# NASEO State Industrial Working Group: Webinar – Renewable Thermal Vision and Industrial Electrification in U.S. States

June 14, 2023, 3:00 pm ET

**Welcome and Introduction to NASEO Industrial Working Group**

*Rodney Sobin, Senior Fellow, NASEO*

**Introduction to the Renewable Thermal Collaborative**

*Blaine Collison, Executive Director, Renewable Thermal Collaborative*

**Renewable Thermal Vision**

*Daniel Riley, Director, Corporate Climate and Renewable Energy, World Wildlife Fund*

**Industrial Electrification in U.S. States**

*Ruth Checknoff, Project and Research Director, David Gardiner and Associates*

**Policy and RTC Tools**

*Chris Kardish, Senior Manager, Industrial Decarbonization, Center for Climate and Energy Solutions (C2ES)*

**Q&A**

**NASEO State Industrial Working Group: Webinar – Renewable Thermal Vision and Industrial Electrification in U.S. States**

June 14, 2023, 3:00 pm ET

*Logistics:*

- Please mute when not speaking.
- Please use Q&A box or chat to offer questions.
- We will record and post presentations.

# + NASEO State Industrial Working Group

https://www.naseo.org/naseo-state-industrial-working-group

- Help State Energy Offices and others to identify, develop, and enhance resources to advance clean manufacturing/industry.
- Enhance cooperation and coordination across technical and business assistance programs.
- Support economic development and productivity, emissions and environmental, and energy reliability and resilience objectives.
- Strengthen existing industries.
- Advance new technologies and industries.

*Thank you to the U.S. DOE and its Industrial Efficiency and Decarbonization Office (IEDO) for generous support.*

Inquiries: industry@naseo.org

# NASEO State Industrial Working Group

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- Working Group

| | |
|---|---|
| California | North Carolina |
| Colorado | Pennsylvania |
| Connecticut | South Carolina |
| Indiana | Tennessee |
| Kentucky | Utah |
| Maine | Virginia |
| Michigan | Washington |
| Mississippi | Wisconsin |
| New York | |

- State Energy Offices and others

Inquiries: industry@naseo.org

# + NASEO State Industrial Working Group

https://www.naseo.org/naseo-state-industrial-working-group

- Web resources and e-mail updates
  - Technical and business assistance programs
  - Funding and financial provisions (incl. IIJA/BIL & IRA)
  - Reports, studies, tools, organizations
  - Events
- Recent items
  - Renewable Thermal Collaborative - Policy Finder, *Industrial Electrification in U.S. States* report, state fact sheets, Heat Pump Decision Support Tools, upcoming June 29 Thermal Efficiency and Heat Recovery Webinar
  - DOE grants for small and medium-sized manufacturers to implement IAC, CHP TAP recommendations
  - Qualifying Advanced Energy Project Credit Program (48C)
  - EPIXC (Electrified Processes for Industry Without Carbon) - New Manufacturing USA Institute at Arizona State University
  - RFI Domestic Manufacturing Conversion Grants for EVs
  - DOE FOA: $54 Million to Expand Industrial Assessment Centers (IACs) and Create Building Training and Assessment Centers (BTACs)
  - DOE FOA: State Manufacturing Leadership Program
  - DOE FOA: Industrial Efficiency and Decarbonization Office (IEDO) FY23 Multi-Topic FOA
  - DOE FOA: Industrial Demonstrations
  - DOE FOA: Onsite Energy Technical Assistance Partnerships
  - ENERGY STAR 2022 certified plants

# NASEO State Industrial Working Group

https://www.naseo.org/naseo-state-industrial-working-group

- Forums (states only) and webinars
  - Past
    - DOE Advanced Energy Manufacturing Grants and Industrial Demonstrations Programs and Connecticut Focus (March 1, 2023)
    - Industrial Assessment Centers and Complementary TA Programs [CHP/Onsite Energy TAPs, Better Plants] (May 3, 2023)
  - Upcoming
    - NIST Manufacturing Extension Partnership and EPA ENERGY STAR Industrial Partnerships - July 12, 2023, 3:00-4:30pm ET: *Forums limited to state participants.*
  - Candidate future topics:
    - IRA tax credits: 45X and 48C
    - DOE Industrial Decarbonization Roadmap; DOE Heat Shot
    - Defense Production Act; CHIPS and Science Act provisions
    - Plus, State Focus Features
- State cases studies – experiences, lessons

We welcome your feedback and suggestions!
industry@naseo.org

# The Renewable Thermal Collaborative

Presented by Blaine Collison

*Executive Director, RTC*

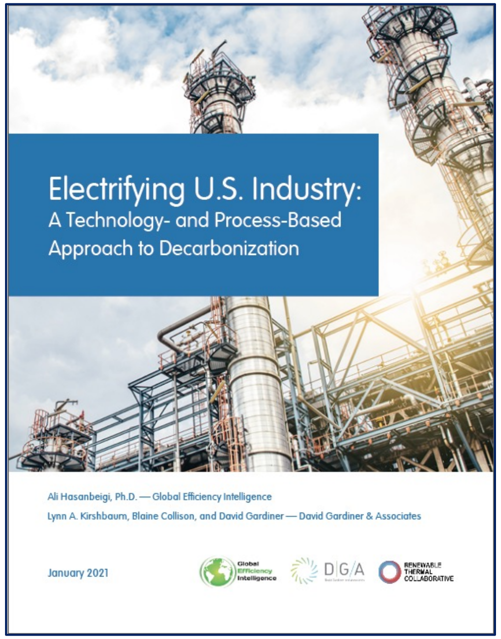
# What is the RTC?

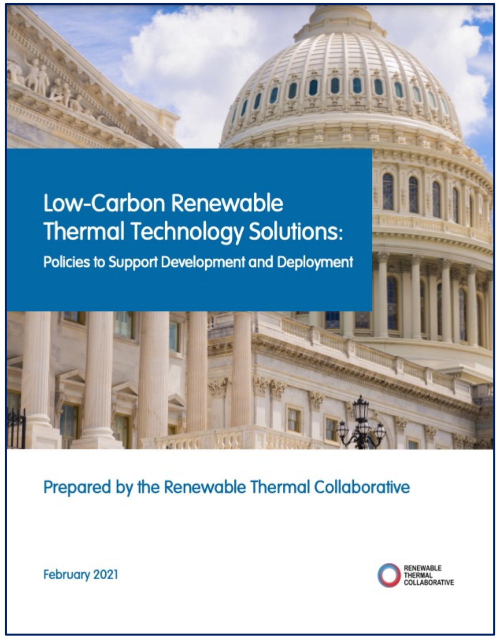
The RTC is the only global, buyer-led coalition focused on decarbonizing thermal energy with renewables.

We focus our work across the intersecting issues of **technology**, **market development**, and **policy**.

RTC Members (buy-side) and Sponsors (solutions-side) are invited to participate in multiple RTC workstreams to:

- Identify and address barriers;
- Accelerate solutions;
- Implement projects and policies.




Facilitated by: C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS — D|G/A David Gardiner and Associates — WWF

# RTC Members

Ansell
AstraZeneca
Bristol Myers Squibb™
Cargill®
city of CINCINNATI
COLGATE-PALMOLIVE
CORNING
DIAGEO
gm
Henkel
HONDA
Johnson & Johnson
KAISER PERMANENTE®
Kimberly-Clark
LACTALIS® US YOGURT
L'ORÉAL USA
MARS Tomorrow starts today
novo nordisk®
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THE CITY OF PITTSBURGH
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SAINT-GOBAIN
sanofi
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OEI Wisconsin Office of Energy Innovation

# RTC Sponsors

Absolicon Solar Collectors
Alturus
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Gas South
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Intersect Power
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Kyotherm investing in clean energy
M-RETS Renewable Thermal
Munich RE
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Rondo
skyven technologies
SoCalGas A Sempra Energy utility
Solar UV Solutions
Southern Company Gas
STX
SunDrum Solar
synergetic
TC Energy
Thermal Energy International
Twin Eagle
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Vanguard Renewables
WES Wilson Engineering Services Energy • Environment • Enterprise
WE Wisewood Energy

RENEWABLE THERMAL COLLABORATIVE

# Renewable Thermal Vision

Presented by Daniel Riley

*Director, Corporate Climate and Renewable Energy, WWF*

# Industrial Thermal Decarbonization

# Approach, Methodology, and Sources

1. Assess industrial thermal emissions and sources to prioritize efforts (EIA Outlook; EPA GHGRP Flight Database 2018)
2. Technology review of available renewable thermal fuels / technologies abatement potential and costs (BCG analysis)
3. Assess fuel supply availability for industrial heat to prioritize low carbon fuel supply for impact (DOE, EIA, NREL)
4. Deploy renewable thermal technologies and fuels to industrial sectors based on heat and process needs, costs, and fuel supply availability (BCG analysis)
5. Model thermal energy consumption and related emissions based on desired uptake, low-cost renewable alternatives, supply availability (EIA Energy Outlook 2022)

# This roadmap focuses on fuel-related emissions and a subset of decarbonization technology pillars within US industrial emissions

## Emission Types

Fuel combustion related

Electricity generation

Process related

Product lifecycle

RTC roadmap focuses on thermal energy and **on-site fuel combustion related industrial emissions**

## Decarbonization Technological Pillars[1]

Low-carbon fuels & energy sources

CCS[2]

Low-carbon feedstocks

Electrification

Energy storage

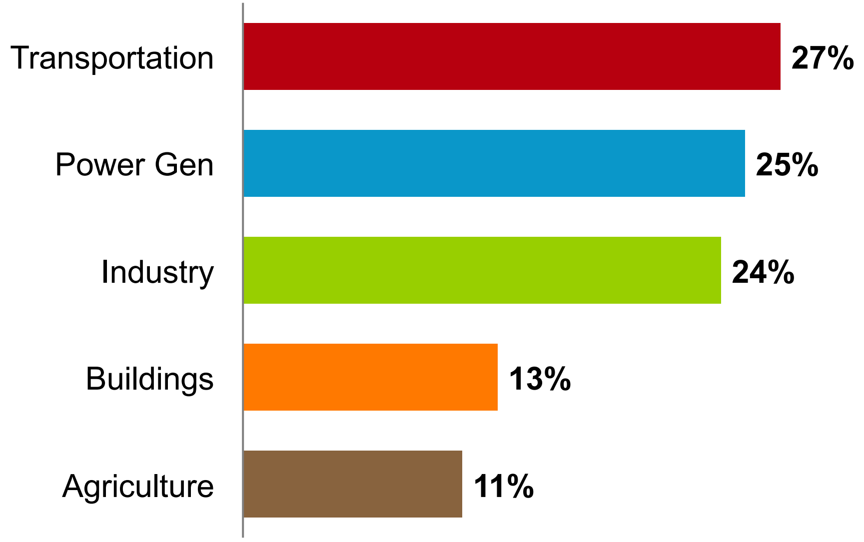
Energy efficiency

Similarly, **decarbonization technologies related to fuels and emissions from fuels** are considered as part of this roadmap

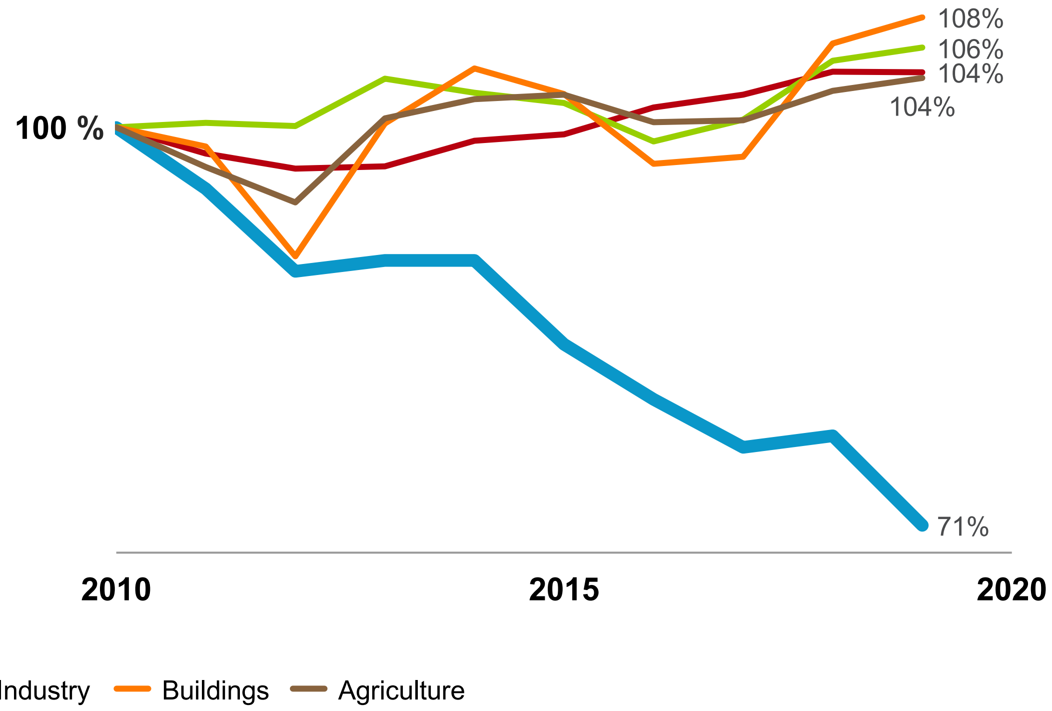
1. This roadmap focusses on growth of renewable thermal energy and related technologies; for prioritization purposes, energy efficiency has not been modeled (except for electric heat pumps and EAF); please refer to the DOE industrial decarbonization roadmap for information on energy efficiency 2. CCS is included given relevance to near- and medium-term abatement objectives; CCUS may be deemed outside of RTC near term priorities

# Heightened attention is needed around industrial emissions; only Power Gen has reduced carbon footprint

Industrial emissions represent
**24%** of total US emissions …




… and have been increasing since 2010;
**only Power Gen has shown improvement**

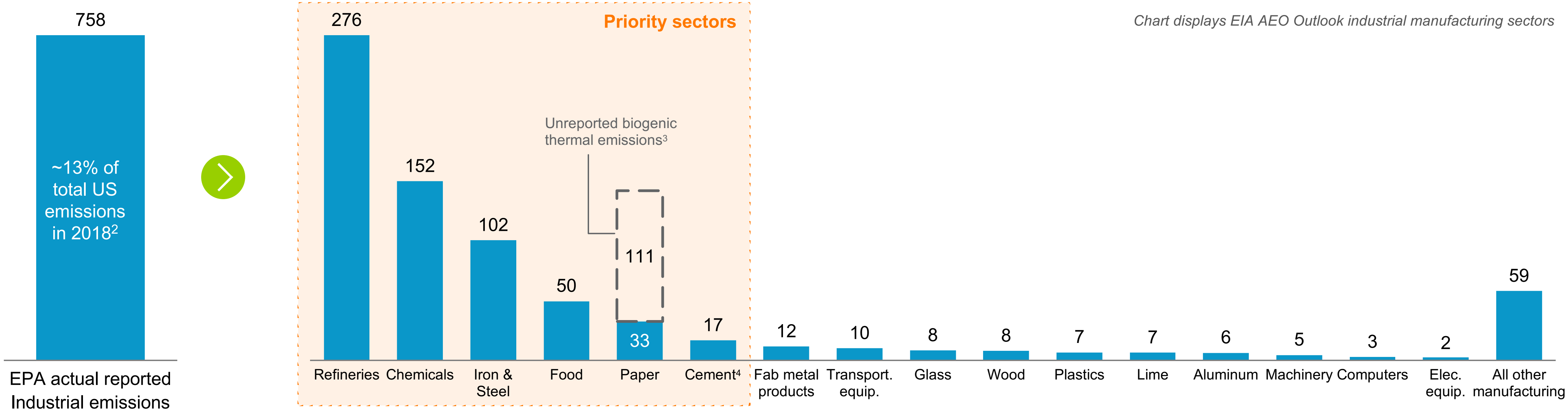



Source: EPA Emissions and Sinks: 1990-2020 (published 2022); displayed data is for 2020

# US industrial thermal emissions totaled 758 million tonnes of CO2e in 2018[1]

## US industrial thermal emissions for all industrial manufacturing sectors (2018)[1]

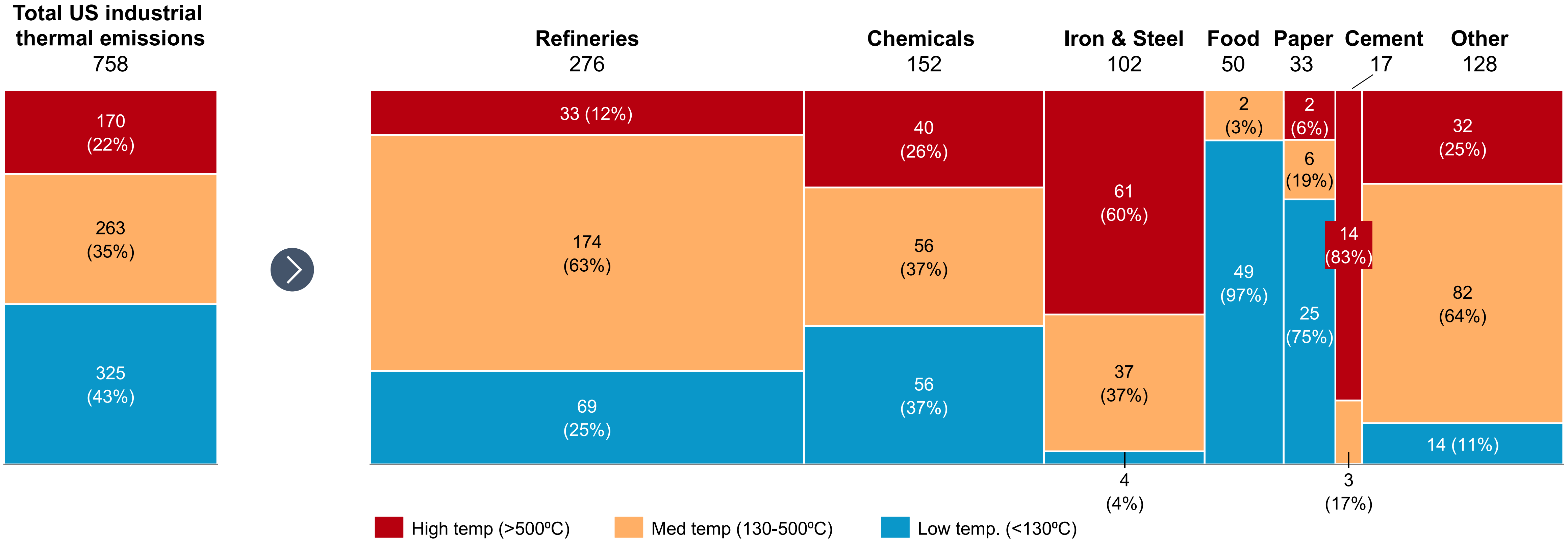
Million tonnes of CO2e




1. Based on AEO 2019 Outlook for 2018 energy consumption by combustible fuel (excludes purchased electricity) for each sector, and EPA emissions intensity of individual fuels except for biomass, which is estimated at 15 kg CO2e/mmBtu; excludes non-manufacturing sectors of Agriculture, Construction, Mining 3. Biogenic emissions are considered 'net zero' by the EPA and are not included/reported in US industrial thermal emissions 2. Based on net emissions (including sinks) of 5,903 million tonnes of CO2e in 2018; gross emissions were 6,677 million tonnes of CO2e 4. Cement sector is estimated to represent 71.8% of the EIA Cement & Lime sector energy consumption
Source: US EIA Energy Outlook 2019 (2018 data); EPA emissions intensity by fuel type (June 2022); NREL (cement energy consumption)

# Low & medium heat processes dominate industrial thermal emissions and account for ~78% of total

## Estimated share of 2018 thermal emissions by temperature range (million tonnes of CO2e)

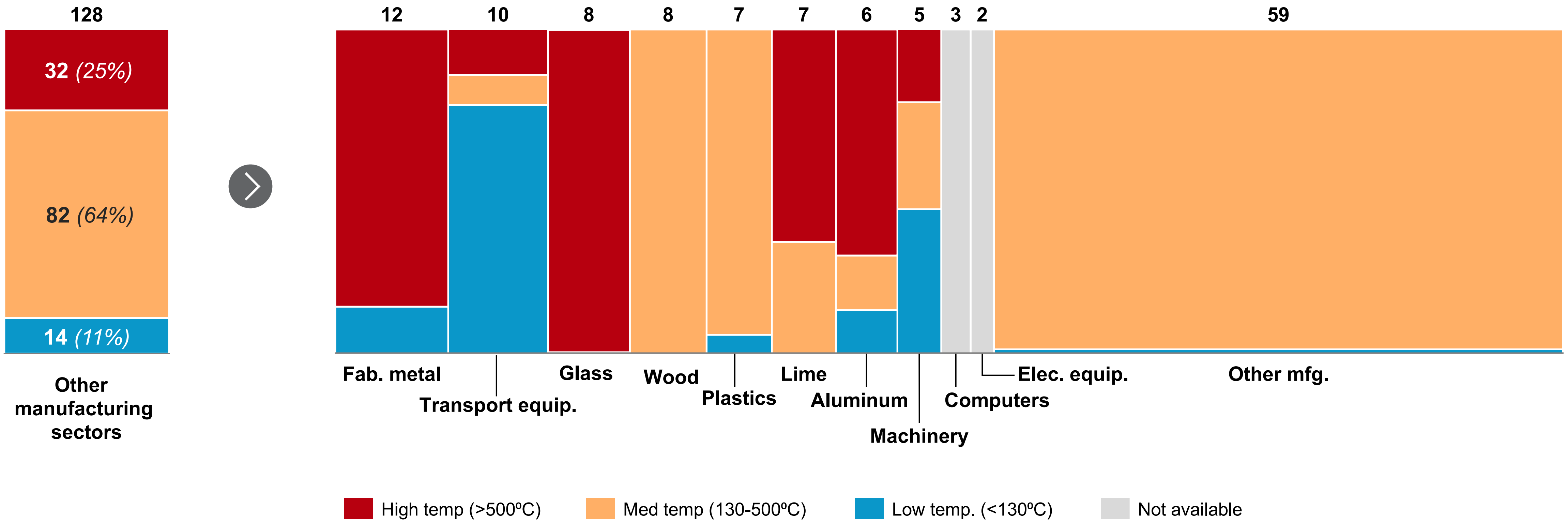



Notes: Energy usage by temperature range was used as a proxy for thermal emissions by temperature range, most of industrial heat is fueled by natural gas across low, medium, and high temperature processes; certain sector emissions (e.g. Iron & Steel, Cement) may skew more towards the higher temperature range as these sectors combust fuels with higher carbon intensity for high temperature processes (e.g. coal in steel making) Source: NREL Manufacturing Thermal Energy Use in 2014 (provides thermal energy use by temperature); EIA Outlook 2019 (provides 2018 energy consumption by fuel); EPA emissions intensity by fuel

Other Manufacturing Sectors

# Estimated Thermal Emissions by Temperature

## Estimated share of 2018 thermal emissions by temperature range (Million Tonnes of CO2e)



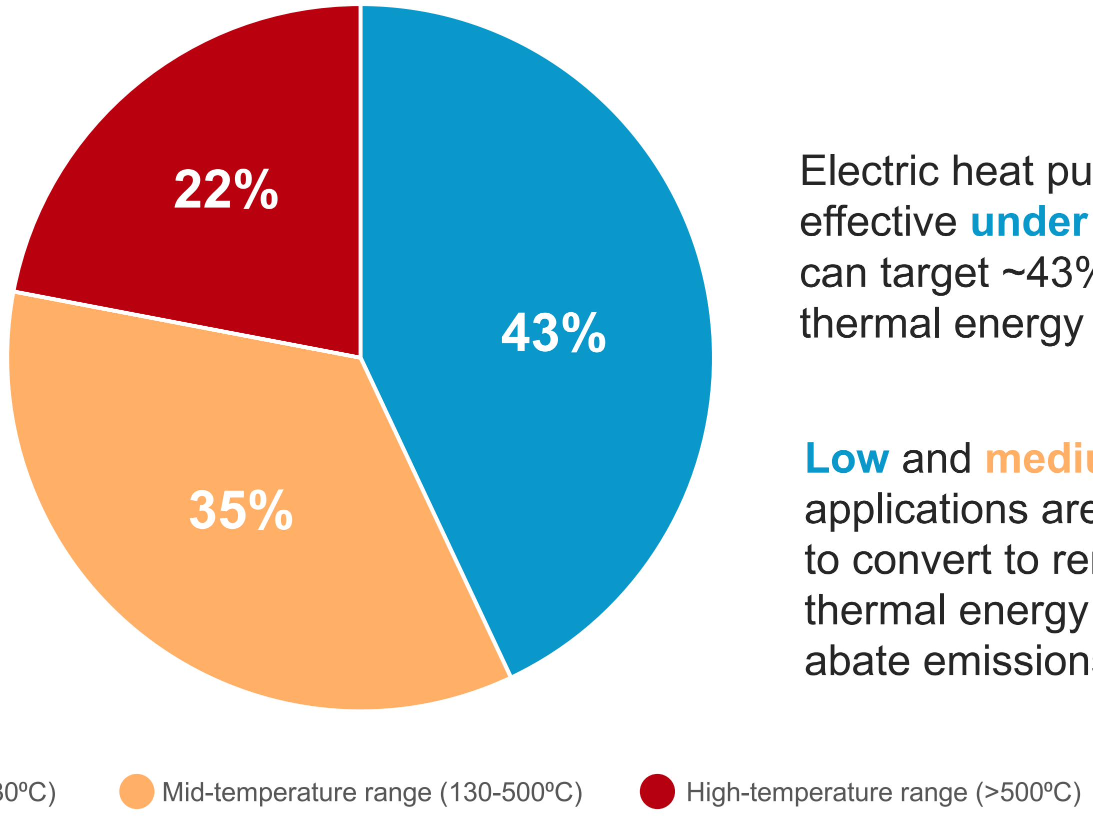

Notes: Energy usage by temperature range was used as a proxy for thermal emissions by temperature range, most of industrial heat is fueled by natural gas across low, medium, and high temperature processes; certain sector emissions (e.g. Iron & Steel, Cement) may skew more towards the higher temperature range as these sectors combust fuels with higher carbon intensity (e.g. coal) Source: NREL Manufacturing Thermal Energy Use in 2014 (provides thermal energy use by temperature); EIA Outlook 2019 (provides 2018 energy consumption by fuel); EPA emissions intensity by fuel

# 78% of industrial heat is needed for low & medium heat applications (<500ºC); only 22% is needed for high heat (>500ºC)

## Industrial thermal energy consumption by heat temperature range

**High heat processes (22% of thermal energy use)** are often bespoke applications, with fewer economic cases for conversion to available renewable thermal energy

Upcoming clean Hydrogen supply (post IRA incentives) will offer cost competitive renewable thermal energy for **high heat**



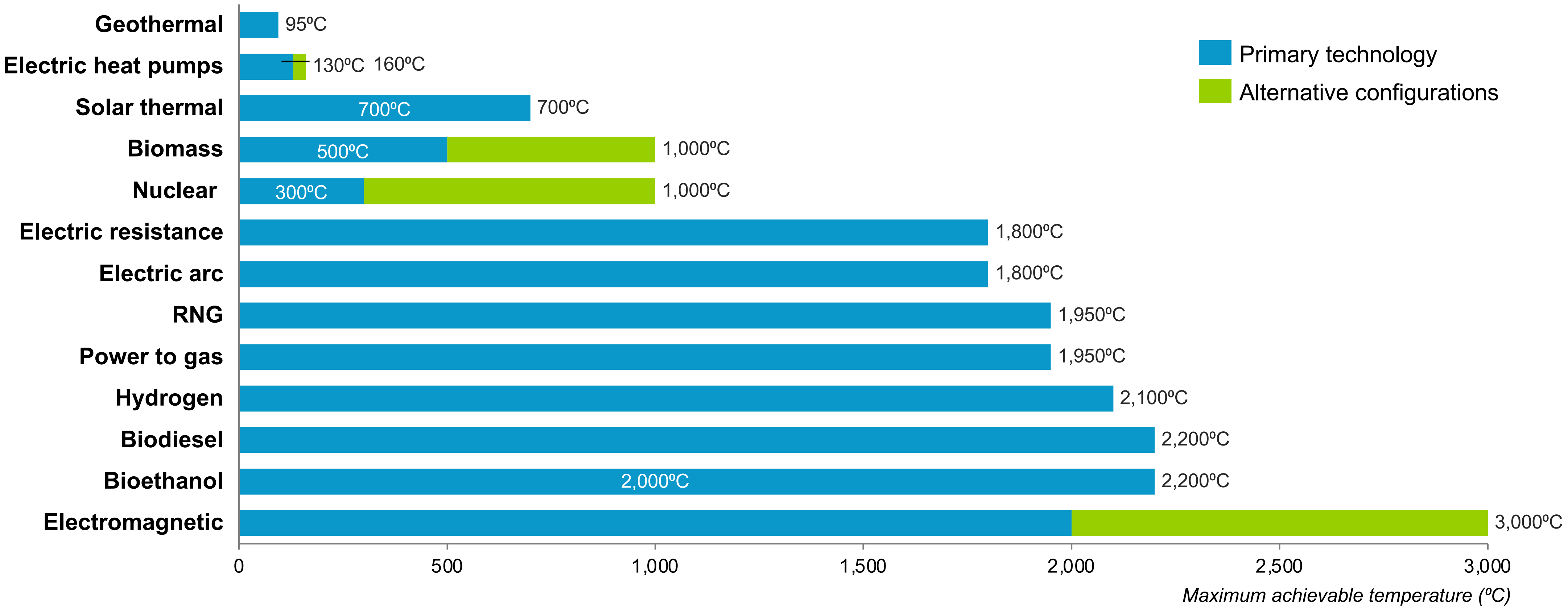

Electric heat pumps are effective **under ~130ºC** and can target ~43% of industrial thermal energy use

**Low** and **medium** heat applications are easier to convert to renewable thermal energy and abate emissions

Note: Cumulative thermal energy only for manufacturing industries, excludes energy use from oil and gas extraction, mining, and waste facilities Source: NREL Manufacturing Thermal Energy Use in 2014

# Renewable thermal technologies are available across a range of temperatures

## Available renewable thermal energy technologies and heat temperature range (ºC)




Source: DOE; research reports, papers, and studies; BCG analysis

# Technologies must be strategically deployed to navigate low carbon fuel supply constraints

| | | Heat pumps | Solar thermal | Biomass | Thermal storage[2] | Other Electric[3] | RNG | Green hydrogen | CCS[4] | Natural gas (reference) |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Primary temp (ºC)** | 160 | 700 | 1,000 | 1,500 | 1,800 | 1,950 | 2,100 | N/A | 1,950 |
| **Food** | <130ºC | ✓ (priority) | ✓ (priority) | ✓ | ✓ (priority) | ✓ (priority) | ✓ | ✓ | ✓ | ✓ |
| **Refineries** | <480ºC | ✓ | | ✓ | ✓ (priority) | ✓ | ✓ | ✓ | ✓ (priority) | ✓ |
| **Chemicals** | <815ºC | ✓ (priority) | | ✓ (priority) | ✓ (priority) | ✓ (priority) | ✓ (priority) | ✓ (priority) | ✓ (priority) | ✓ |
| **Paper** | <200ºC | ✓ (priority) | ✓ | ✓ (priority) | ✓ (priority) | ✓ (priority) | ✓ | ✓ | ✓ (priority) | ✓ |
| **Cement** | 600-1,500ºC | | | ✓ (priority) | ✓ (priority) | ✓ | ✓ | ✓ (priority) | ✓ (priority) | ✓ |
| **Iron & Steel** | 1,600-2,000ºC | | | ✓ | ✓ | ✓ (priority) | ✓ | ✓ (priority) | ✓ (priority) | ✓ |
| **Avg US LCOH[1]** ($/MMBtu) | | 12 | 13 | 13 | 14 | 25 | 21 | 15 | 15-20[2] | 10 |

✓ Technology is applicable in the sector

✓ (priority) Technology identified as priority for the sector to evaluate

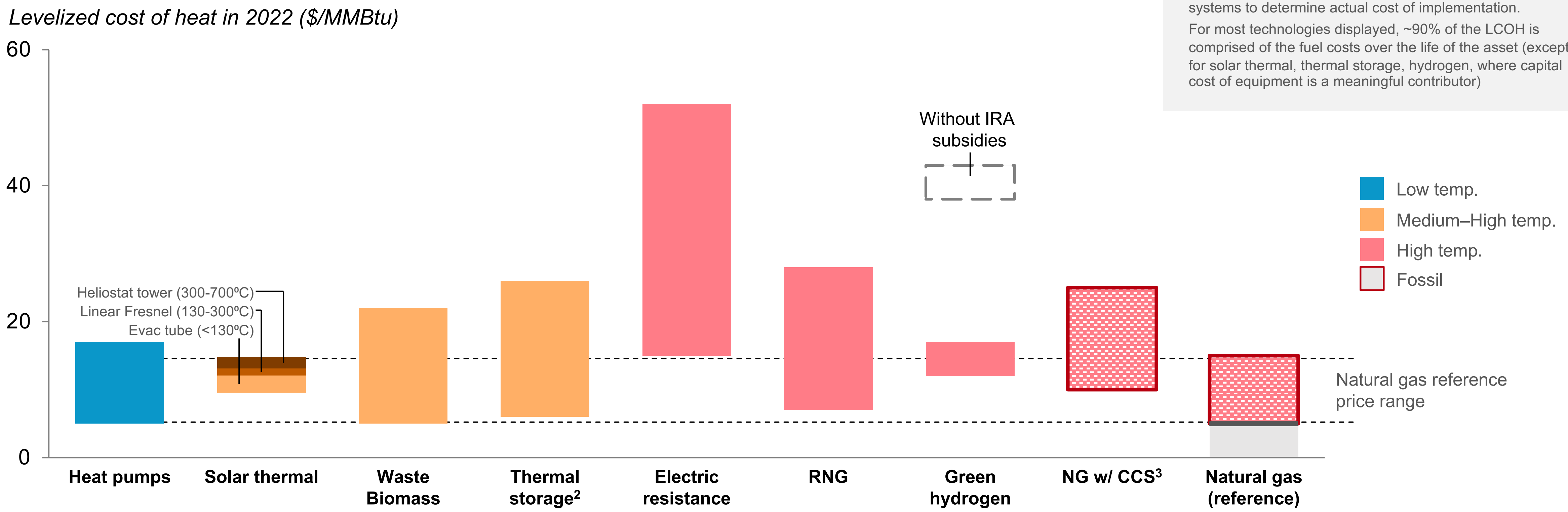
1. Levelized cost of heat in 2022 using national weighted averages for end user industrial electricity and natural gas pricing for the past 12 months as of June 2022 2. Combined with electric resistance at inexpensive intermittent electricity rates; should be evaluated for economics and deployed across sectors where economic 3. Includes electric resistive technologies, electric arc heating, and other developed electric heating technologies (e.g., electric steam boilers) 4. Using natural gas combustion as baseline fuel with emissions intensity of 53.06 kg/MMBtu; includes cost of natural gas fuel and $85/metric ton 45Q tax credits from IRA Source: EIA; EPA; BCG analysis

# Prioritized technologies offer competitive levelized cost of heat relative to natural gas

Note: Analysis reflects macro levelized cost of producing heat for each technology and is intended to provide overall cost of heat delivery of technologies relative to one another. Sector and process specific considerations will impact the generalized costs below; further analysis should be performed to consider industry heat application process and systems to determine actual cost of implementation.

For most technologies displayed, ~90% of the LCOH is comprised of the fuel costs over the life of the asset (except for solar thermal, thermal storage, hydrogen, where capital cost of equipment is a meaningful contributor)

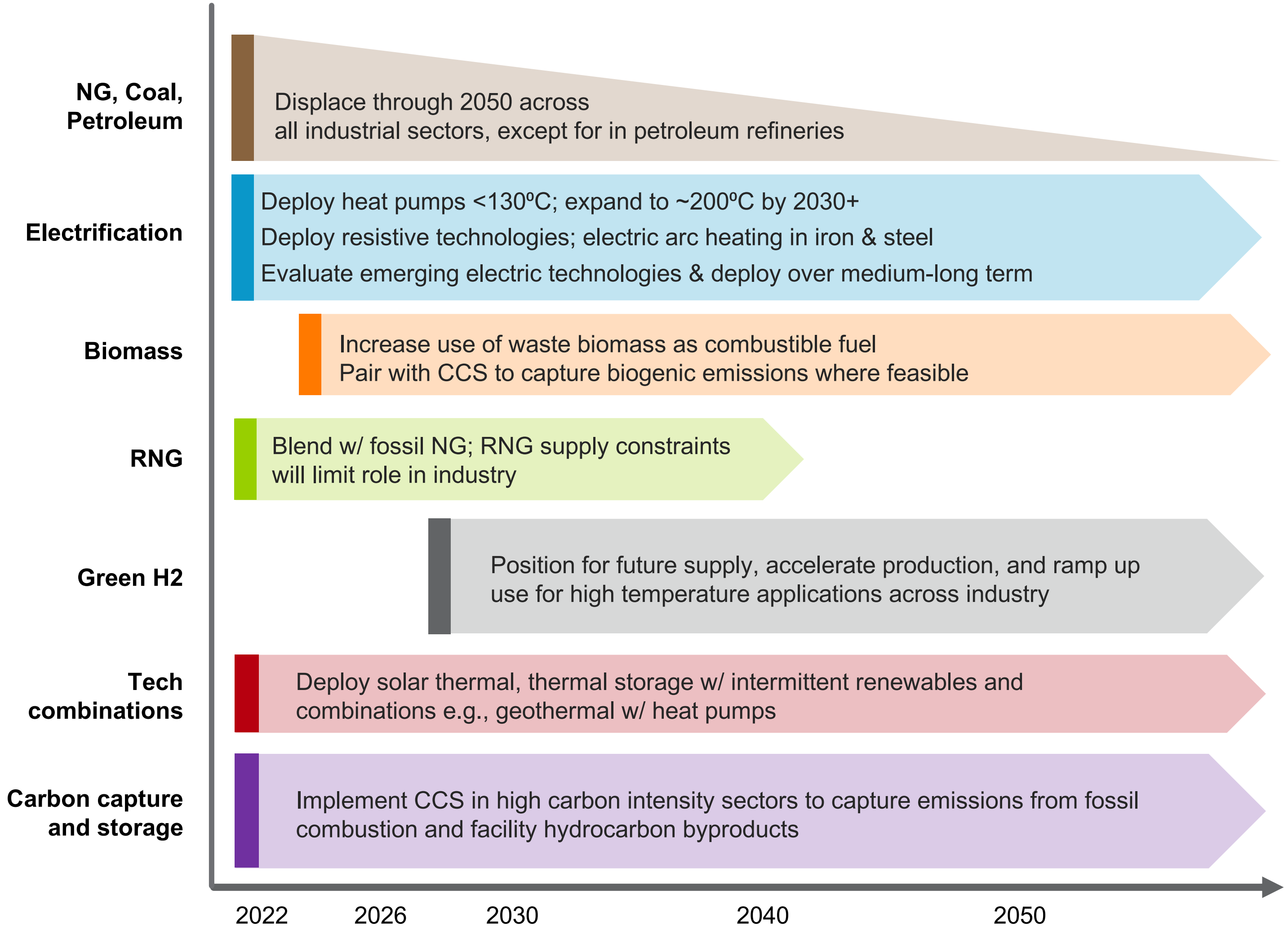
## Levelized cost of heat (LCOH) delivery across renewable thermal technologies[1]




1. LCOH compares project lifetime costs against lifetime energy produced; costs include capital costs of equipment, fuel costs, and maintenance cost assumptions over the usable life of the energy asset. Electricity and natural gas pricing is based on state wholesale industrial end user electricity and natural gas prices for the past 1 year as of June 2022. Electric heat pumps, electric resistive, and natural gas heating efficiencies modeled at 300%, 99%, 75%, respectively. Includes Inflation Reduction Act incentives 2. Cost is modeled for the most economic configuration; thermal storage combined with electric resistance using inexpensive intermittent electricity and post-IRA subsidized solar, onshore wind, and offshore electricity prices without T&D costs 3. Cost of natural gas combustion with CCS; includes $85/metric ton 45Q tax credits from IRA Source: EIA; EPA; Inflation Reduction Act; BCG analysis

# The full suite of abatement levers will be needed to achieve short- and long-term goals

## Thermal energy & technology actions across industry



Decarbonization Roadmap

# Refineries*, Chemicals, Iron & Steel, Cement, Food, Paper

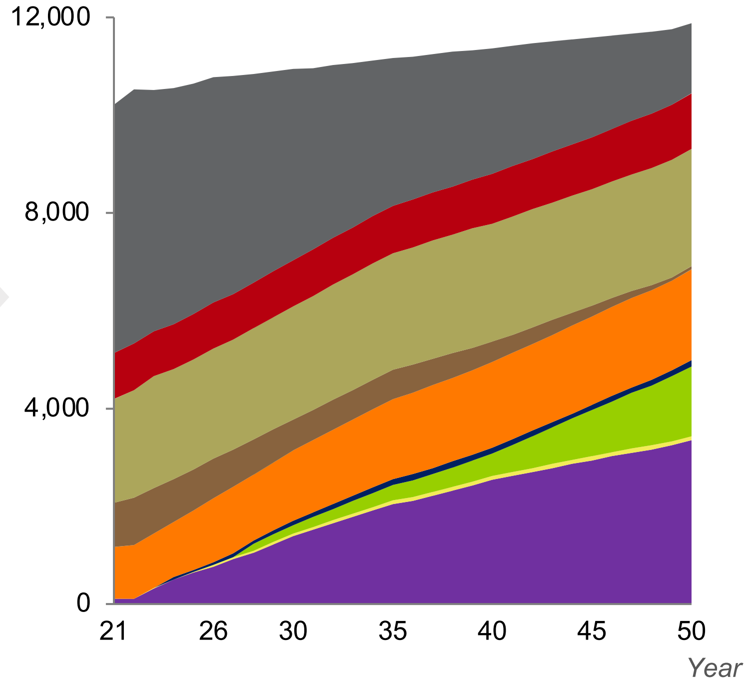
**For consistency across sectors, EIA energy consumption forecast for refineries is used below; however, refinery energy consumption is likely to decline in the 2030-2050 period as fossil fuel usage is reduced globally. Accordingly, overall thermal energy consumption, thermal emissions, and related carbon capture needs are expected to be lower than projected below (using EIA energy forecast)*

## Decarbonization pathways

- Phase out fossil natural gas, coal, and petroleum in all sectors except for Refineries
- Electrify low and medium temperature processes across all sectors, and on an accelerated timeline in the Food, Paper, and other sectors where low temperature processes dominate
- Deploy and increase use of waste biomass in Chemicals and Paper, respectively. Implement CCS to capture thermal emissions, and biogenic emissions in Paper sector where there is opportunity to generate negative emissions annually
- Prioritize and deploy green hydrogen for high heat applications in Chemicals, Iron & Steel, Cement
- Accelerate electric grid decarbonization to ~80% renewables by 2030 and ~100% by 2050 to meet full decarbonization goals6
- Deploy CCS as the primary decarbonizing lever for refineries, where majority of industrial heat is generated from combustion of refinery byproducts; refineries are the only sector projected to use fossil fuels by 2050

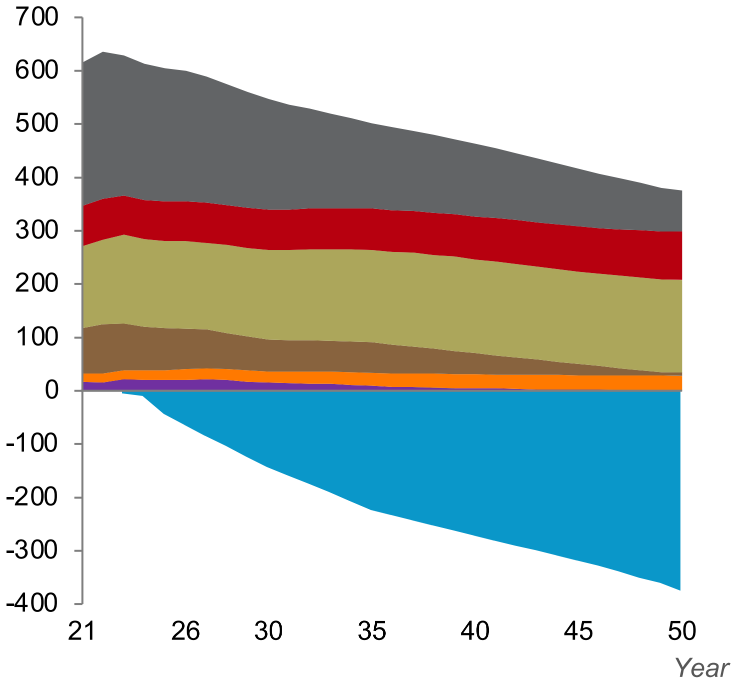
### Thermal energy consumption[1]

Tbtu of thermal energy




### Thermal emissions[2]

Millions tonnes of CO2e in thermal emissions




Natural gas | Petroleum & other | Coal | Clean Hydrogen | Electrification
Biofuels & coproducts | Waste Biomass | RNG | Solar thermal | CCS

1. Total thermal energy consumption based on EIA 2022 Outlook; forecasted energy mix per BCG analysis 2. Thermal emissions calculated based on emissions intensity of individual fuels; RNG and clean hydrogen assumed to be net zero fuels, biomass assumed to have an emissions intensity of 15 kg CO2e per mmBtu, electricity based on forecasted US electric grid emissions intensity assuming 80% renewables by 2030 3. Renewable energy includes biomass, RNG, hydrogen and electrification (with a decarbonizing grid) 4. Biomass supply potential per DOE and EIA 5. DOE target of 50 million tonnes of clean hydrogen by 2050 translates to 5,690 Tbtu 6. Assumes insufficient net new (V)PPA green electricity supply to meet projected demand for industrial electrification Source: EIA outlook; EIA emissions intensity; BCG analysis

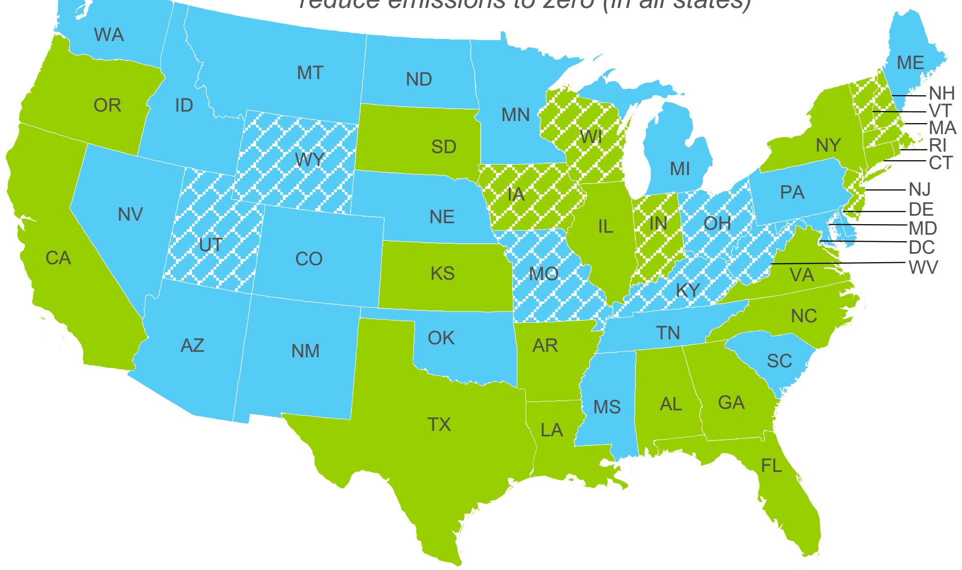
# Electrification is a primary decarbonization pathway in the short, medium, and long-term

## Electricity offers immediate decarbonization opportunities and a sustainable net zero fuel

- Electric heat pumps can be deployed effectively today at temperatures under ~130ºC, representing ~42%[1] of industrial thermal emissions
- Heat pumps can achieve efficiencies of 300%+ (natural gas <85%) because they move heat around vs. generate heat. Heat pumps with "dirty" grid electricity can replace natural gas and reduce emissions in nearly every US state today; furthermore, total levelized cost of heat (LCOH) for heat pumps is cost competitive to natural gas today, and lower in many states
- Electric resistance, while not as efficient as heat pumps, can replace natural gas combustion to reduce emissions in ~half of US states today, using grid electricity
- Other electric heating technologies such as electric arc heating have valuable niche applications, are already deployed in the US, and are one of the primary decarbonizing levers for Iron & Steel
- Furthermore, electric heat pumps are expected to achieve max temp. of ~200ºC by 2030+ and may become applicable for up to ~60%[1] of industrial thermal energy consumption occurring under ~200ºC

## Heat pumps are cost competitive & reduce emissions across the US, even with "dirty" grid electricity

*Electric technologies paired with green electricity reduce emissions to zero (in all states)*




*LCOH for heat pump vs. natural gas*

Heat Pumps Cheaper

Natural Gas Cheaper

*Emissions savings converting natural gas combustion[2] to electric heat pumps[3]:*

Today (2022)

By 2035 or sooner[4]

1. NREL Manufacturing Thermal Energy Use (2014) 2. Calculated using 85% efficiency for natural gas boiler; 3. Calculated using a conservative COP of 3; COP can increase if a waste heat source is available 4. IN, WV electric grid offer abatement by 2035, UT by 2030, WY, MO, KY, OH by 2026 Source: US EIA; State Renewable Portfolio Standards; IEA ETSAP Industrial Combustion Boilers Fact Sheet; BCG analysis

# Parallel pathways to decarbonize industrial heat[1]

## Electrify industry processes

- Electrify low temperature processes with cost competitive heat pumps
- Electrify remaining US steel blast furnaces with DRI-EAF[2]
- Electrify steam boilers & deploy other electric resistance technologies in medium-high temp. processes

## Green the grid

- Enter (V)PPAs to reduce electric carbon footprint where possible
- Accelerate the transition to a carbon free electric grid to meet industrial green electricity needs

## Deploy renewable fuels

- Deploy RNG as supply constraints allow
- Deploy biomass from waste feedstock; develop and deploy BECCS (Bio-energy w/ CCS) for new and existing biomass combustion
- Develop, procure, and deploy green hydrogen

## Deploy renewable technologies

- Deploy solar thermal where economically viable
- Pair thermal storage with intermittent renewables; use cases likely to grow as grid mix of renewable grows
- Clean tech combinations e.g., heat pumps with geo or solar thermal

## Capture & store carbon

- Deploy CCS & DAC using scale efficiencies as a short- and medium-term lever in specific sectors. Phase down CCS as industry transitions to clean processes

*Energy efficiency spans across pillars[1]*

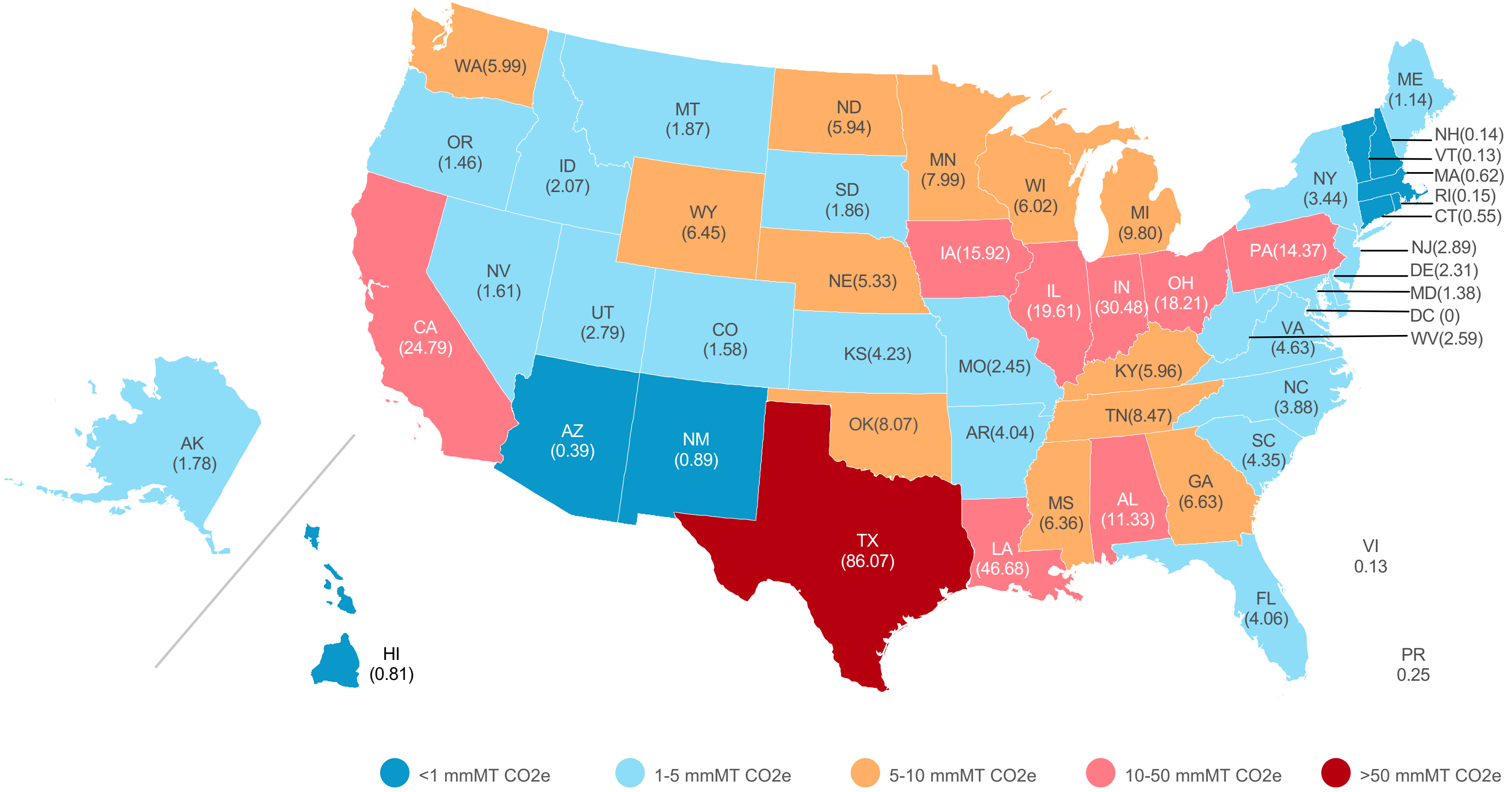
1. This roadmap focusses on growth of renewable thermal energy and related technologies; for prioritization purposes, industrial heat application process changes and energy efficiency have not been modeled (except for electric heat pumps and EAF); please refer to the DOE industrial decarbonization roadmap for information on process changes and energy efficiency 2. Direct reduced iron in an electric arc furnace with green hydrogen

# A State Level Look by Key Sector

RENEWABLE THERMAL COLLABORATIVE

US industrial thermal emissions

# Thermal emissions are concentrated in the Gulf Coast, the Midwest, & California




**US thermal emissions footprint is driven by the geographic concentration of industrial activity for key sectors:**

- Refineries
- Chemicals
- Iron & Steel
- Paper
- Food
- Cement

Source: US EPA GHG Inventory Flight Database 2018; captures large emitter emitting >25K tonnes of $CO_2e$ per year

Food

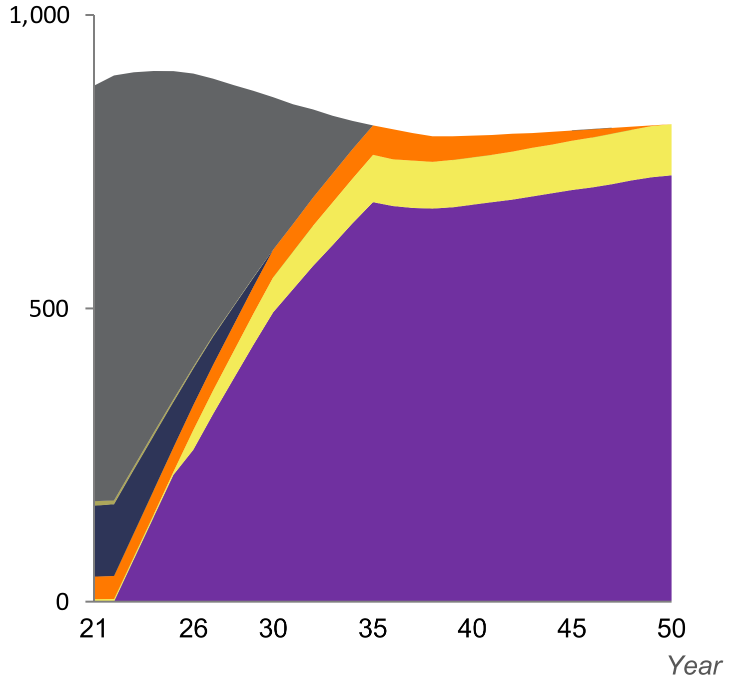
# Thermal Energy Decarbonization

## Decarbonization pathways

- 97% of industrial heat needs are for applications is in the low temperature range (<130ºC), which can be decarbonized on an accelerated timeline with electrification and heat pumps. Natural gas, which combusts at ~1,850ºC is not required for most heat needs in the sector
- Use of fossil coal and petroleum is phased out by 2030, and natural gas phased out by 2035 - replaced with electrification
- Solar thermal energy with battery storage should also be considered, particularly in the US Southwest, and/or when electric heat pumps have a higher cost to generate heat than fossil natural gas (e.g. California)
- Thermal storage with electric resistance heating when paired with inexpensive electricity (<$20/MWH) should be evaluated and deployed

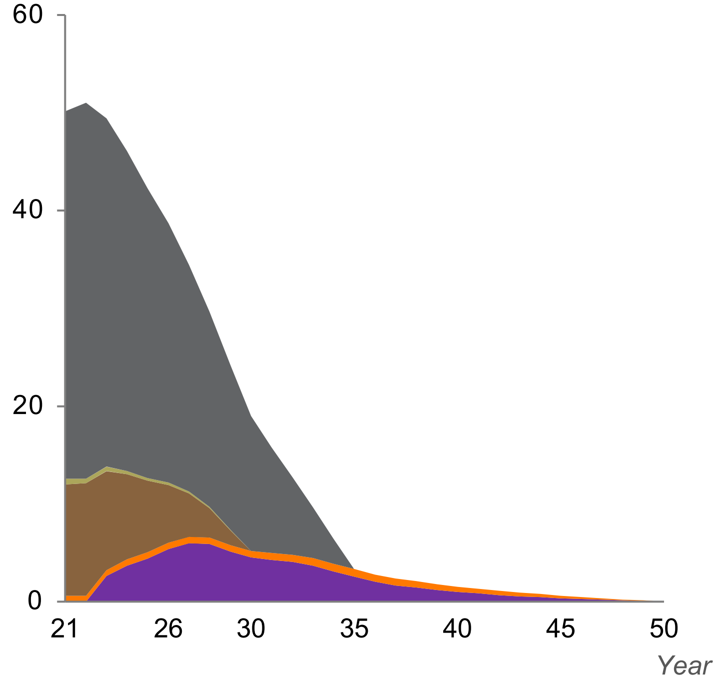
## Thermal energy consumption[1]

Tbtu of thermal energy




## Thermal emissions[2]

Millions tonnes of CO2e in thermal emissions

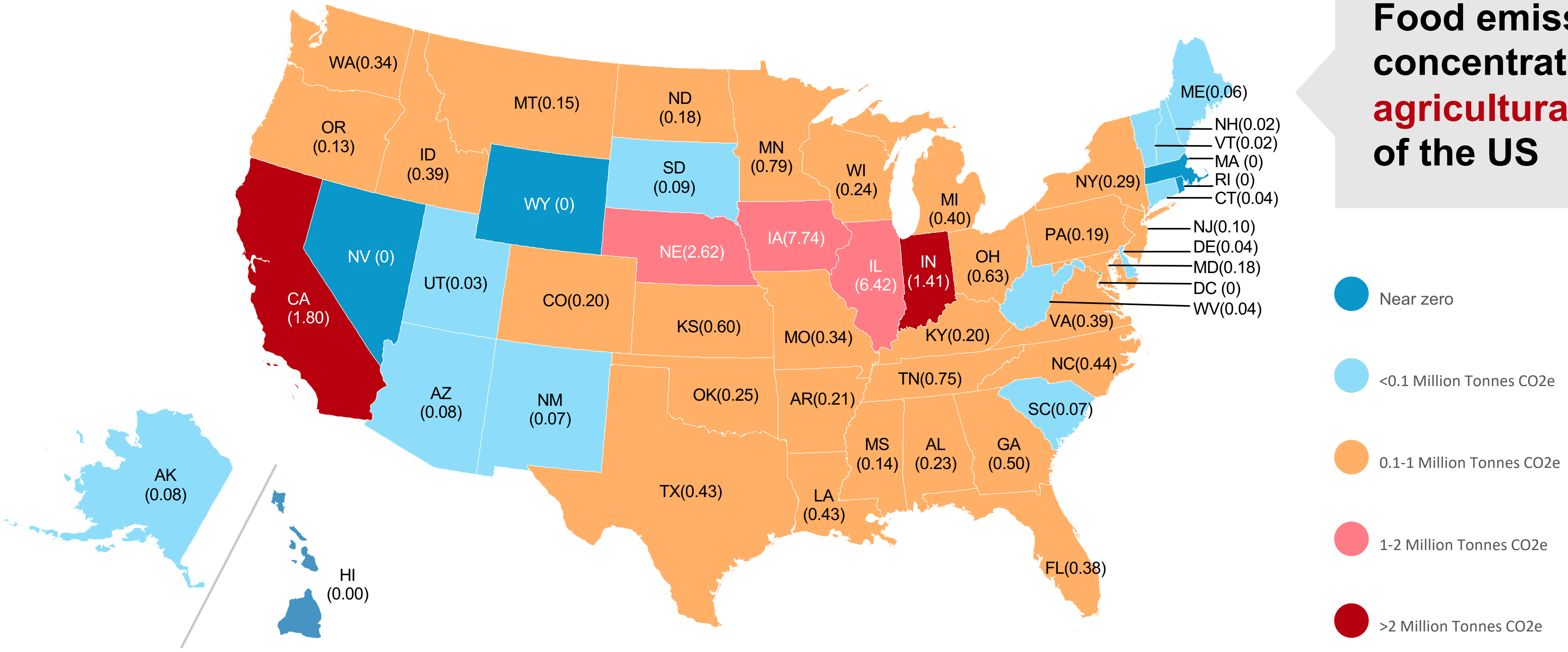



Natural gas | Petroleum & other | Coal | Solar Thermal
Biofuels & coproducts | Waste Biomass | RNG | Electrification

1. Total thermal energy consumption based on EIA 2022 Outlook; forecasted energy mix per BCG analysis 2. Thermal emissions calculated based on emissions intensity of individual fuels; RNG and clean hydrogen assumed to be net zero fuels, biomass assumed to have an emissions intensity of 15 kg CO2e per mmBtu, electricity modeled based on US electric grid emissions intensity assuming 80% and 100% renewables by 2030 and 2050 Source: EIA outlook; EIA emissions intensity; BCG analysis

# Food thermal emissions are concentrated in the Midwest and California

## Food thermal emissions by state (Million Tonnes of CO2e)[1]

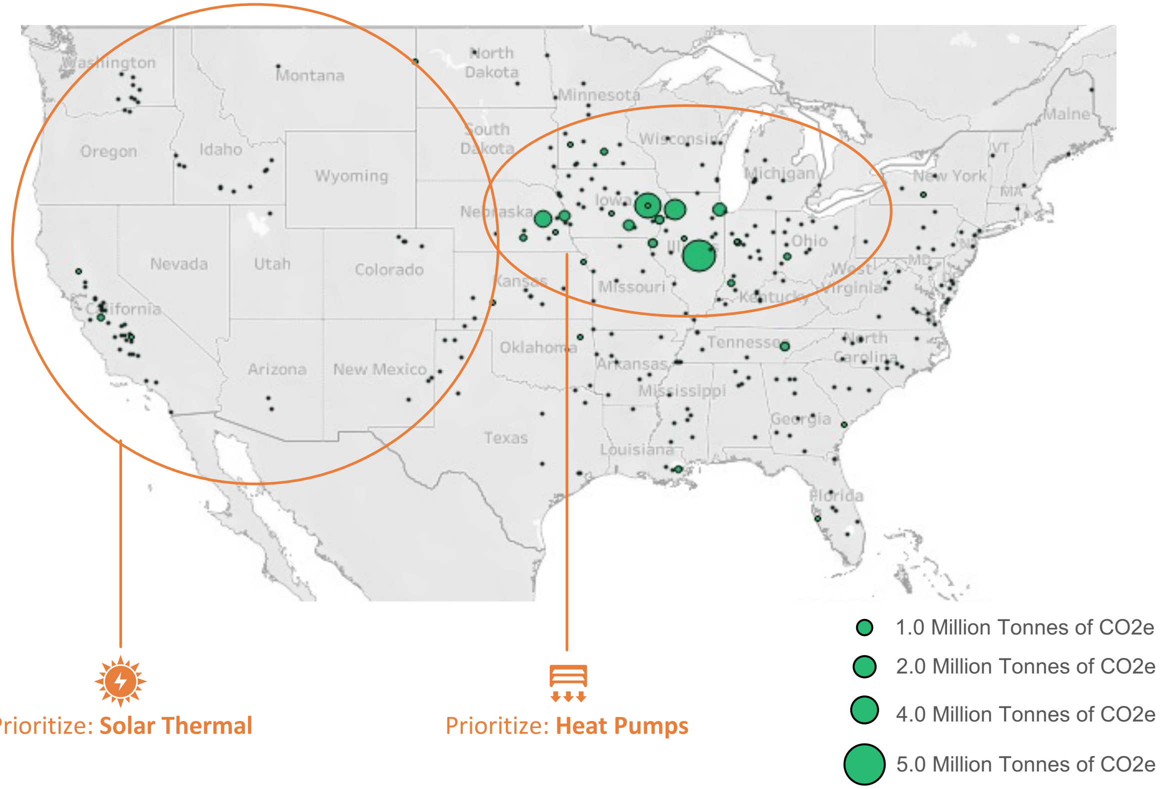



**Food emissions concentrate in the agricultural regions of the US**

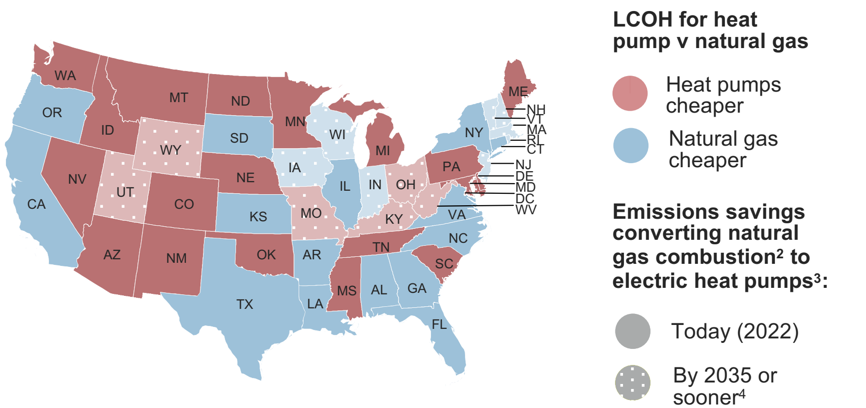
1. *EPA GHGRP Inventory FLIGHT Database (2018); captures actual onsite reported emissions for large emitters emitting >25K tonnes of CO2e/year*

# Heat pumps and solar thermal can be deployed in most heavy-emissions areas

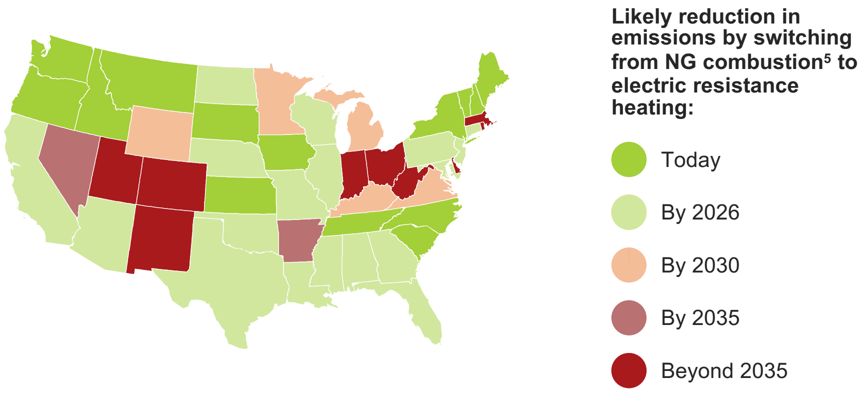
## US Food thermal emissions by zip code[1]



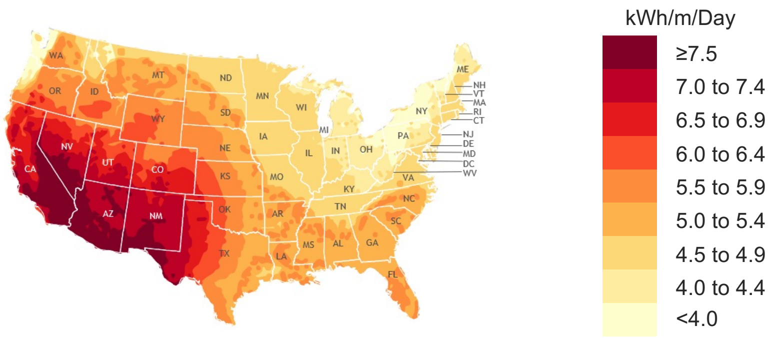

**Heat pumps v. Natural gas[2,4]**




**Elec. resistance v. NG[3]**




**Solar thermal availability[4]**




*1. EPA GHGRP Inventory FLIGHT Database (2018); captures actual onsite reported emissions for large emitters emitting >25k tons of CO2e per year 2. US EIA Industrial Electricity Prices (May 2022), US EIA Industrial Natural Gas Prices (May 2022), Industrial Heat Pumps: Electrifying Industry's Process Heat Supply – ACEEE; 3. US EPA GHGRP (2019); US EIA; State Renewable Portfolio Standards; IEA ETSAP Industrial Combustion Boilers Fact Sheet; BCG analysis; 4. NREL 5. Calculated using 85% efficiency for natural gas boiler; 6. Calculated using a conservative COP of 3*

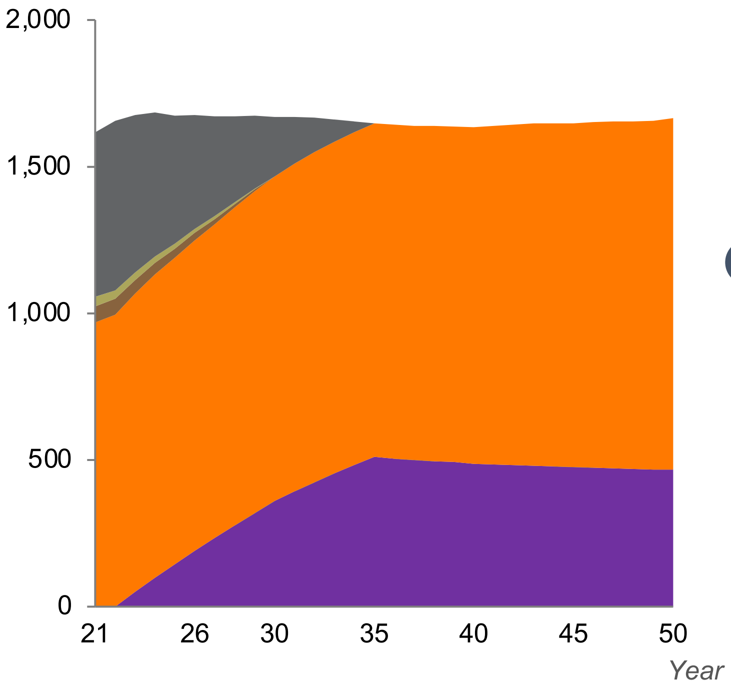
# Thermal Energy Decarbonization

## Decarbonization pathways

- 94% of industrial heat is in low (75%) and medium (19%) temperature ranges, which can be decarbonized on an accelerated timeline with electrification and heat pumps
- Use of fossil coal and petroleum is phased out by 2030, and natural gas phased out by 2035 – replaced primarily by electrification
- Woody biomass represents majority of current energy consumption; increased efficiency in use of biomass is recommended to reduce released carbon from waste
- The sector generated 111 million tonnes of biogenic CO2e3,4 in 2018 primarily due to combustion; while these emissions are unreported, there is an opportunity for the sector to capture this carbon, equating to a ~15% reduction in total US industrial thermal emissions
- Cost of carbon capture on biomass ranges from $60-$120/tonne of carbon with cost reductions expected due to technology maturity; EIA estimates cost of transport and storage at $12-24/tonne of carbon. The Inflation Reduction Act offers a credit of $85/tonne of carbon, which may allow a significant portion of the biogenic emissions to be captured economically over the short and medium term (with increasing economic viability over time)
- Thermal storage with electric resistance heating when paired with inexpensive electricity (<$20/MWH) should be evaluated and deployed

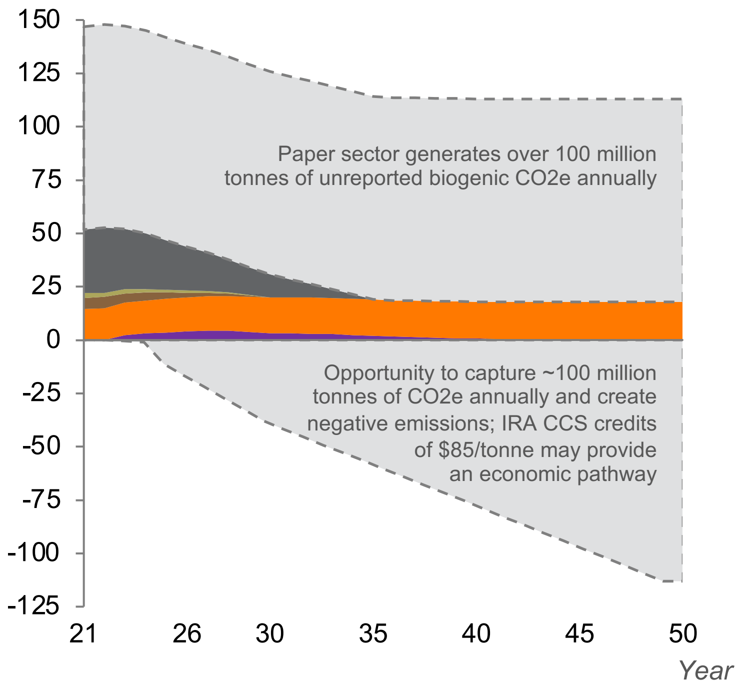
## Thermal energy consumption[1]

Tbtu of thermal energy




## Thermal emissions[2]

Millions tonnes of CO2e in thermal emissions



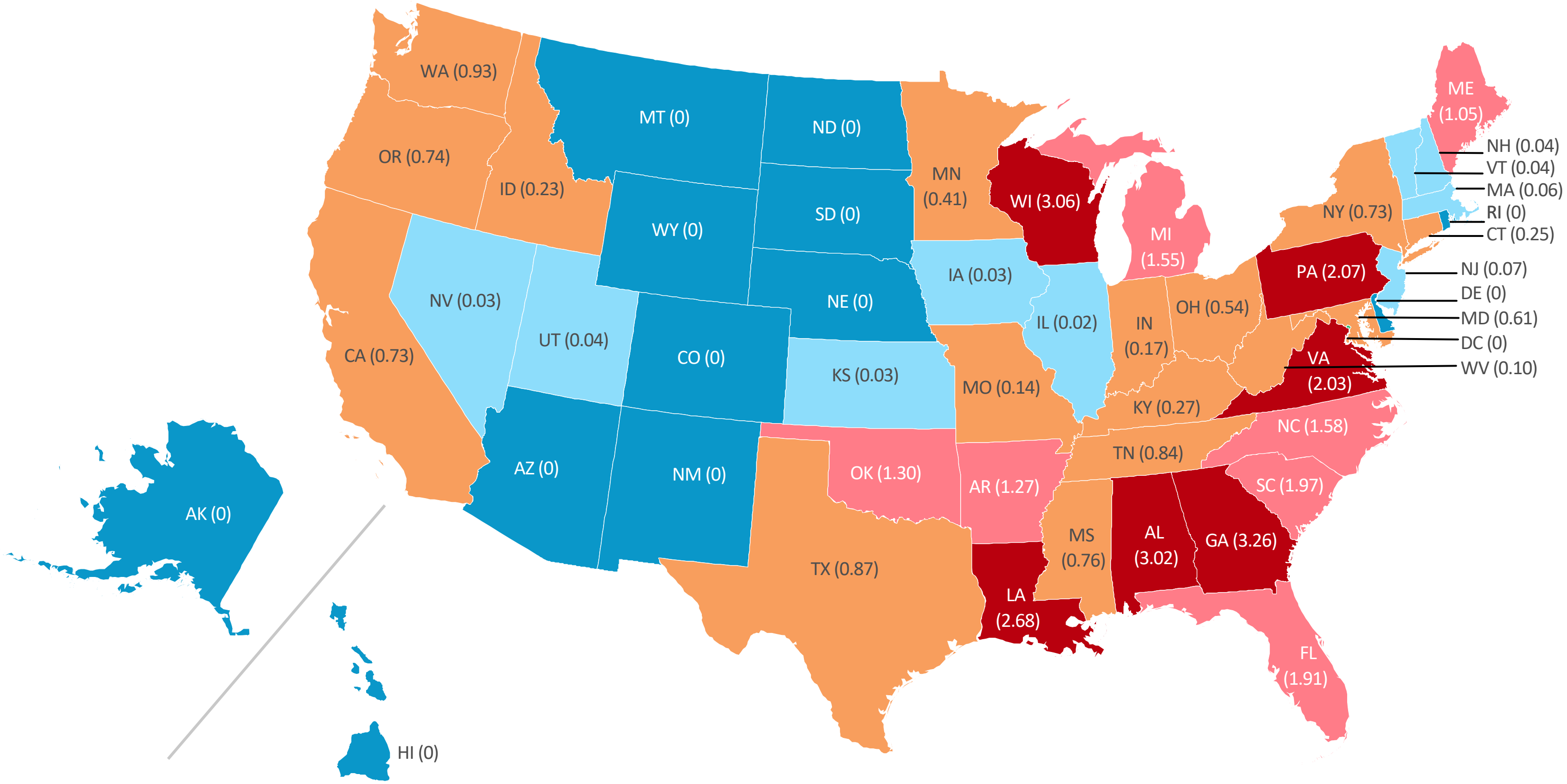

Natural gas | Petroleum & other | Coal | Electrification
Biofuels & coproducts | Waste Biomass | Clean Hydrogen | Biogenic CO2e & CCS

1. Total thermal energy consumption based on EIA 2022 Outlook; forecasted energy mix per BCG analysis 2. Thermal emissions calculated based on emissions intensity of individual fuels; RNG and clean hydrogen assumed to be net zero fuels, biomass assumed to have an emissions intensity of 15 kg CO2e per mmBtu, electricity modeled based on US electric grid emissions intensity assuming 80% and 100% renewables by 2030 and 2050 3. Biogenic emissions are not included in EPA GHGRP stationary combustion emissions since EPA accounts for these fuels as net zero 4. Biogenic combustion is unlikely net zero; the US has lost tree cover annually since 2000; 16% total loss from 2000-2021 equating to 17.4Gt of CO2e Source: EIA outlook; EIA emissions intensity; Global Forest Watch; USDA; industry reports; BCG analysis

# Paper thermal emissions are concentrated in the Southeast and Great Lakes

**Paper industries are focused in the Southeast and Great Lakes regions, where there are abundant and fast-growing wood resources**

## Food thermal emissions by state (Million Tonnes of CO2e)[1]




- Near zero
- <0.1 Million Tonnes CO2e
- 0.1-1 Million Tonnes CO2e
- 1-2 Million Tonnes CO2e
- >2 Million Tonnes CO2e

1. EPA GHGRP Inventory FLIGHT Database (2018); captures actual onsite reported emissions for large emitters emitting >25K tonnes of CO2e/year 2. May include some process emissions (<25% of total)

Chemicals

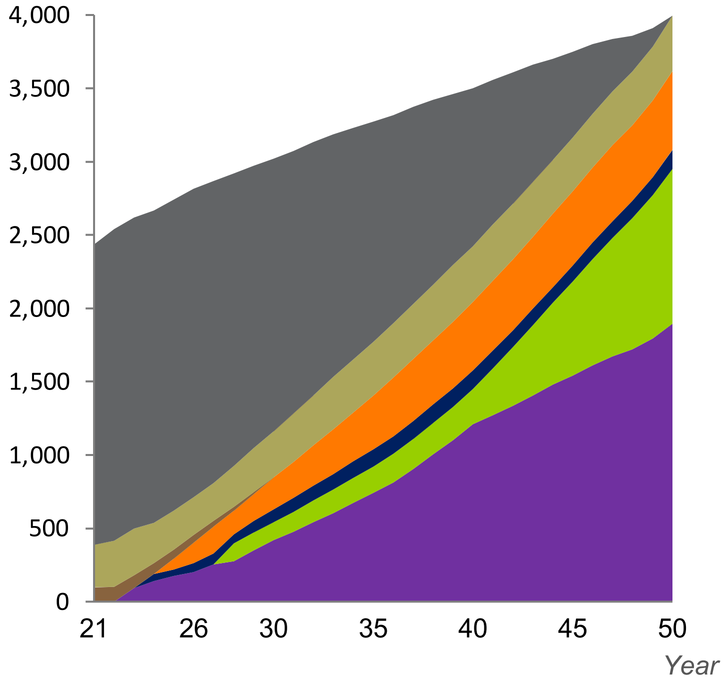
# Thermal Energy Decarbonization

## Decarbonization pathways

- Use of fossil natural gas is eliminated through 2050
- RNG and biomass are deployed as immediate solutions for medium and high heat applications; Biomass use continues to grow over the forecast period (RNG use is not expected to scale due to RNG supply constraints)
- Electrification of low and medium temperature applications is deployed beginning immediately; electric grid emissions intensity is lower than fossil NG for heat pumps in nearly all states today; can be deployed against <130ºC processes representing ~37% of total thermal emissions in the sector.  As heat pumps improve to ~200ºC, higher heat applications can be electrified
- CCS is expected to be deployed in the Chemicals sector to abate process emissions, which outsize thermal emissions for this sector.  CCS deployments can be leveraged to abate the thermal emissions from waste products (included under petroleum & other liquids) and biomass that is combusted for heat
- Thermal storage with electric resistance heating when paired with inexpensive electricity (<$20/MWH) should be evaluated and deployed

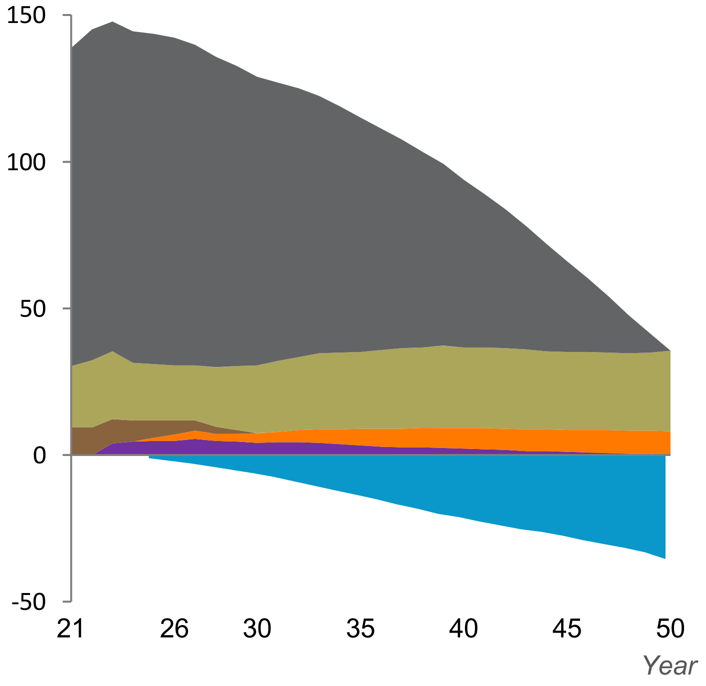
## Thermal energy consumption[1]

Tbtu of thermal energy




## Thermal emissions[2]

Millions tonnes of CO2e in thermal emissions

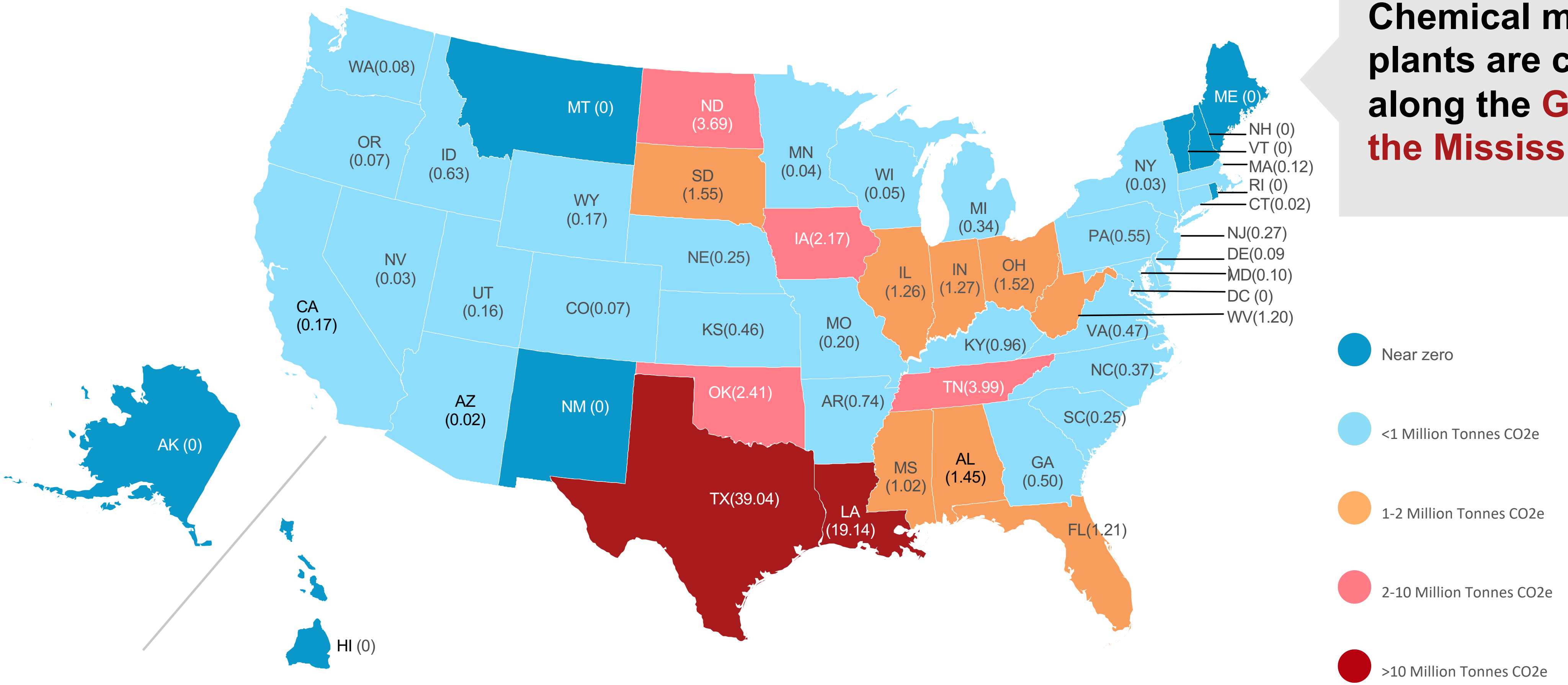



Natural gas | Petroleum & other | Coal | Clean Hydrogen | CCS
Biofuels & coproducts | Waste Biomass | RNG | Electrification

1. Total thermal energy consumption based on EIA 2022 Outlook; forecasted energy mix per BCG analysis  2. Thermal emissions calculated based on emissions intensity of individual fuels; RNG and clean hydrogen assumed to be net zero fuels, biomass assumed to have an emissions intensity of 15 kg CO2e per mmBtu, electricity modeled based on US electric grid emissions intensity 80% and 100% renewables by 2030 and 2050  3. DOE Industrial Decarbonization Roadmap (2022)  4. PCA Roadmap to Carbon Neutrality (2021)  Source: EIA outlook; EIA emissions intensity; BCG analysis

# Chemicals thermal emissions are concentrated along the Gulf Coast (where refineries are also concentrated)

## Chemicals thermal emissions by state (Million Tonnes of CO2e)[1]

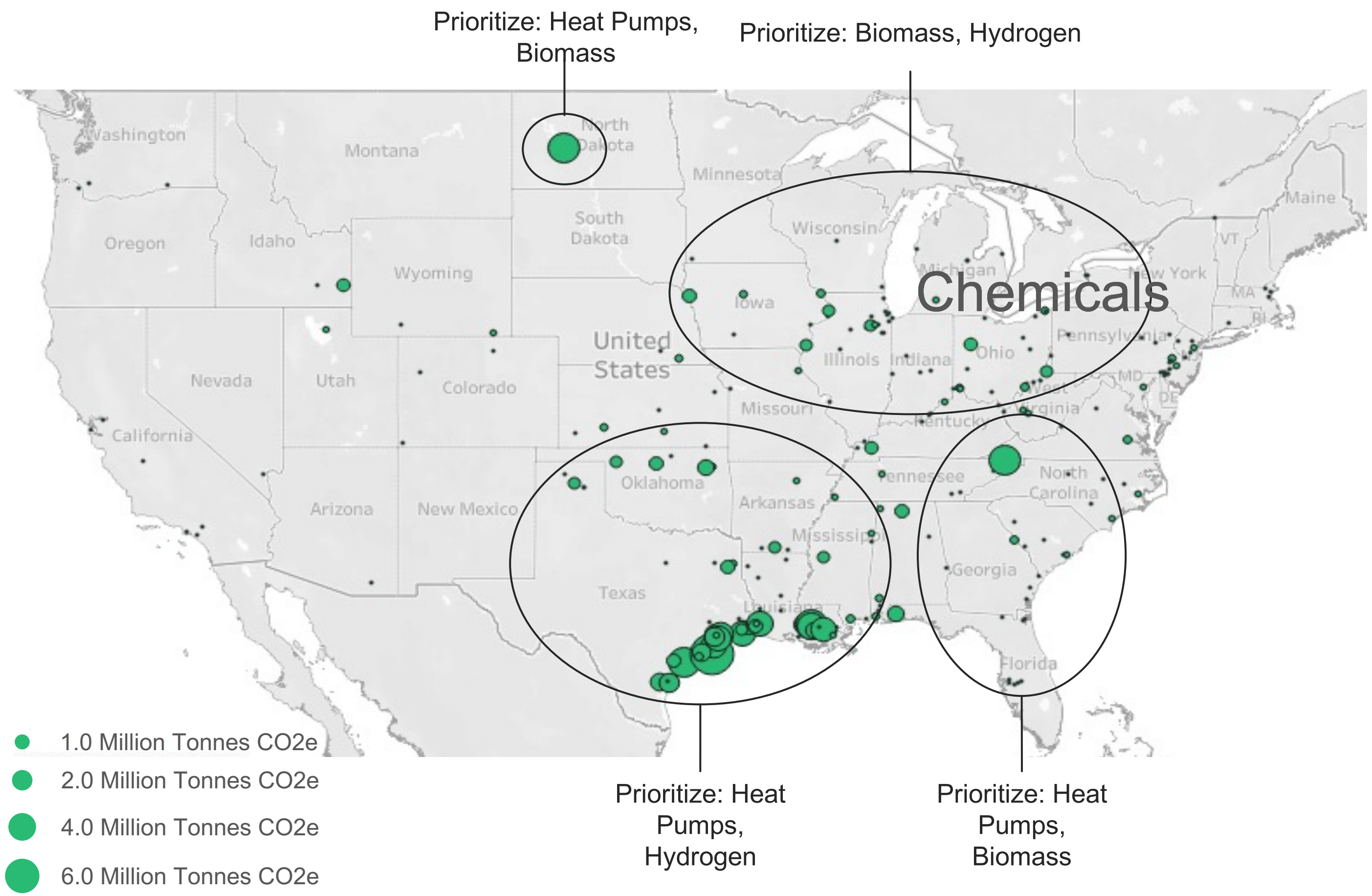



**Chemical manufacturing plants are concentrated along the Gulf Coast and the Mississippi river**

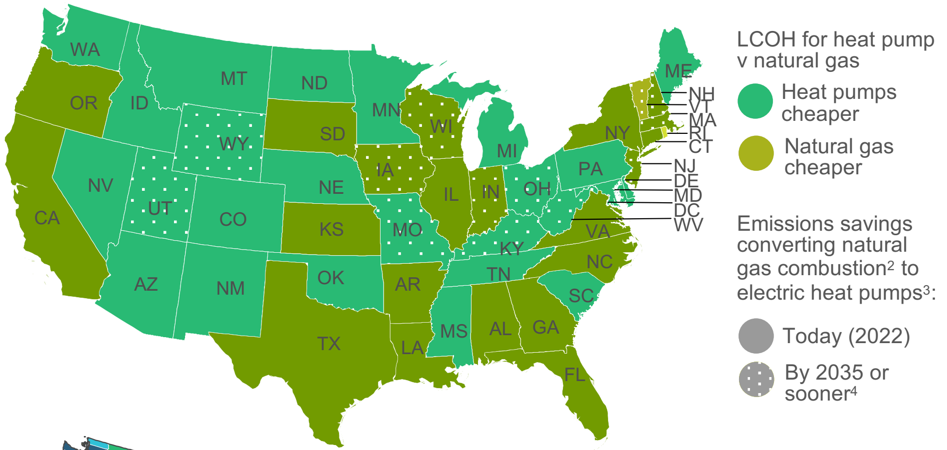
1. EPA GHGRP Inventory FLIGHT Database (2018); captures actual onsite reported emissions for large emitters emitting >25K tonnes of CO2e/year

# Hydrogen, biomass, and heat pumps are available in heavy-emissions areas

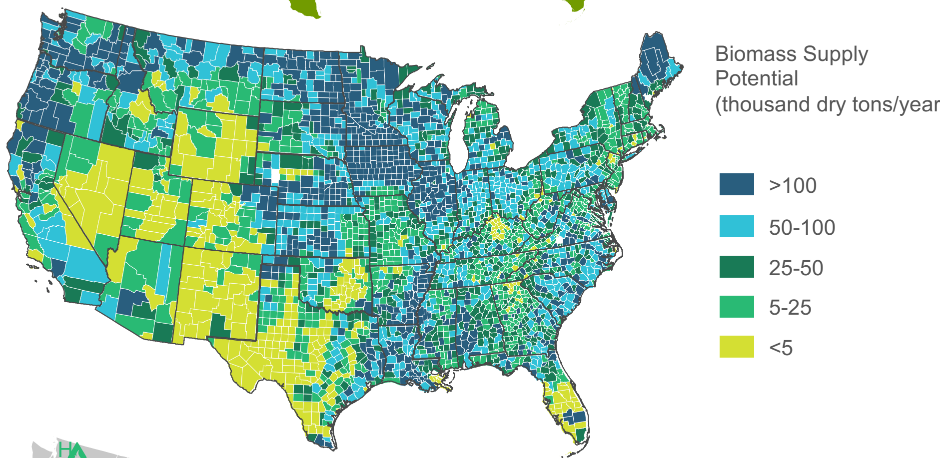
## US Chemicals sector thermal emissions by zip code[1]



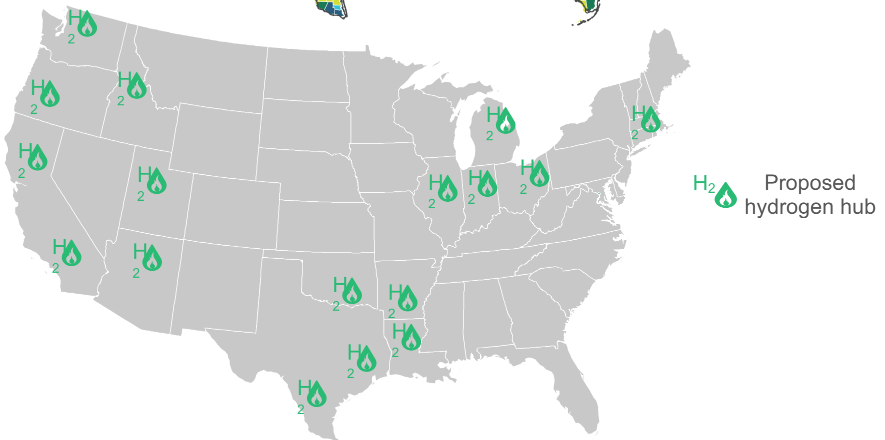

Heat pumps v. Natural gas[2,4]




Biomass supply[3]




Proposed hydrogen hubs[4]




1. EPA GHGRP Inventory FLIGHT Database (2018); captures actual onsite reported emissions for large emitters emitting >25k tonnes of CO2e per year 2. USGS, NETL NATCAB 3. CSIS (2022)

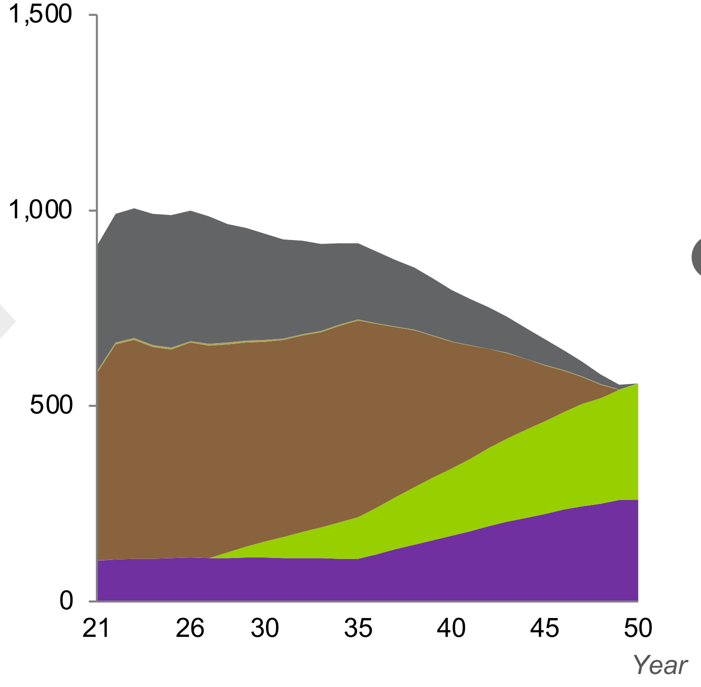
# Thermal Energy Decarbonization

## Decarbonization pathways

- Primary decarbonizing pathway is transitioning away from blast furnaces (BF) and basic oxygen furnaces (BOF), which use coal, to electrified processes – producing direct reduced iron (DRI) with electricity & clean hydrogen (replaces BF) and using an electric arc furnace (EAF; replaced BOF). This process largely eliminates use of coal. DRI-EAF with green hydrogen is less energy intensive than BF-BOF and total thermal energy consumption is expected to decline as sector transitions
- More than 2/3rds of US steel facilities today use EAFs, and only ~10 facilities remain operating ~14 total blast furnaces - these facilities generated 77% of total thermal emissions for the sector in 2018
- Data suggests current stock of BF-BOFs will require upgrades from 2023-2036 period, however, due to various sector specific factors including insufficient DRI supply to produce high quality steel, the remaining BF-BOFs are not expected to convert to DRI-EAF w/ green hydrogen in the short and medium term. The decarbonization pathway model delays converting BF-BOFs to 2036 and converts all ~14 BF-BOFs by 2050.
- In the interim period, the sector should deploy CCS to capture emissions while the transition to DRI-EAF w/ green hydrogen occurs, upon which CCS can be phased out
- This sector also combusts natural gas for heat in upstream and downstream heat applications (e.g. hot rolling); use of fossil combustion can be displaced through 2050 with green hydrogen

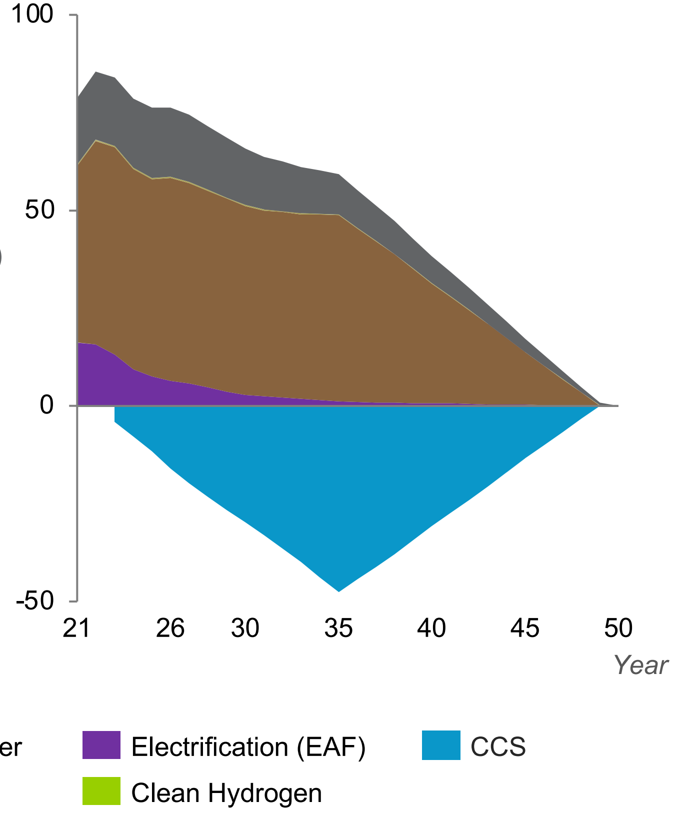
## Thermal energy consumption[1]

Tbtu of thermal energy




## Thermal emissions[2]

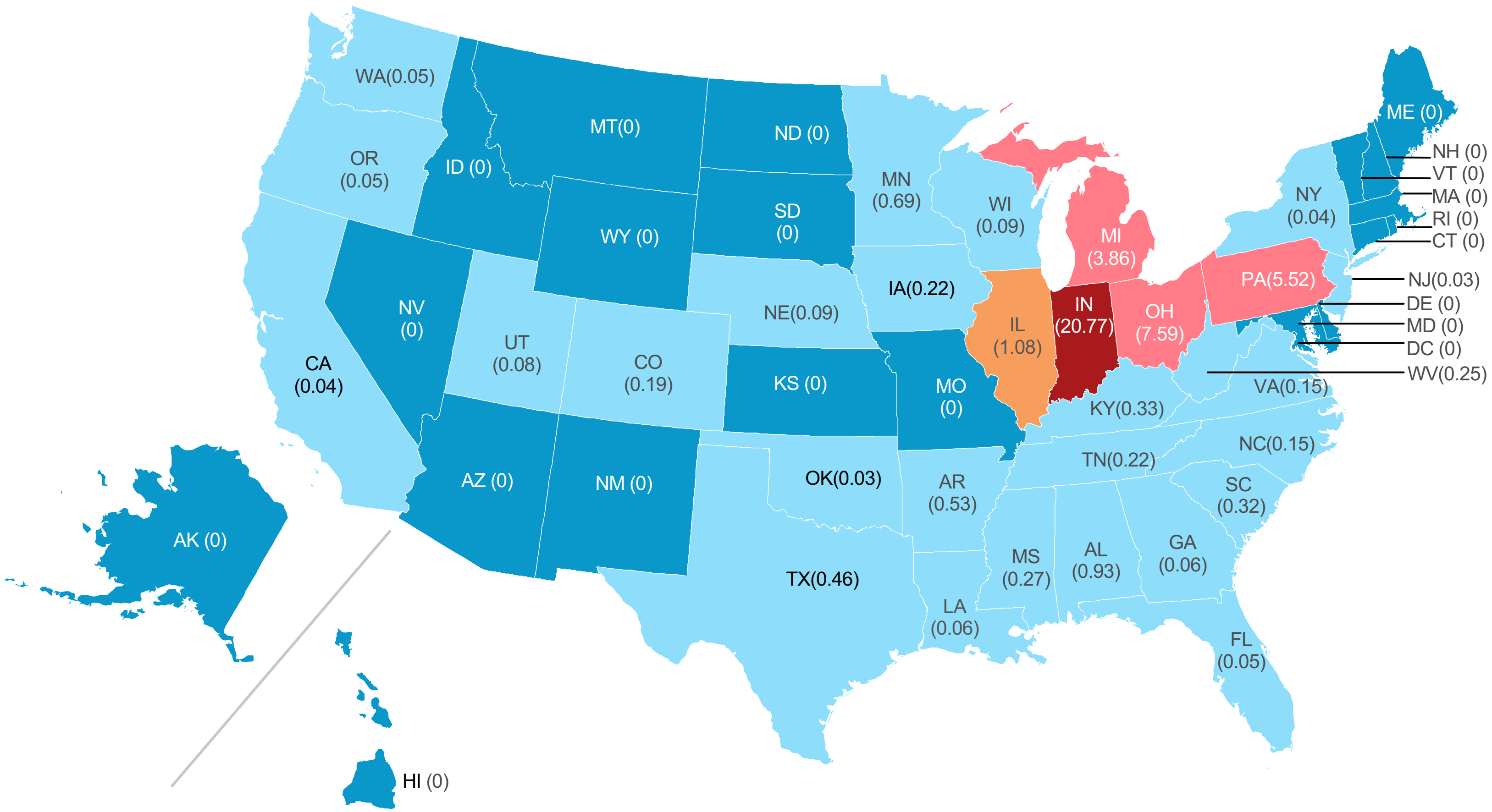
Millions tonnes of CO2e in thermal emissions




1. Total thermal energy consumption based on EIA 2022 Outlook; forecasted energy mix per BCG analysis 2. Thermal emissions calculated based on emissions intensity of individual fuels; RNG and clean hydrogen assumed to be net zero fuels, biomass assumed to have an emissions intensity of 15 kg CO2e per mmBtu, electricity modeled based on US electric grid emissions intensity 80% and 100% renewables by 2030 and 2050 Source: EIA outlook; EIA emissions intensity; BCG analysis

# Iron & steel thermal emissions are concentrated in the Midwest

## Iron & Steel thermal emissions by state (Million Tonnes of CO2e)[1]




- Near zero
- <1 Million Tonnes CO2e
- 1-2 Million Tonnes CO2e
- 2-10 Million Tonnes CO2e
- >10 Million Tonnes CO2e

**Iron & Steel emissions are focused in the Midwest primarily due to the concentration of iron and steel production facilities**

1. EPA GHGRP Inventory FLIGHT Database (2018); captures actual onsite reported emissions for large emitters emitting >25K tonnes of CO2e/year

# There are three types of facilities in the US; the Blast Furnace-Basic Oxygen Furnace plants are the heaviest emitters

**BF-BOF**
(Blast furnace – Basic oxygen furnace)

~10 facilities[1]

The conventional method of producing steel involves the use of blast furnaces and basic oxygen furnaces

This process uses coal, is highly carbon intensive, and accounts for the vast majority of thermal emissions in the steel industry

**~77% of thermal emissions[1]**

**Scrap-EAF**
(scrap metal with electric arc furnace)

~100 facilities

EAFs produce steel by heating metal feedstock to temperatures up to 1800ºC

EAFs are electrified, less energy intensive, can rapidly start and stop, and produce significantly fewer thermal emissions vs. BF-BOFs

Most US steel facilities use EAFs with scrap metal as feedstock; this produces lower grade steel than the BF-BOFs process

**DRI-EAF**
(direct reduced iron with electric arc furnace)

3 facilities

To produce higher quality steel, DRI (direct reduced iron) can be fed into EAFs along with scrap metal

DRI is largely produced using natural gas for combustion and as a feedstock; however, green hydrogen is a viable substitute for heat and as feedstock in next 10-20 years

Clean hydrogen and DRI production scaling is needed to decarbonize BF-BOFs

**~23% of thermal emissions**

## US BF-BOF & DRI-EAF locations

★ US BF-BOF with coal ★ US DRI-EAF with natural gas

1. There were 10 active plants running BF-BOFs the US in 2018, representing 34 million tonnes of CO2e and 77% of sector thermal emissions; this represents 8% of the total US industrial thermal emissions across all sectors included in this analysis; in 2020, one BF-BOF plant shut down its BF-BOFs and there are now approximately 9 plants operating BF-BOFs in the US Source: EPA GHGRP 2018; BCG analysis

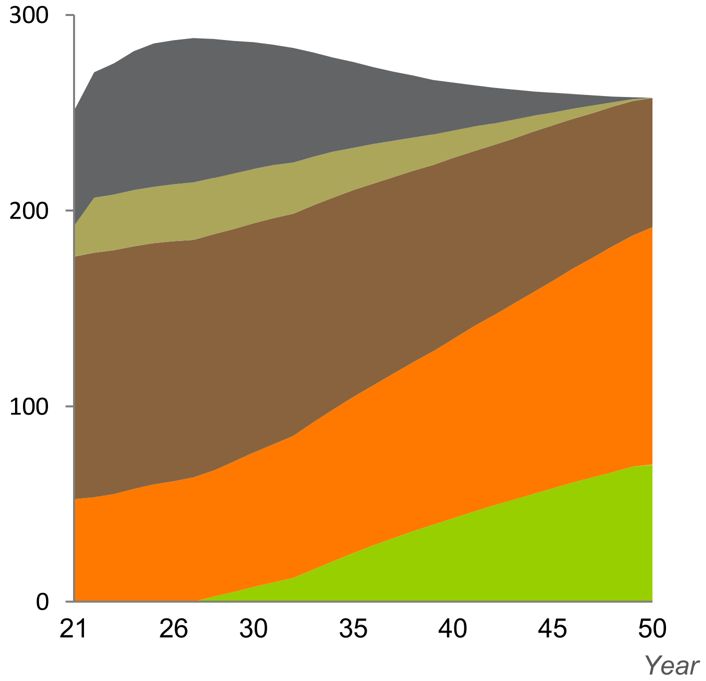
# Thermal Energy Decarbonization

## Decarbonization pathways

- The Cement sector creates more process emissions than thermal emissions, and both emissions are typically emitted in the same air stream. As a result, it is difficult to distinguish between process and thermal emissions and the EPA GHGRP flight database does not identify meaningful thermal emissions. However, thermal emissions make up ~42% of total emissions (process emissions make up ~58%)[3]
- The cement industry heat process applications require heat driven by fossil fuel combustion as well as fossil coal as a feedstock
- Heavy emitting coal, which is used for heat and as feedstock in the rotary kiln, can be partially displaced with biomass, which can compose up to 50% of the total rotary kiln mix by 2050; some European cement manufacturers are using ~60% alternative fuels in their rotary kiln mix (displacing ~40% of coal)[4]
- Given the inability to distinguish process and thermal emissions, it is likely that carbon capture deployed to capture process emissions (~58% of total emissions) will also be used to capture thermal emissions (~42% of total emissions), until a longer-term alternative for coal-based cement production is developed

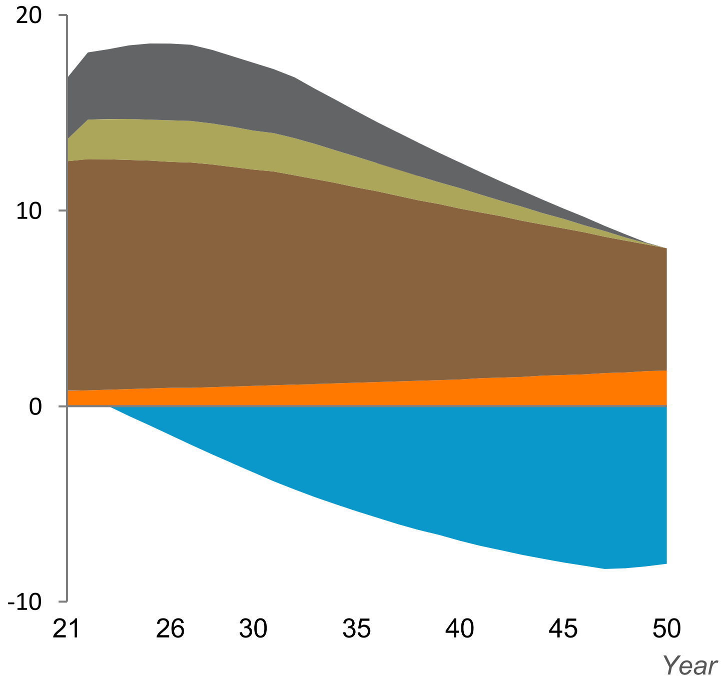
## Thermal energy consumption[1]

Tbtu of thermal energy




## Thermal emissions[2]

Millions tonnes of CO2e in thermal emissions

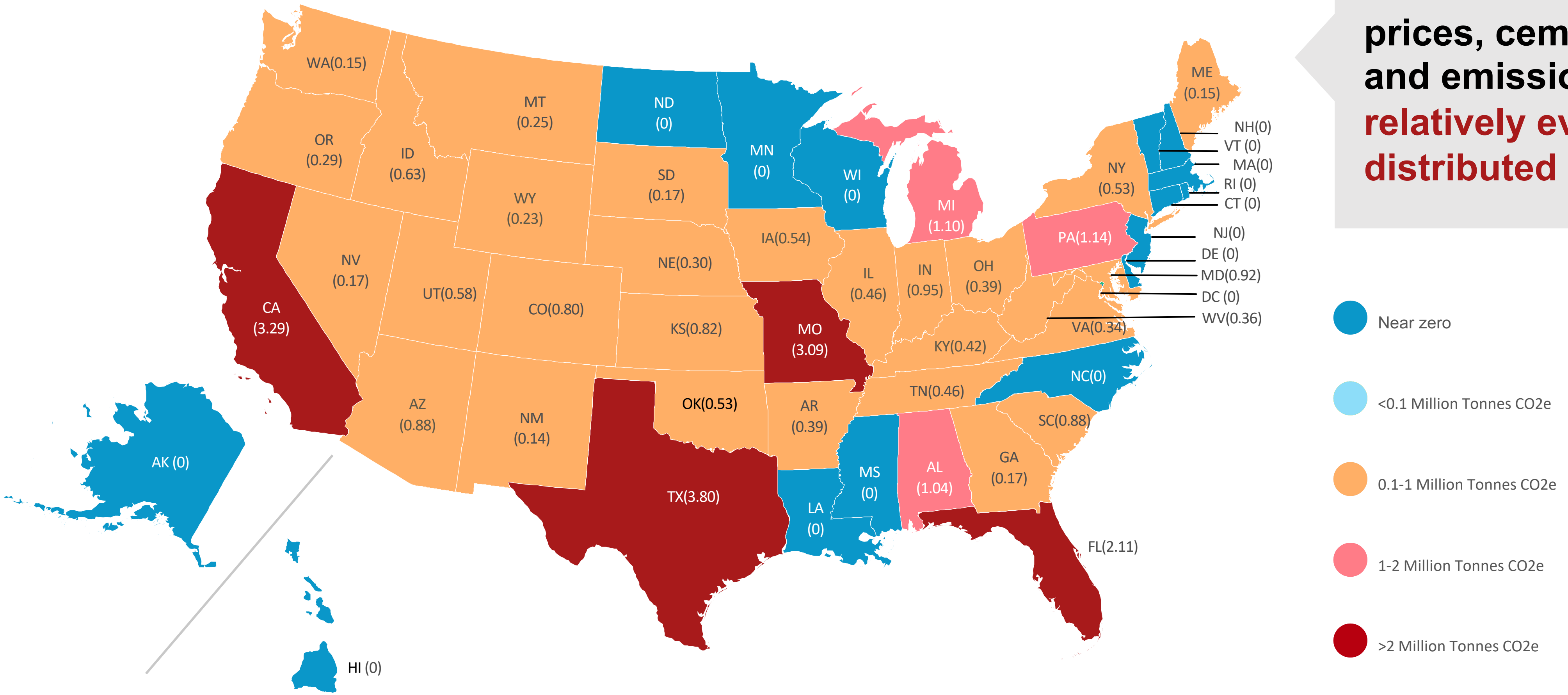



Natural gas | Petroleum & other | Coal | CCS
Biofuels & coproducts | Waste Biomass | Clean Hydrogen

1. Total thermal energy consumption based on EIA 2022 Outlook; forecasted energy mix per BCG analysis 2. Thermal emissions calculated based on emissions intensity of individual fuels; RNG and clean hydrogen assumed to be net zero fuels, biomass assumed to have an emissions intensity of 15 kg CO2e per mmBtu, electricity modeled based on US electric grid emissions intensity 80% and 100% renewables by 2030 and 2050 3. DOE Industrial Decarbonization Roadmap (2022) 4. PCA Roadmap to Carbon Neutrality (2021) Source: EIA outlook; EIA emissions intensity; BCG analysis

# Cement thermal emissions are evenly distributed across the country

## Cement thermal emissions by state (Million Tonnes of CO2e)[1]



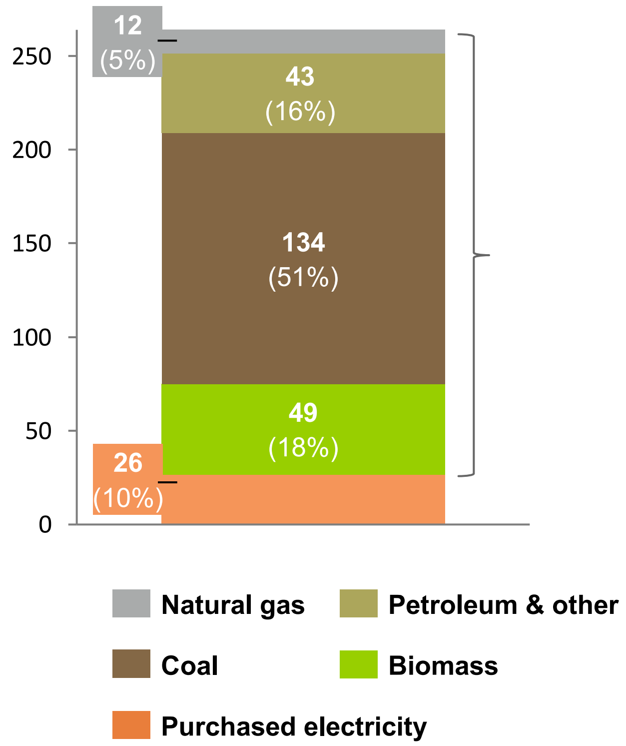

**Due to high transportation costs relative to material prices, cement production and emissions are relatively evenly distributed across the US**

1. EPA GHGRP Inventory FLIGHT Database (2018); captures actual onsite reported emissions for large emitters emitting >25K tonnes of CO2e/year

# Coal is the primary fuel and source of emissions; 83% of thermal emissions are produced at high temperatures

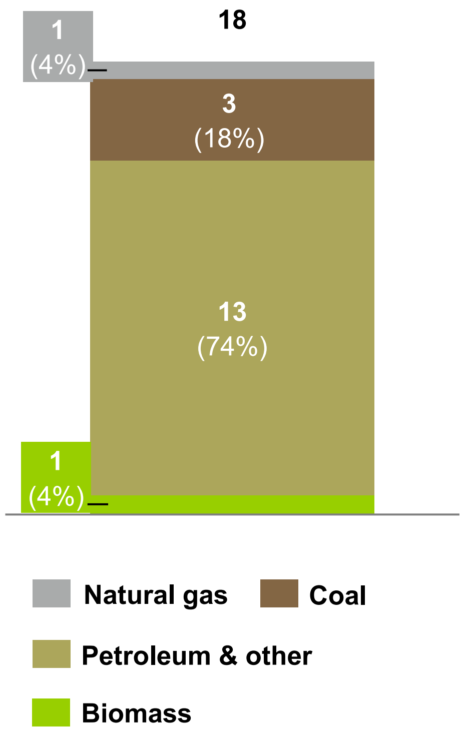
## Total energy consumption (2018)[1]

Trillion Btu



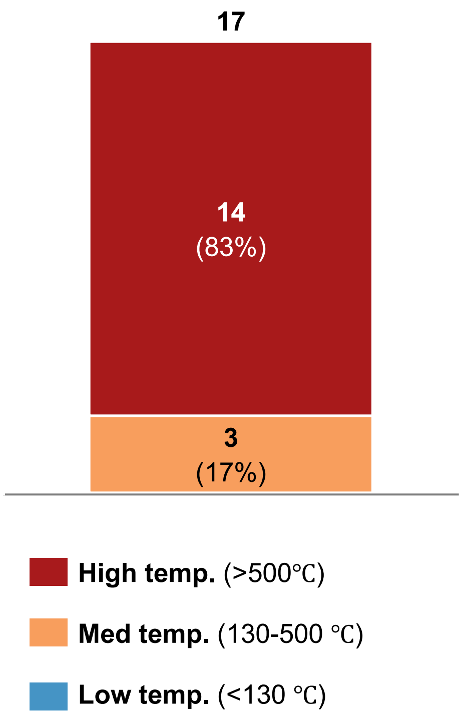

## Thermal emissions (2018)[2]

Million Tonnes of CO2e




## Estimated thermal emissions by process temperature (2018)[3]

Million Tonnes of CO2e




1. EIA Annual Energy Outlook 2019 2. Based on AEO 2019 Outlook for 2018 energy consumption by combustible fuel (excludes purchased electricity) and EPA emissions intensity of individual fuels; RNG and green hydrogen are considered net zero, biomass is estimated at 15 kg CO2e/mmBtu 3. Calculated using the NREL MECS survey data for thermal energy use (2014)
Source: EIA; EPA; NREL; BCG analysis

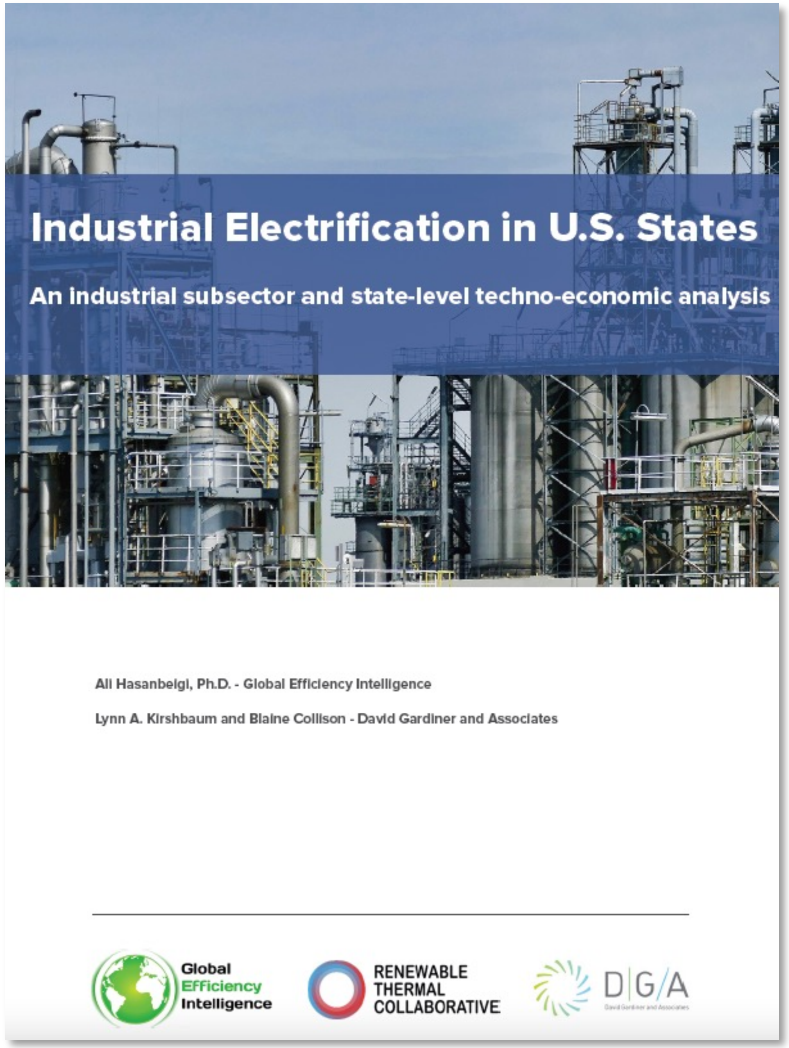
RENEWABLE THERMAL COLLABORATIVE

# Industrial Electrification in U.S. States

Presented by Ruth Checknoff

*Project and Research Director, DGA*

# Beneficial Electrification

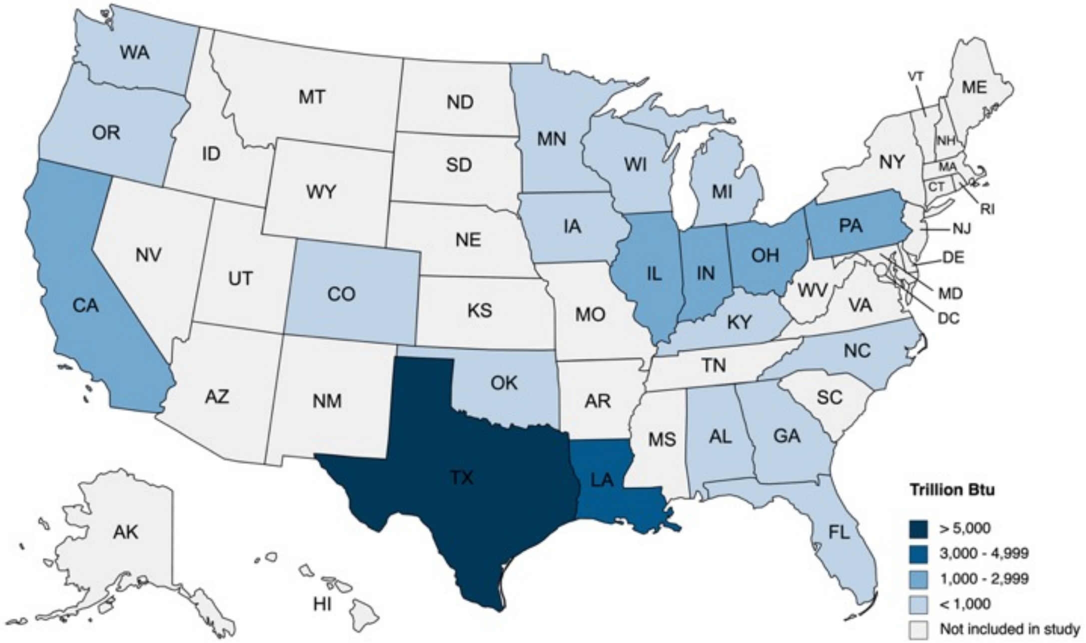



Download the report:
https://www.renewablethermal.org/state-electrification-report/

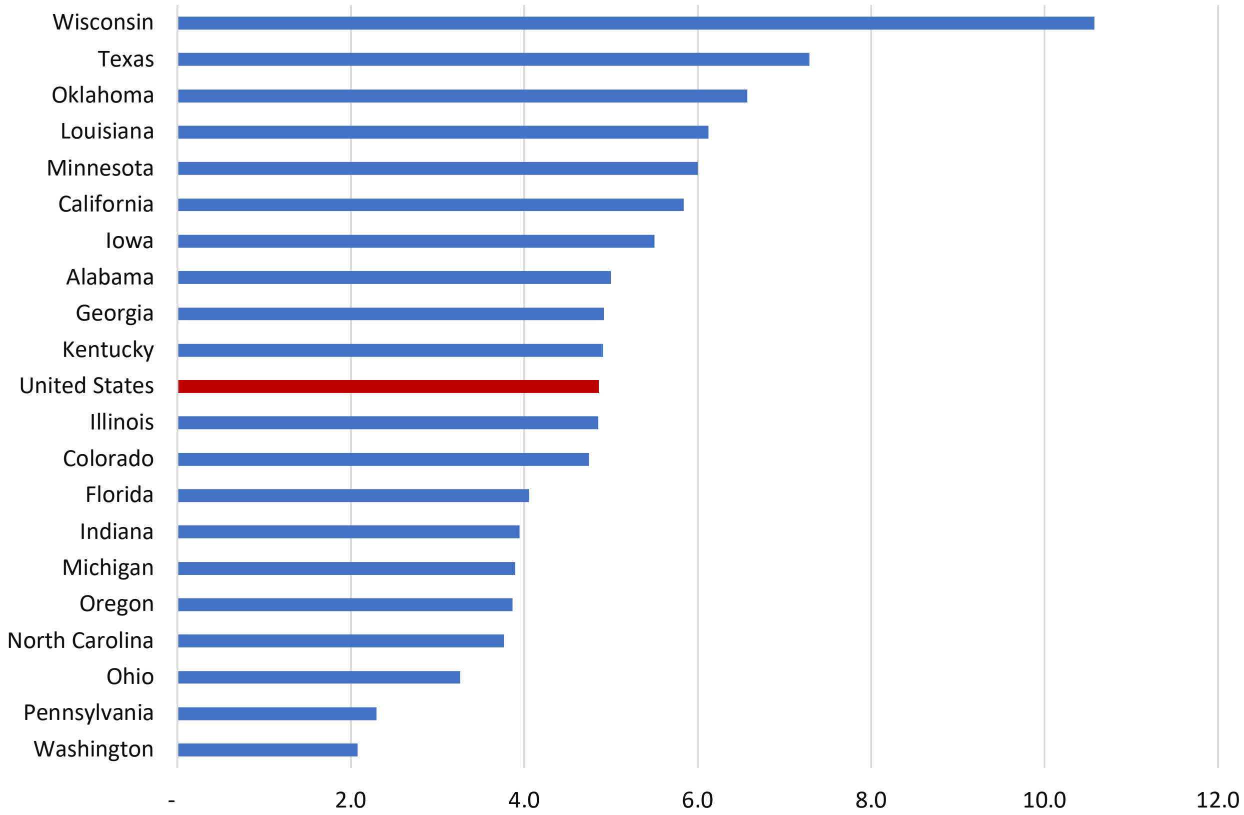
Download state factsheets:
https://www.renewablethermal.org/state-electrification-factsheets/

- Alabama
- California
- Colorado
- Florida
- Georgia
- Illinois
- Indiana
- Iowa
- Kentucky
- Louisiana
- Michigan
- Minnesota
- North Carolina
- Ohio
- Oklahoma
- Oregon
- Pennsylvania
- Texas
- Washington
- Wisconsin

# State-Level Analysis




Industrial energy use in 2019 (trillion Btu)



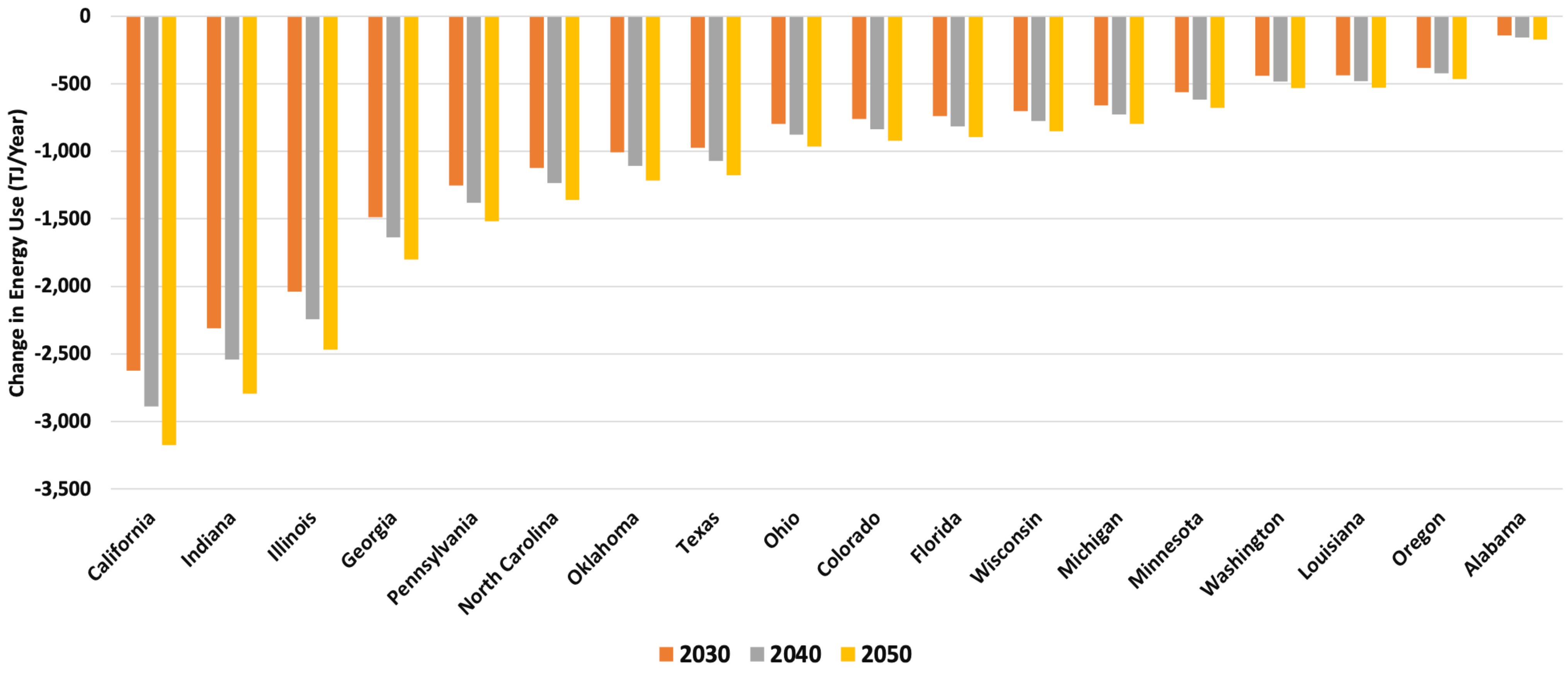

Ratio of the industrial unit price of electricity to natural gas in 2021

# Sectors Included in Study Scope

Table 1. U.S. industrial subsectors analyzed in this study

| No. | Industry subsector | No. | Industry subsector |
|---|---|---|---|
| 1 | Aluminum casting | 7 | Steel |
| 2 | Pulp and paper | 8 | Beer |
| 3 | Container glass | 9 | Beet sugar |
| 4 | Ammonia | 10 | Milk powder |
| 5 | Methanol | 11 | Wet corn milling |
| 6 | Recycled plastic | 12 | Crude soybean oil |

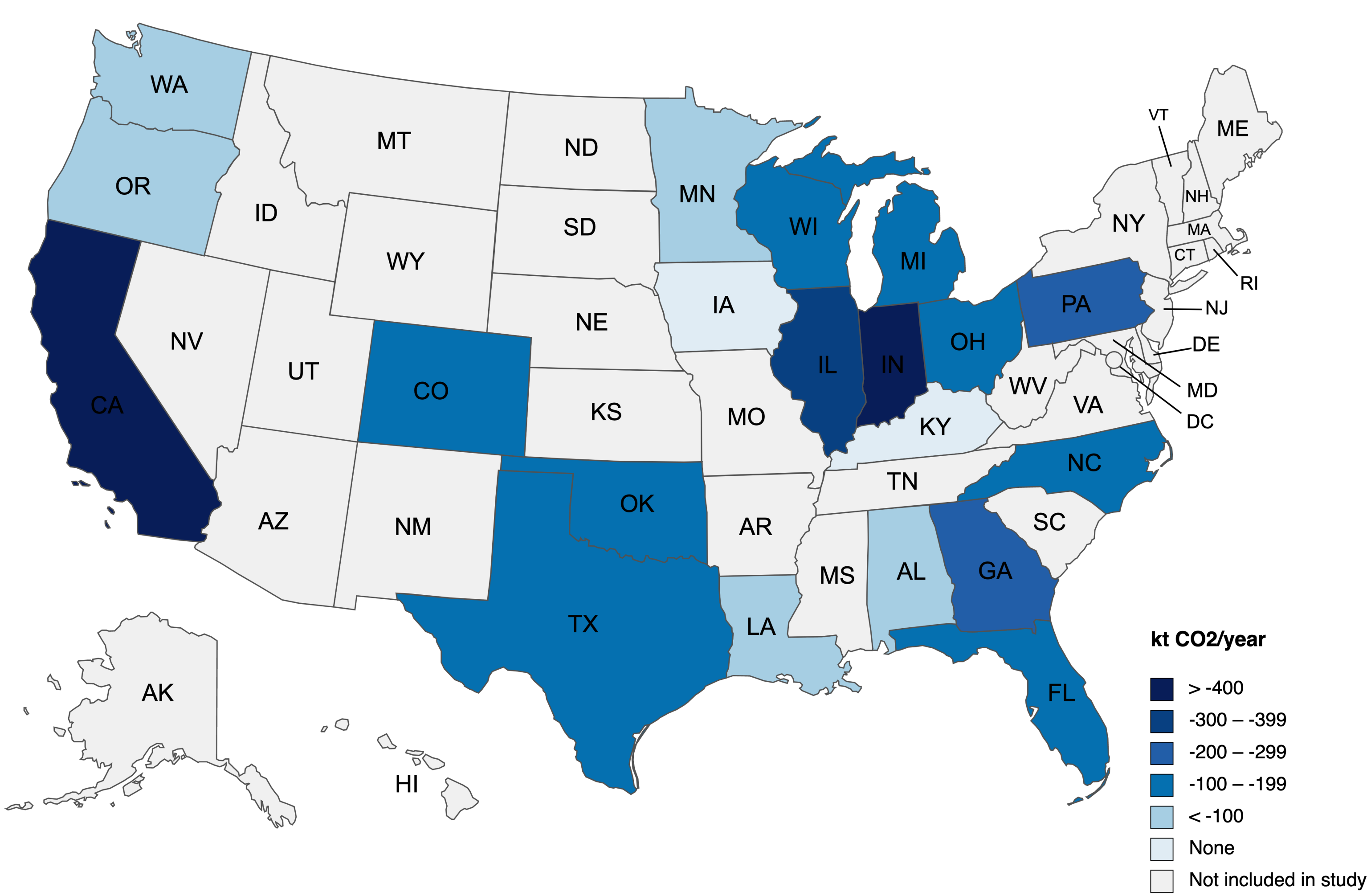
# Electrification of the Container Glass Industry – Energy Savings




Change in the container glass industry's total final energy use after electrification

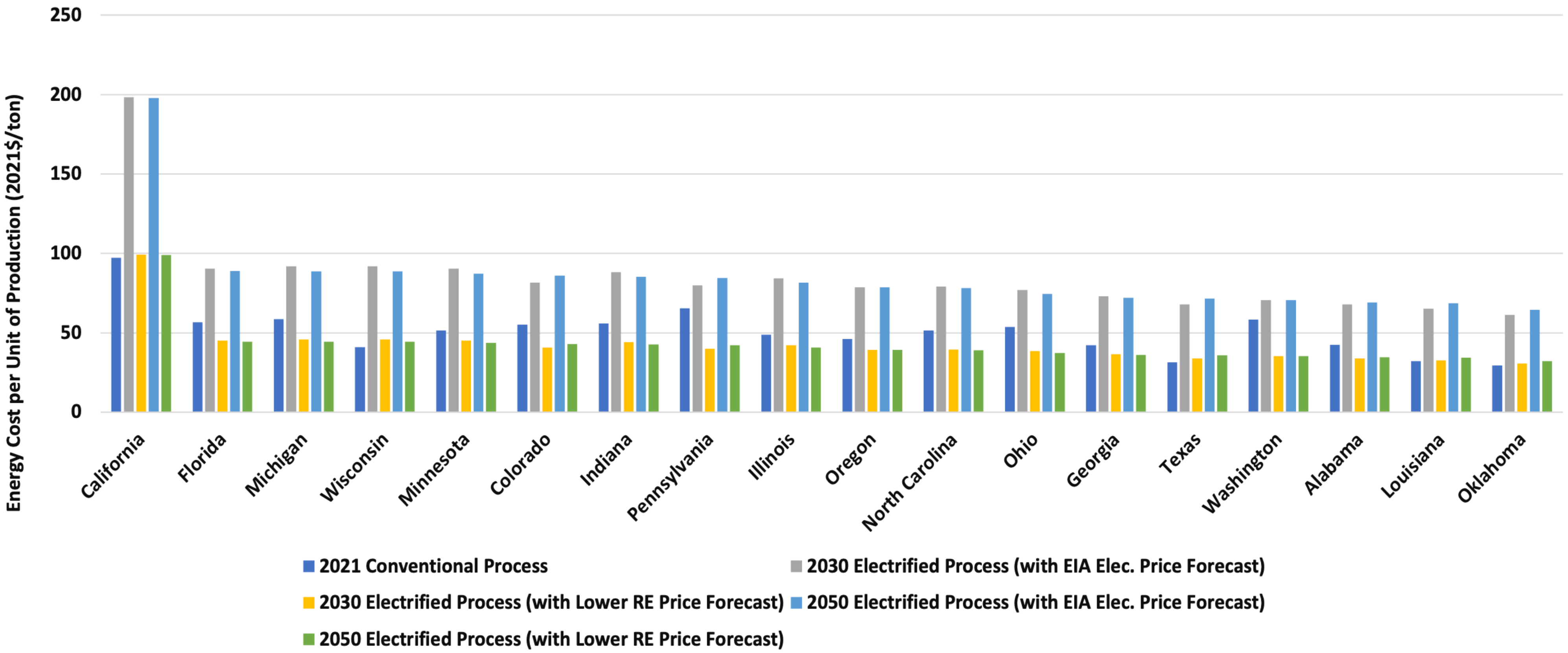
(Technical potential assuming 100% adoption rate)

# Electrification of the Container Glass Industry – Emissions Reductions




Change in $CO_2$ emissions in the container glass industry in 2050

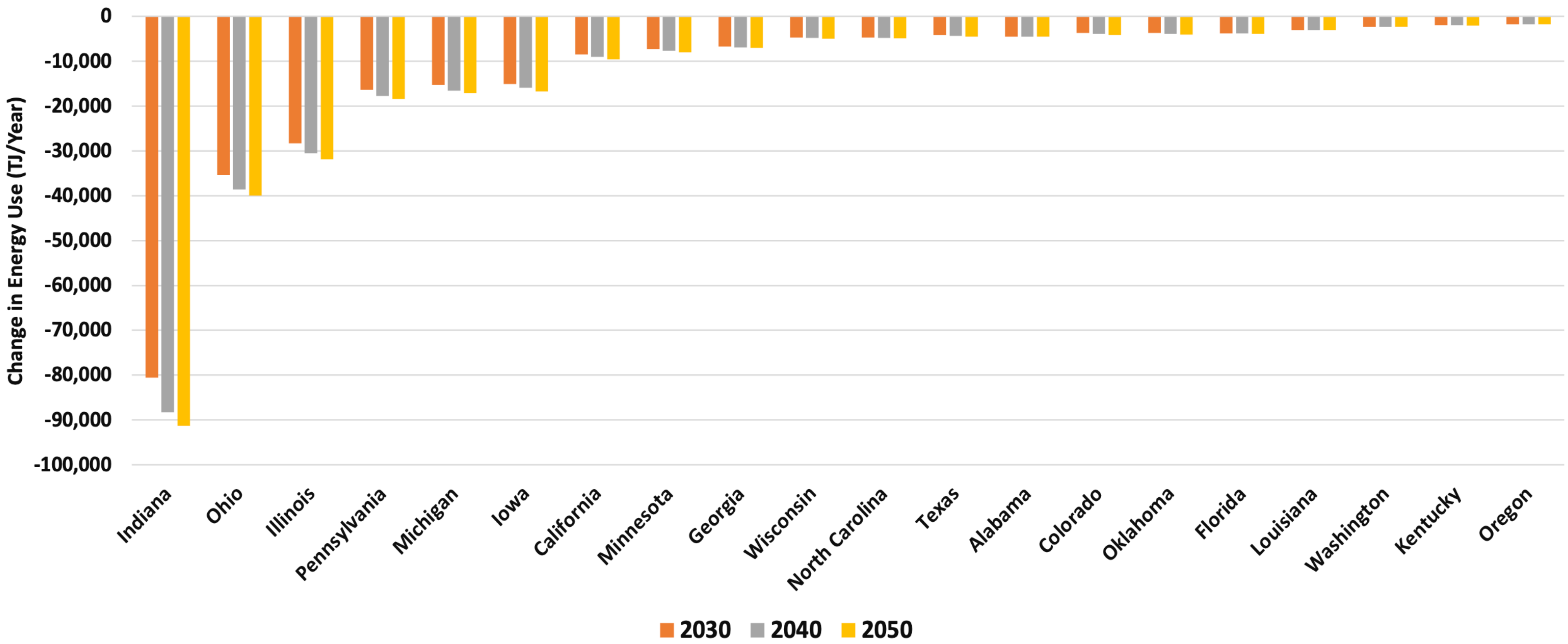
# Electrification of the Container Glass Industry – Energy Costs




Energy cost per unit of production in the container glass industry

**Energy cost is only a small portion of total manufacturing cost** for many industrial subsectors. Therefore, a moderate increase in energy cost per unit of product resulting from electrification will have a minimal impact on the price of final product and final consumers.

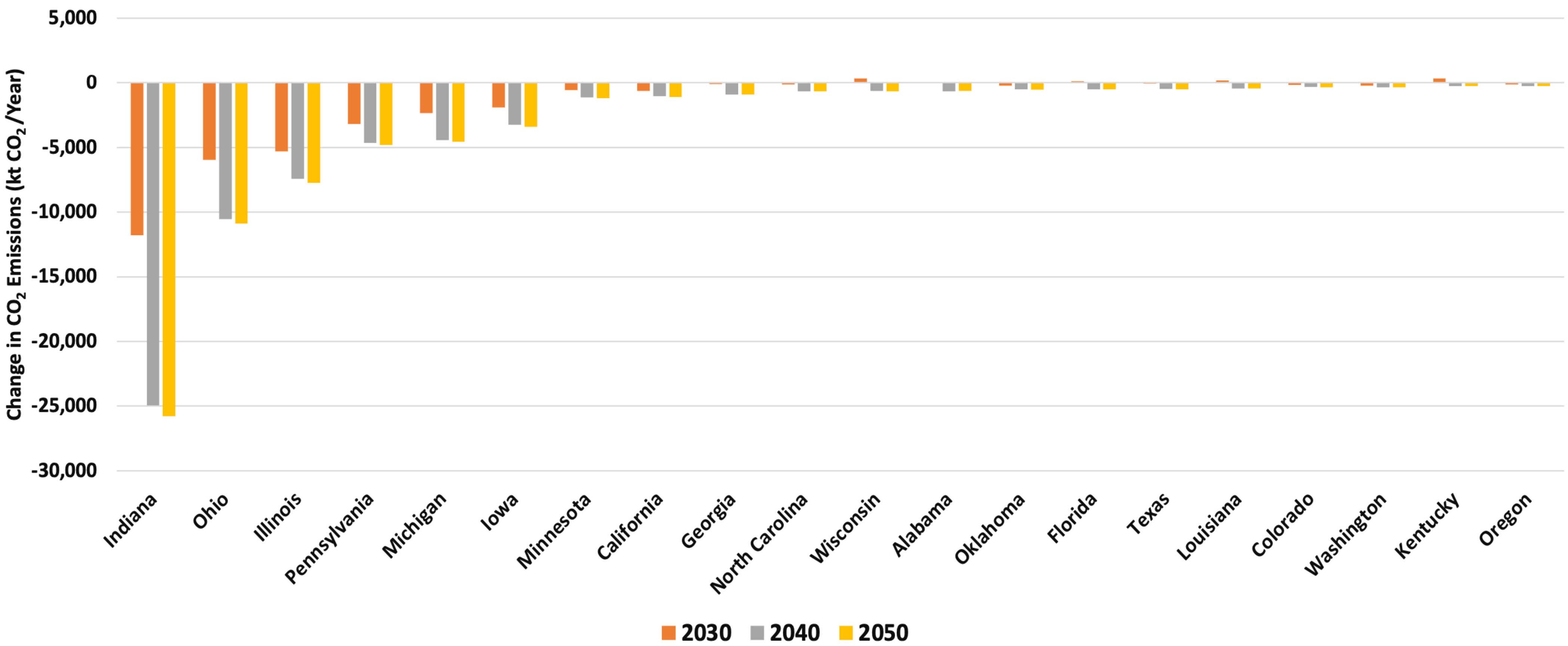
# Significant Energy Savings




Change in industrial energy use using electrified processes in nine industries studied

(excludes ammonia, methanol, and plastic recycling industries, technical potential assuming 100% adoption rate)

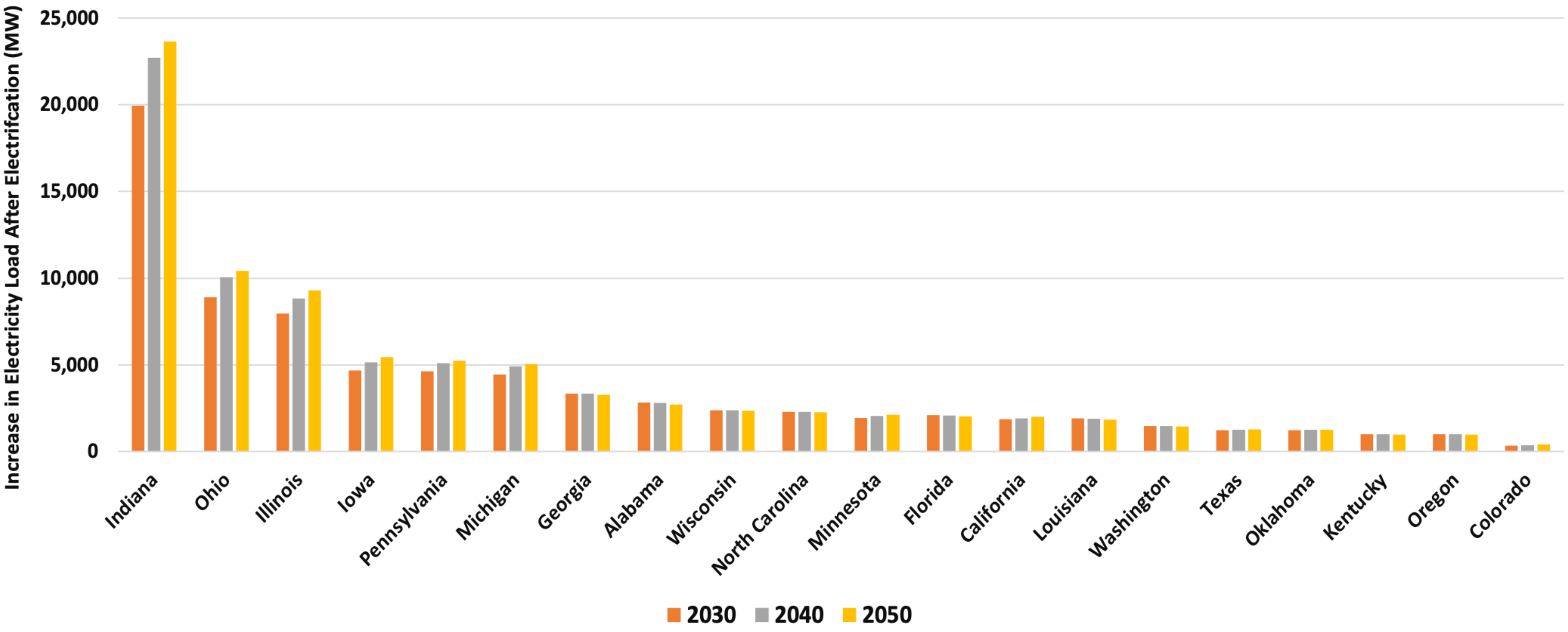
# Industrial Emissions Reductions




Change in industrial net CO2 emissions using electrified processes in nine industries studied

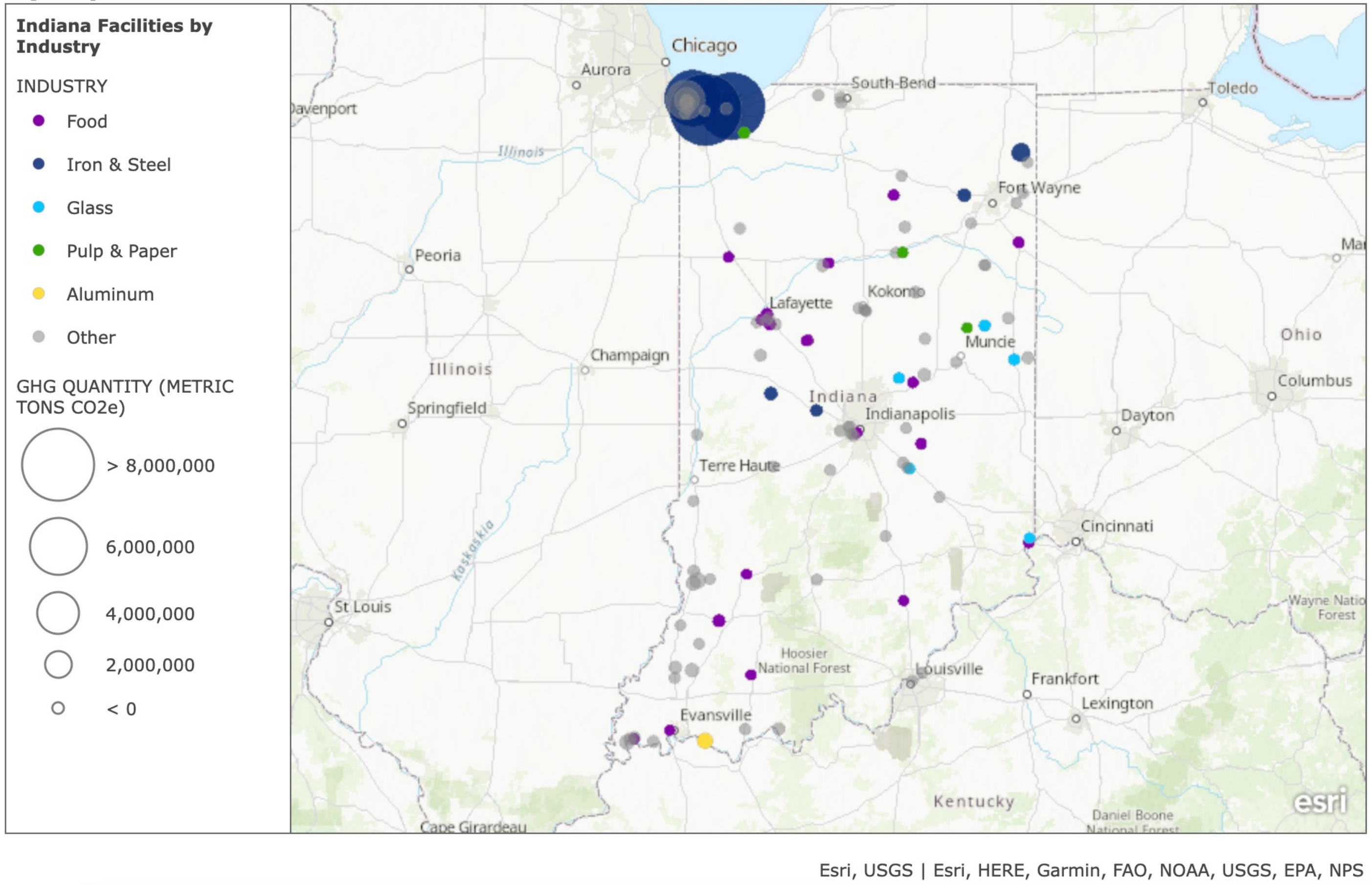
(stated policy scenario; excludes ammonia, methanol, and plastic recycling industries; technical potential assuming 100% adoption rate)

# Electricity Demand Impacts




Increase in electricity load after industrial electrification assuming 100% adoption rate (MW)

# State Factsheet: Indiana



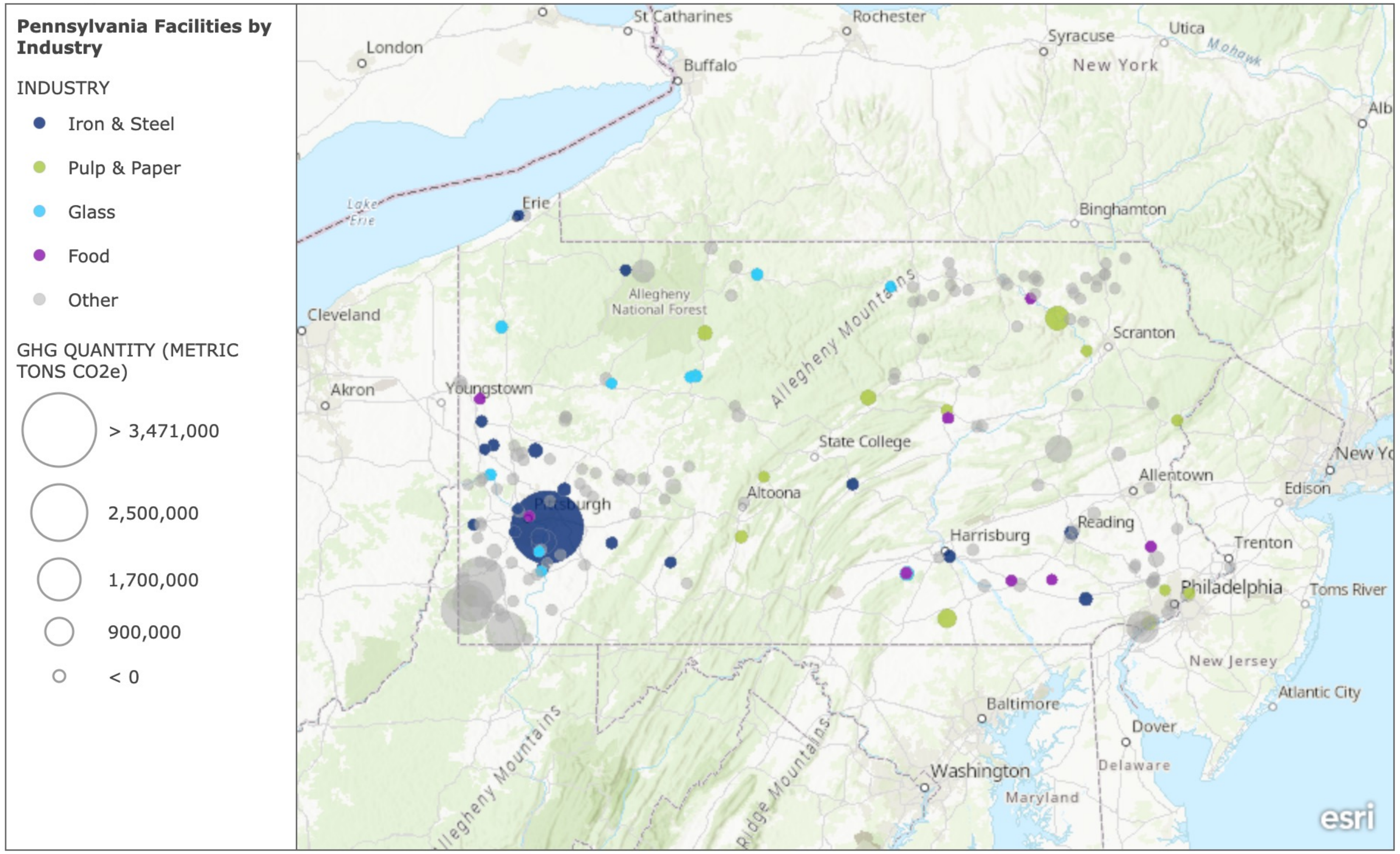

This map shows the relative emissions of large industrial facilities. Facility types that are included in the full report analysis are shown in colors while other industrial facility types are shown in grey.

Built using ArcGIS online with U.S. Environmental Protection Agency's Facility Level Information on GHGs Tool (FLIGHT) 2020 data. U.S. Environmental Protection Agency, "Greenhouse Gas Reporting Program (GHGRP)," last accessed February 25, 2022, https://www.epa.gov/ghgreporting.

- Sectors with greatest potential for emissions reductions from electrification by 2050 in Indiana:
  - Steel (24160 kt CO2)
  - Soybean oil (677 kt CO2)
  - Wet corn milling (487 kt CO2)

- Electrifying steel, recycled plastic, milk powder, container glass, soybean oil, cast aluminum, and beer production may **reduce energy costs** per unit of production.

# State Factsheet: Pennsylvania




Esri, USGS | Centre County Government, data.pa.gov, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS

This map shows the relative emissions of large industrial facilities. Facility types that are included in the full report analysis are shown in colors while other industrial facility types are shown in grey.

Built using ArcGIS online with U.S. Environmental Protection Agency's Facility Level Information on GHGs Tool (FLIGHT) 2020 data. U.S. Environmental Protection Agency, "Greenhouse Gas Reporting Program (GHGRP)," last accessed February 25, 2022, https://www.epa.gov/ghgreporting.

- Sectors with greatest potential for emissions reductions from electrification by 2050 in Pennsylvania:
  - Steel (4318 kt $CO_2$)
  - Plastic Recycling (306 kt $CO_2$)
  - Container Glass (218 kt $CO_2$)
- Access your state factsheet: https://www.renewablethermal.org/state-electrification-factsheets/

# Key Takeaways

- There is significant potential to decarbonize U.S. industry with electrification.
- Using grid electricity, $CO_2$ emissions reduction from electrification can be achieved today in some states and in more states in 2030.
- Plant-level $CO_2$ emissions reductions can be achieved today in any state through electrification projects with sufficient renewable electricity supply (e.g., through a PPA).
- Energy cost per unit of production for electrified processes is higher but can be competitive with conventional processes if low price renewable electricity is available.
- Industrial electrification provides co-benefits (air pollution reduction, health benefits, production cost reduction, O&M cost reduction, etc.).

# Recommendations

- Start electrifying in states with favorable conditions:
  - Cleaner Grids: AL, CA, GA, IL, IA, MN, NC, OR, OK, PA, WA
  - Relatively Lower Electricity Prices: CO, FL, IL, IN, MI, NC, OH, OR, PA, WA
- Initiate partnerships between government and industry to develop/scale electrification
- Six actions to support increased industrial electrification in U.S. states:
  1. Support demonstration of emerging technologies and new applications of existing technologies
  2. Financially incentivize electrification
  3. Increase renewable electricity generation capacity
  4. Enhance the electricity grid
  5. Engage communities
  6. Develop the workforce

RENEWABLE THERMAL COLLABORATIVE

# RTC Policy and Tools on Electrification

Presented by Chris Kardish

*Senior Manager of Industrial Decarbonization, C2ES*

# Some Leading Electrification Options

## Industrial Heat Pumps (IHPs)

- Transfer heat from surroundings or waste heat streams for process application's via electricity to drive mechanical compression
- Heat supplied typically greater than electricity consumed (Coefficient of Performance) but influenced by input/output temperatures
- Ideal for low temperature applications (<130°C, but degraded efficiency past 100°C)

## Thermal Energy Storage (TES)

- Capturing renewable power (and other energy sources) for conversion to heat for direct use and long-duration storage
- Storage medium can include solids (e.g., ceramic, rocks), liquids, and solid-to-liquid (phase change), and others
- Temperatures up to 1,500°C (potentially higher with graphite as storage medium)

## Electrical resistance technologies

- Uses electric current to provide heating due to a material's electrical resistivity
- Common types of equipment: ovens, furnaces, boilers
- High efficiency but generally tops out at 99%
- Lacks efficiency of IHPs and ability capture lowest-cost grid electricity like thermal storage but allows facilities to continue steam-based processes (e.g., electric boiler)


Air source heat pump[2]


Water source heat pump[3]


Absorption heat pump[4]

Source: RTC Vision Report


Source: Canary Media


Electric ovens[4]


Electric furnaces[5]


Electric boilers[6]

Source: RTC Vision Report

# IRA Good on Green Electricity (Less on Electrification)

- Inflation Reduction Act's (IRA) long-term extensions of clean electricity investment and production credits will accelerate greening of grid

- Little to incentivize electrification of industrial end uses
  - Sec. 48 ITC not applicable to many electrification technologies
  - Sec. 45X not applicable to IHPs (and possibly TES)
  - Limited applicability to TES in Sec. 48 ITC
  - But some potential to boost heat pump manufacturing through DPA

- Opportunities through 48C Advanced Manufacturing Credit and Advanced Industrial Facilities Deployment Program limited in funding (and competitive)

# State-Level Somewhat Mirrors Federal

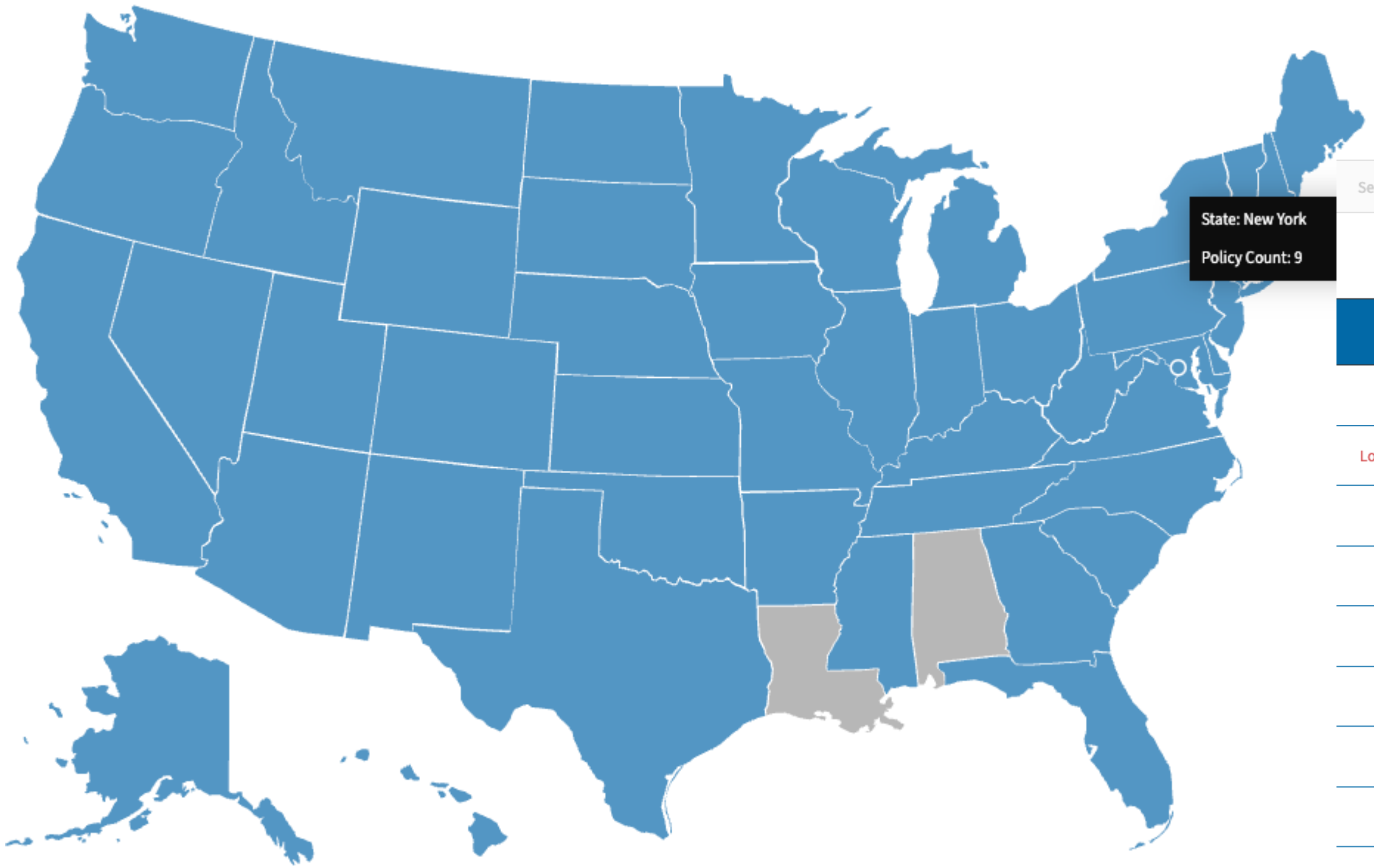
- Policies directly targeting industrial end-use electrification still relatively uncommon
- Often support on-site deployment of renewables rather than end-use electrification
- State governments more constrained in level of financial support they can provide
- Tax incentives usually targeted at areas within state/local purview
  - Property tax deductions/exemptions and sales and use tax exemptions on relevant equipment

# RTC Policy Finder

Technology

Policy Type

Search...



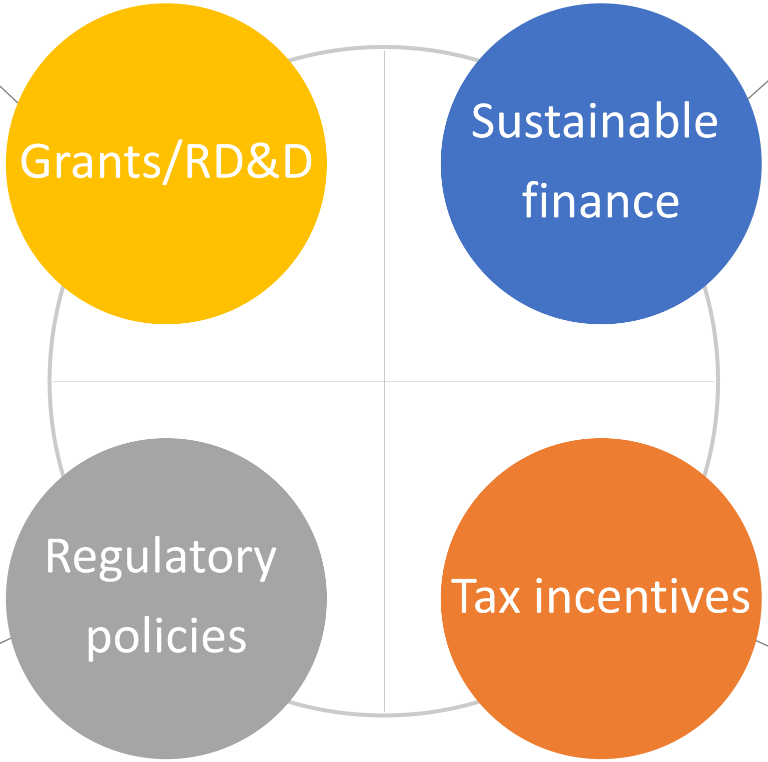

Search...

SEARCH

Filter

| Policy | State | Policy Type | # of relevant technologies |
|---|---|---|---|
| NY-SUN Commercial Solar Incentives and Financing | New York | Grant, Sustainable Finance | 2 |
| Local Option – Solar, Wind & Biomass Energy Systems Exemption | New York | Tax Incentive | 4 |
| Retail Energy Storage Incentive Program | New York | Tax Incentive | 1 |
| Bulk Energy Storage Incentive Program | New York | Tax Incentive | 1 |
| Clean Energy Fund > Market Development Portfolio | New York | Grant | 9 |
| Clean Energy Fund > Innovation & Research | New York | Grant, RD&D | 9 |
| NYS Clean Heat Program | New York | Tax Incentive | 2 |
| Commercial and Industrial Carbon Challenge | New York | Grant | 9 |
| Clean Energy Fund > NY Green Bank | New York | Sustainable Finance | 9 |

# State Support Across Regions and Policy Types




- Many grants that directly support deployment but often limited
- Some that directly target industrial end use: NY Commercial and Industrial Carbon Challenge, Efficiency Maine Commercial and Industrial Custom Thermal Projects, CO Clean Air Program
- Often more focused on RD&D of novel technologies (e.g., CA Climate Innovation Program, AK Energy Technology Fund, WA Clean Energy Fund, ND Clean Sustainable Energy Fund)

- Some green banks, including NY, DC, CT
- Clean energy funds that aim to provide bridge finance: CO Clean Energy Fund, ME Clean Energy Accelerator, NY Clean Energy Fund
- Loans and bonds for electrification-related investments: Energize DE Green Bond, ID State Energy Loan Program, IA Energy Infrastructure Revolving Loan Program, MI Energy Efficiency and RE Revolving Fund

- Largely portfolio standards, which indirectly support electrification of industrial end uses
- Occasionally carbon pricing and similar measures (e.g., CA, WA, OR)

- Property tax exemptions or abatement for installation: AZ, FL, MI, OR, WI
- Sales/use tax exemptions or reimbursements: CA, CT, FL, RI, SD
- Less frequently, credits (e.g., income, corporate): AZ, FL, NM, UT

# Exploring Policies to Support Electrification

- Expanding tax incentives federally to build domestic supply chains of technologies and boost deployment (e.g., 45X, 48 ITC, and beyond)
- Funding demonstrations to de-risk deployment and spread knowledge
- Addressing market access barriers for TES through FERC and/or RTOs/ISOs
- Expanding and enhancing performance-based ratemaking for utilities to encourage more nuanced pricing structures
- Creating and expanding support on workforce development for key electrification technologies (e.g., IHPs)

# RTC Resources

**Convenings:**

Annual Summit (Oct 19-20, 2023 - Washington, DC):
https://www.renewablethermal.org/rtc-summit/

Monthly Community Calls: Second Tuesday, 11a-12p ET

Working Groups:

- Electrification, Green Hydrogen, RNG, Solar Thermal
- Greenhouse Gas Accounting and Claims
- Policy

**Tools:**

Policy Finder:
https://www.renewablethermal.org/policy-finder/

Partner Locator:
https://www.renewablethermal.org/partner/

Heat Pump Decision Support Tools:
https://www.renewablethermal.org/heat-pump-decision-support-tools/

Electrification Road Map (update pending):
https://www.renewablethermal.org/electrification-road-map/

**Publications:**

Renewable Thermal Vision:
https://www.renewablethermal.org/vision/

Case Studies:
https://www.renewablethermal.org/category/publications/case-studies/

Industrial Electrification:
https://www.renewablethermal.org/state-electrification-report/

Green Hydrogen Technology Assessment:
https://www.renewablethermal.org/gh2-tech-assessment/

**Communications:**

Monthly newsletter:
https://www.renewablethermal.org/contact-us/

LinkedIn and Twitter