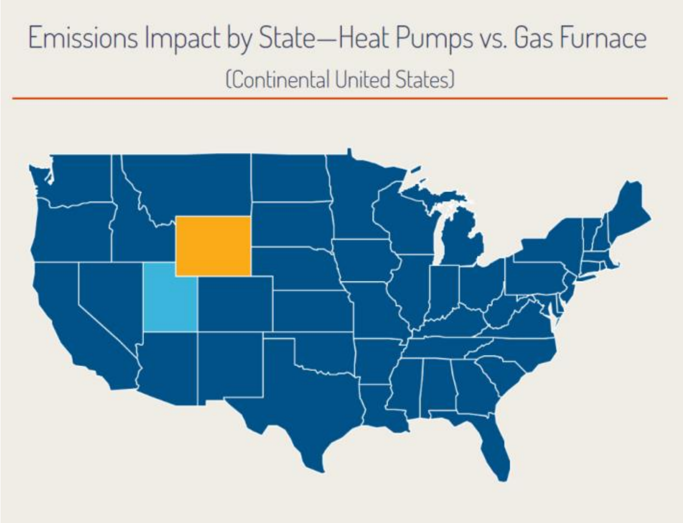
Tool calculates home electricity and fuel use based on internal correlations (site energy)

↓

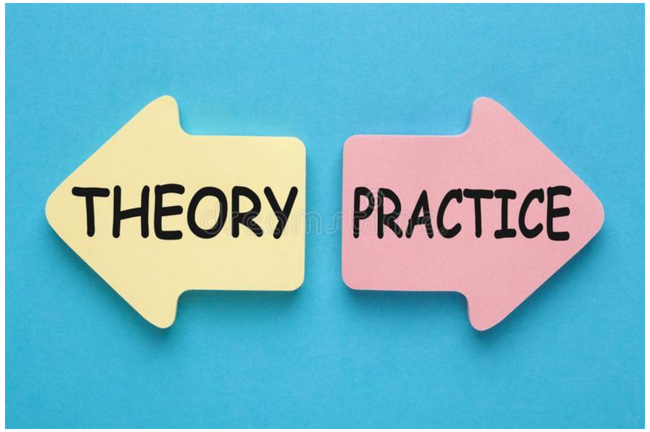
Source energy, emissions, and cost calculated based on regional energy mix and prices

Observations About RMI Analysis
"It's Time to Incentivize Residential Heat Pumps"

- RMI analysis is incomplete:
  - Should use **winter marginal emissions** profile for electric space heating (uses **future average** values)
    - **Analysis assumes baseline electricity use**, but space heating electrification significantly increases peak winter demand and implies a different generation scenario
  - **High seasonal COP heat pump values used**
    - In practice many consumers unwilling or unable to pay for premium equipment
    - Efficiency will be demonstrably lower during very cold temperatures and grid capacity will be highly stressed – elevating risks of grid forced outages
  - If electric heat pumps are incentivized, a hybrid gas/electric approach should be factored from a consumer/grid perspective



It's Time to Incentivize Residential Heat Pumps - RMI



Complementary "Hybrid" Natural Gas and Electric Space Conditioning Systems

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- **"Hybrid" space conditioning systems** allow consumers to make smart choices
  - While avoiding using electric systems when they're inefficient, costly, place extreme loads on distribution systems, and have high GHG emission profiles
- Steps
  1. Replace conventional air conditioner with electric heat pump (electric EE programs)
  2. Retain/use high-efficiency gas furnace as appropriate (natural gas EE programs)
  3. Smart thermostat chooses electric or gas space heating depending on outdoor temperature, operating cost, or other factors

Decarbonizing Dispatchable Generation
Natural Gas Combined-Cycle Power Plants

Using Renewable Gas

- *Landfill gas (LFG)*
- *Animal manure*
- *Water resource recovery facilities (WRRF)*
- *Food waste*

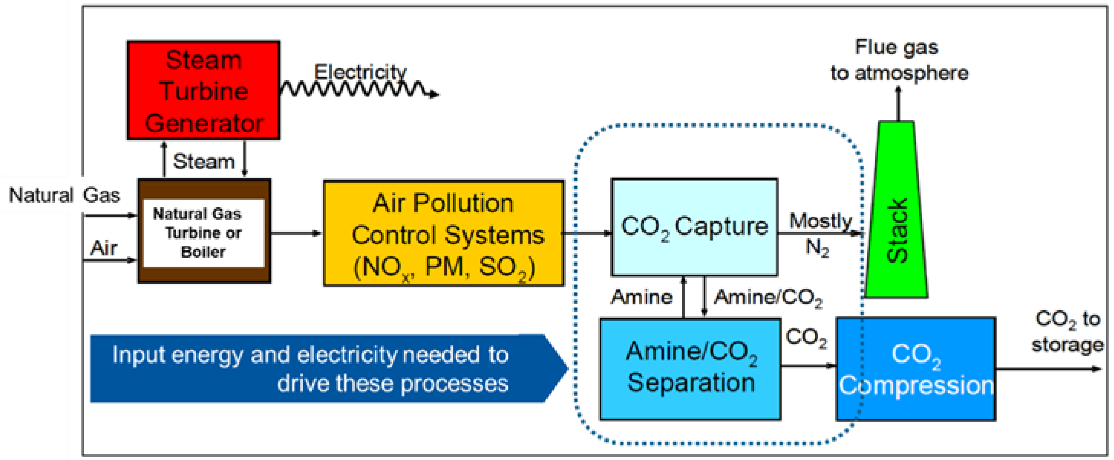
- *Agricultural residue*
- *Forestry and forest product residue*
- *Energy crops*
- *Municipal solid waste (MSW)*

- *Renewable electricity*

Renewable gas can be used to decarbonize gas space heating or gas power generation

Using Carbon Capture

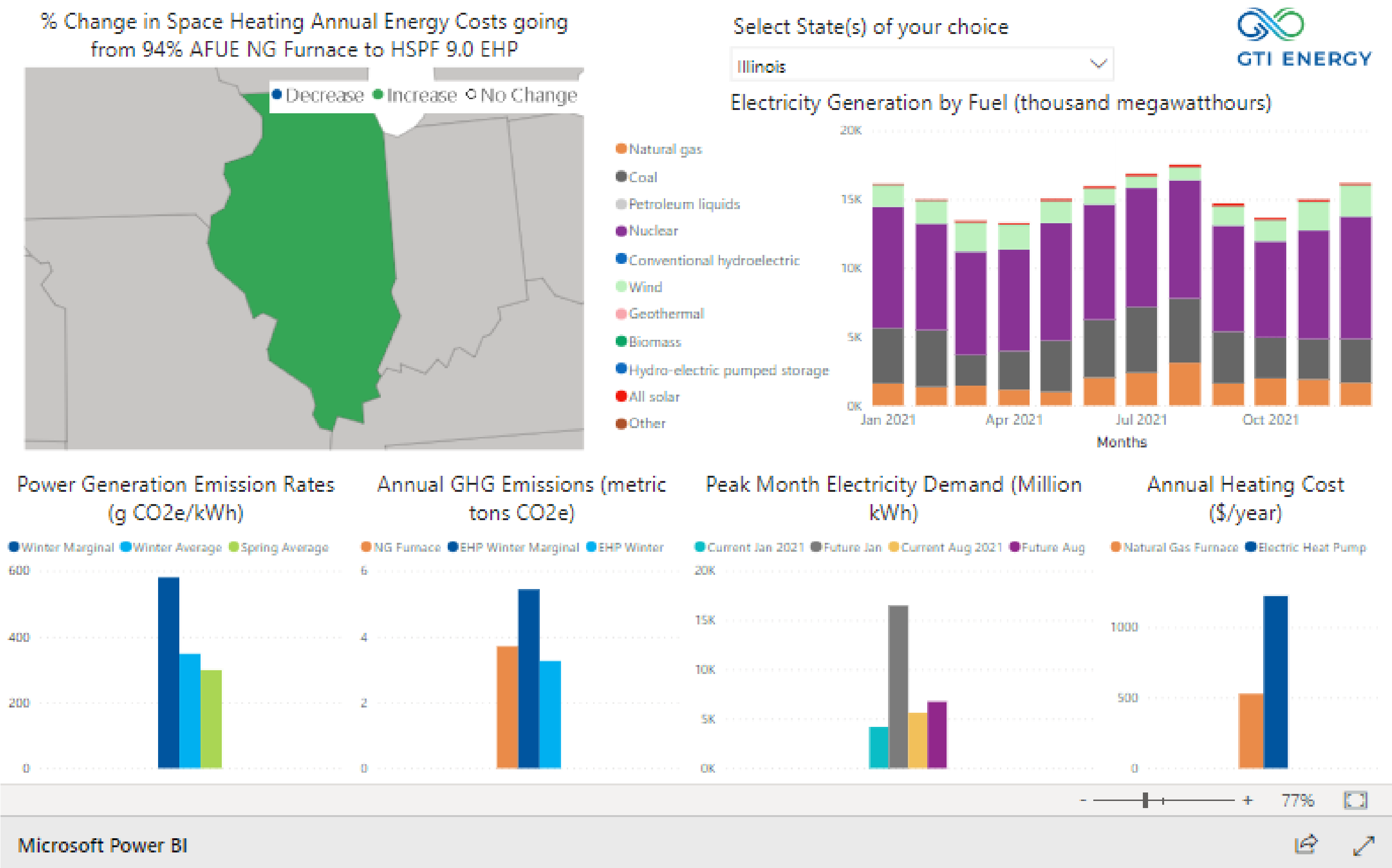
Post-Combustion CO_2 Capture: Example Process



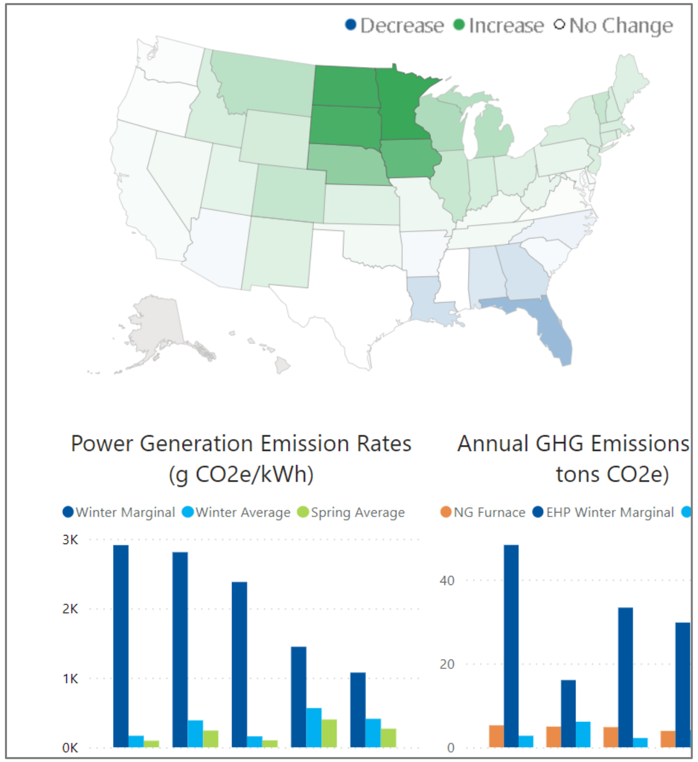
Adapted from: **Source:** E. S. Rubin, "CO_2 Capture and Transport," *Elements*, vol. 4 (2008), pp. 311-317.

Interactive Website and Data Viewer

Residential Space Heating Comparison



Explore grid mix, energy cost, and emissions by state or groups of states



https://www.gti.energy/residential-space-heating/

Summary

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- Challenges using electric space heating, especially in cold regions/during cold periods
  - Heating loads >> cooling loads in most of the country
  - Sensitivity of electric heat pump efficiency to outdoor temperatures
  - Higher CO_2 emission rates from seasonal power generation
  - Together, these limit ability to capture real-world GHG reductions
- Solutions
  - Residential hybrid natural gas/electric space heating systems
    - Using gas furnaces or boilers during colder temperatures
  - Decarbonizing dispatchable winter electricity generation such as natural gas combined-cycle generation plants

Thank you to AGA for hosting this webinar and the Carbon Management Information Center (CMIC) members for their support of the underlying EPAT analytical tool (and AGA) and report production!