Paper

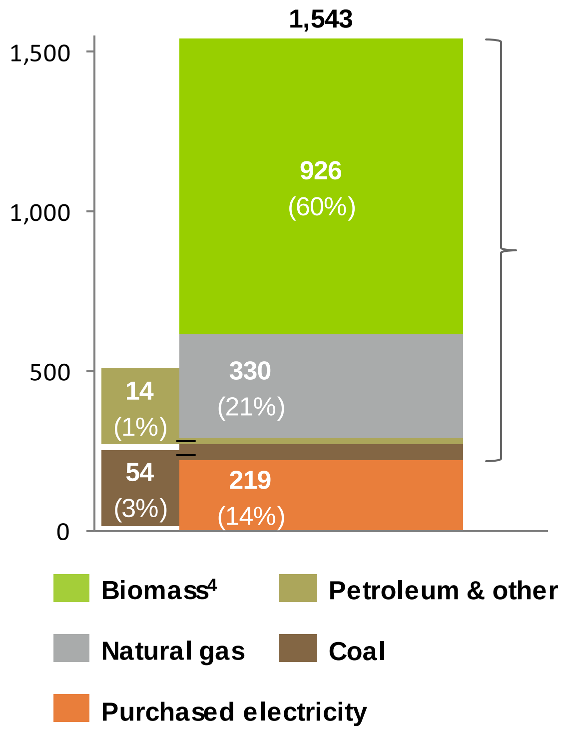
Sector Perspectives

RENEWABLE THERMAL COLLABORATIVE

60% of thermal energy is from combustion of biofuels, which produces unrecorded biogenic emissions of over 100 million tonnes of CO2e annually

Total energy consumption (2018)[1]

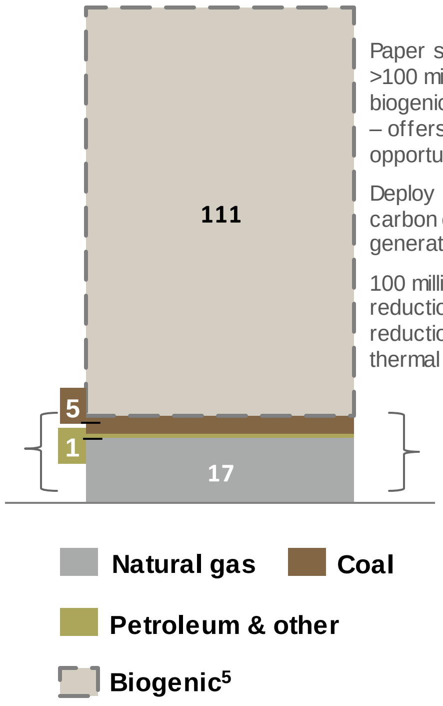
Trillion Btu



Thermal emissions (2018)[2]

Million Tonnes of CO2e

24 (fossil) + 111 (biogenic) = **135 total**



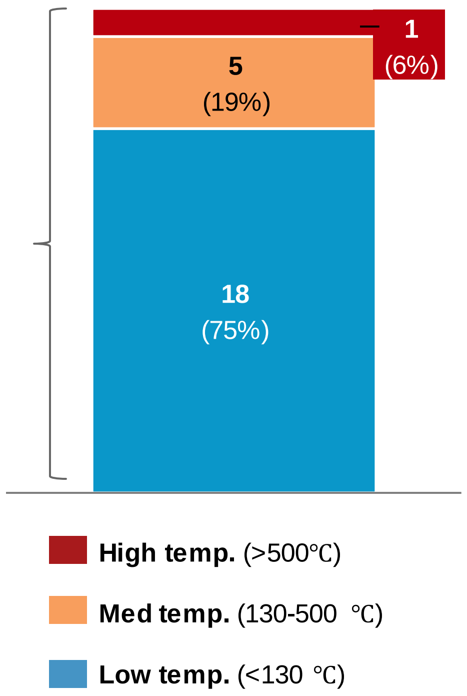
Paper sector generates >100 million tonnes of biogenic emissions annually – offers sizeable abatement opportunity:

Deploy BECCS using IRA carbon capture credits and generate negative emissions

100 million tonne emissions reduction equates to a ~15% reduction in US industrial thermal emissions

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

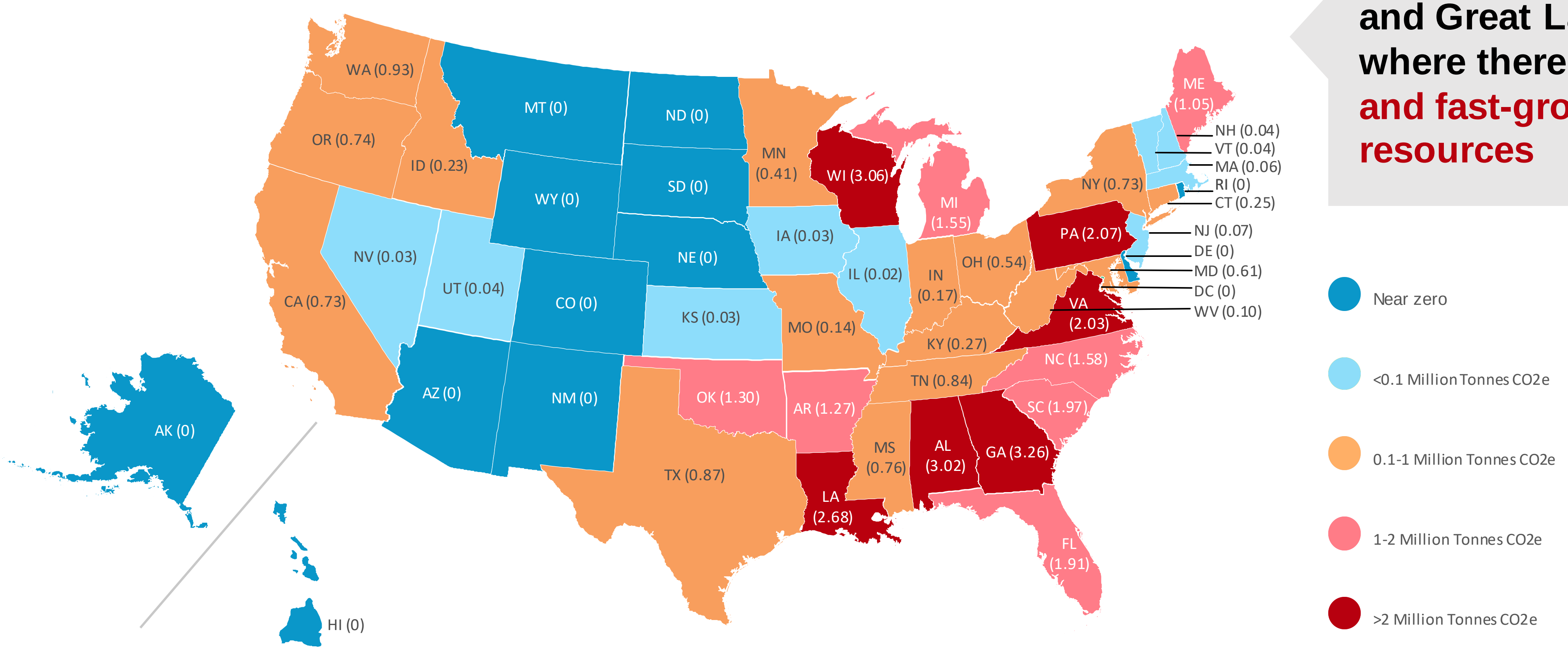
Million Tonnes of CO2e



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) 4. Biomass emissions are considered net zero by EPA and related biogenic emissions are not recorded in EPA thermal emissions data 5. Total paper sector biogenic CO2e emissions exceed 111 million tonnes in 2018 with the top 50 facilities generating ~75 million tonnes of biogenic CO2e; biogenic emissions primarily result from combustion of woody biomass and black liquor Source: EIA; EPA; NREL; BCG analysis

Thermal emissions are concentrated in the Southeast and Great Lakes

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



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

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)

Key heat applications require low & medium temperatures and can be electrified; several processes are already electrified at some facilities

Wood Processing

200 ºC

The paper making process usually begins with **wood processing**, which involves the de-barking and chipping of wood (e.g. whole trees, short wood, wood chips, woody biomass) to produce wood chips that can be used in pulp production.

Evaporation & Chemical Preparation

60-200 ºC

Processed woodchips are cooked in a **pressurized digester** to break down lignin and produce pulp. The chips are heated under pressure along with white liquor (strong alkaline solution composed of NaOH and Na2S). The resultant pulp is called brown liquor and the byproduct is called black liquor.

Bleaching

60-150 ºC

The chemically processed pulp is often **bleached** in order to lighten its color. The major bleaching agents used in paper mills today include chlorine dioxide, oxygen, hydrogen peroxide, and ozone. Steam from boilers is used in the bleaching process to add heat to the pulp.

Stock Steaming Preparation

60-150 ºC

After bleaching, pulp is fed into a **stock machine**, in which the pulp's fibers are blended, refined, diluted, and metered. Various fillers are also added for purposes such as whitening, strength, and opacity.

Drying

70-150 ºC

The **drying process** typically involves refined and pressed pulp sheets being winded over heated steam cans, causing most of the moisture to evaporate. This is the second most energy-intensive process in papermaking, after chemical preparation.

Re-causticizing

800-1200 ºC

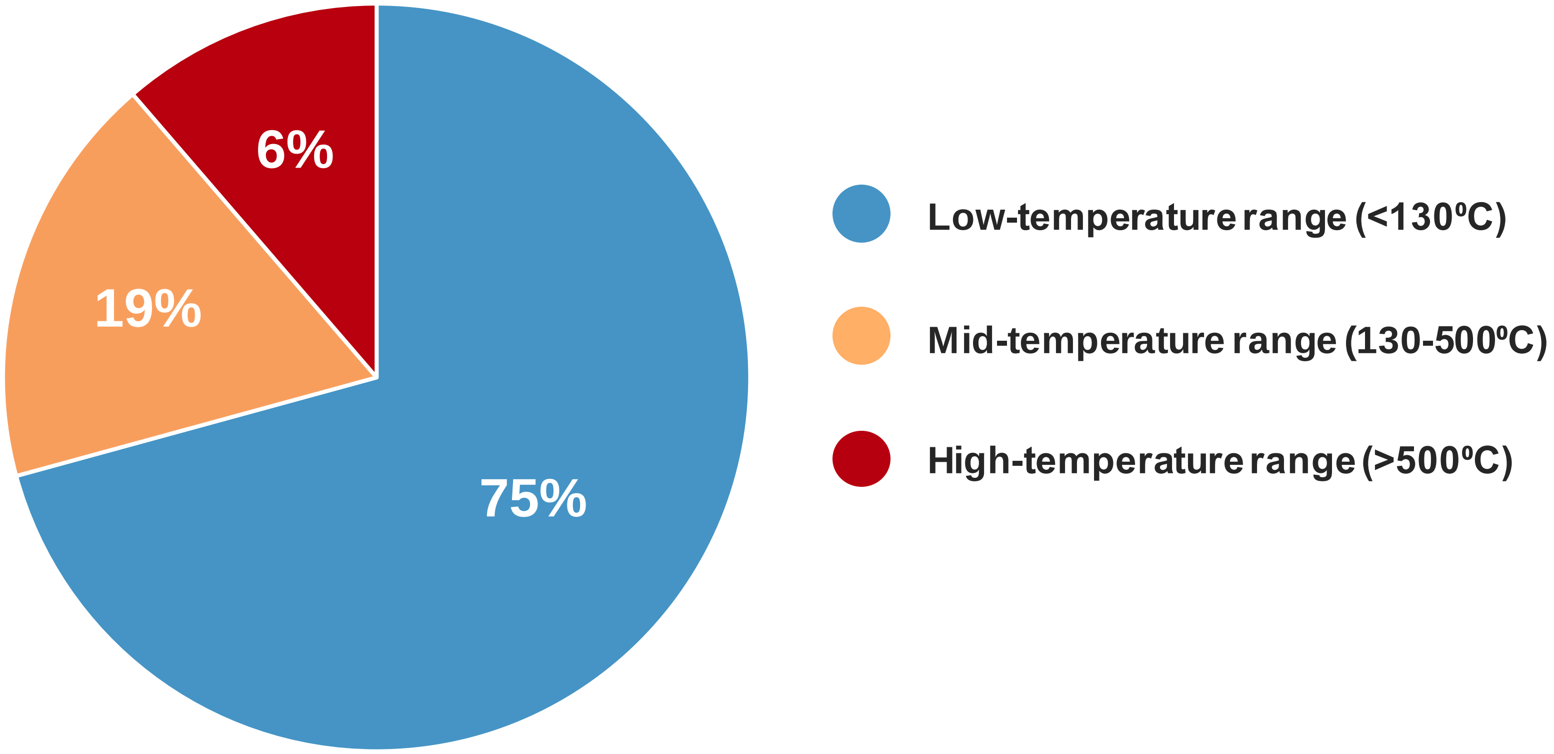
In order to optimize the efficiency of the chemical digestion process, recovery boilers and lime kilns are used to convert green liquor (sodium carbonate) to white liquor (sodium hydroxide), which is used for chemical digestion. This process is known as **re-causticizing**.

Low-temperature heat processes are well suited for electrification, solar thermal, biomass

Source: DOE (2022), industry reports and papers, BCG analysis

~94% of thermal energy consumption occurs in the low- and medium-temperature ranges

Thermal energy consumption (TBtu) by heat temperature range (ºC)[1]

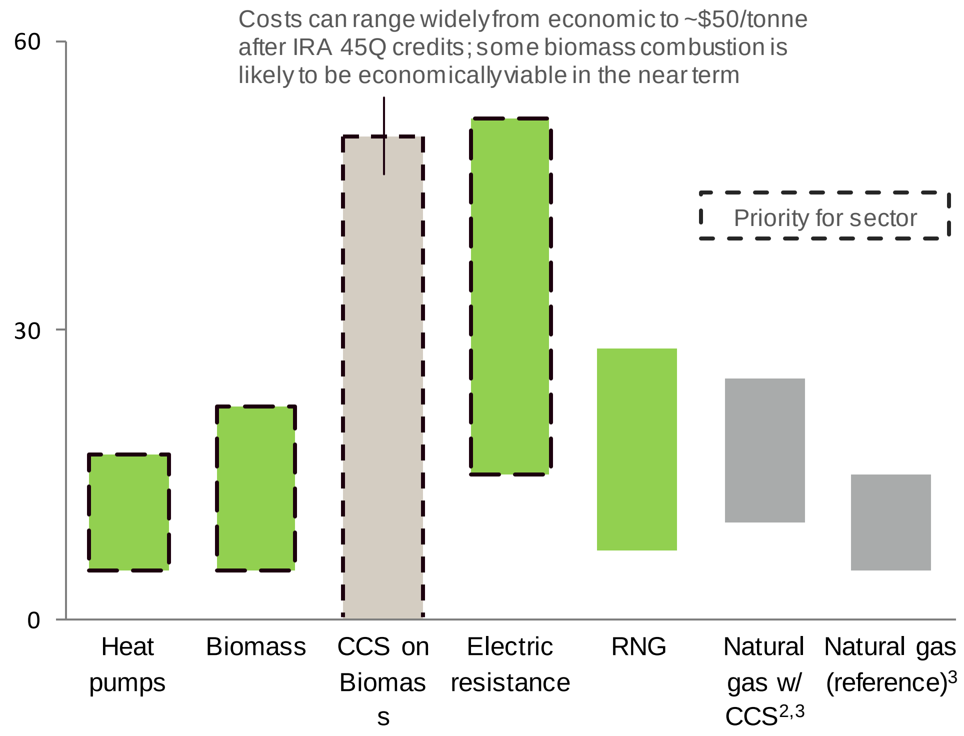


1. NREL Manufacturing Thermal Energy Use in 2014
Source: DOE (2022), industry reports and papers, BCG analysis

Biomass and heat pumps are the most economic renewable fuel alternatives to natural gas in the short, medium and long term

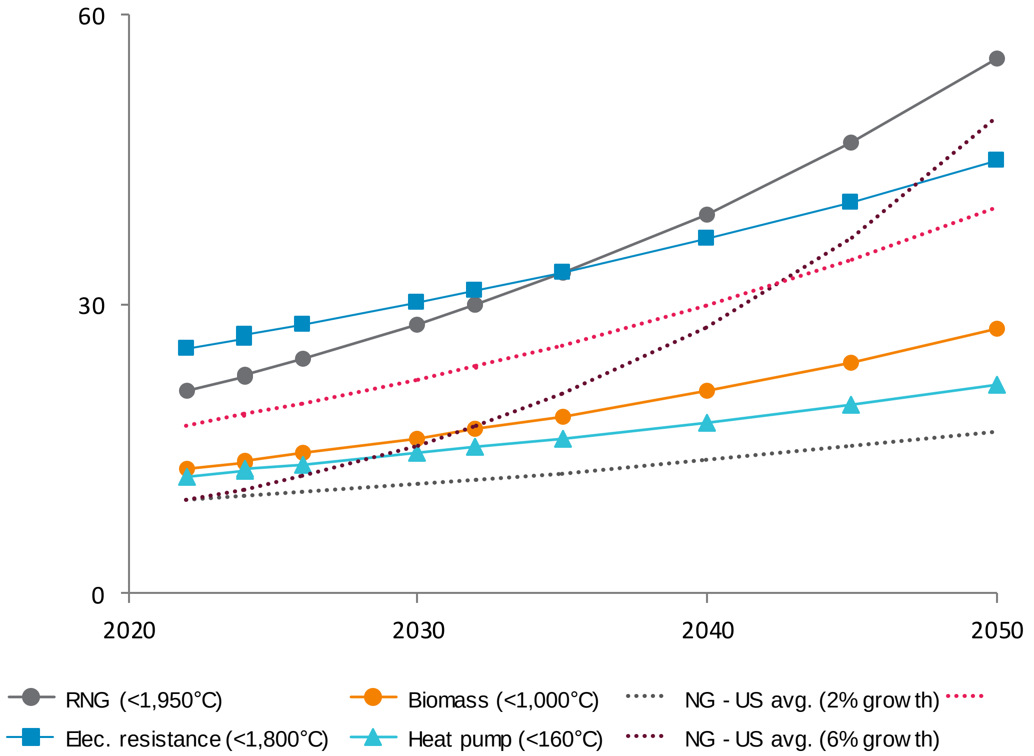
2022 LCOH for relevant technologies[1]

($/MMBtu)



Projected LCOH for relevant technologies[1]

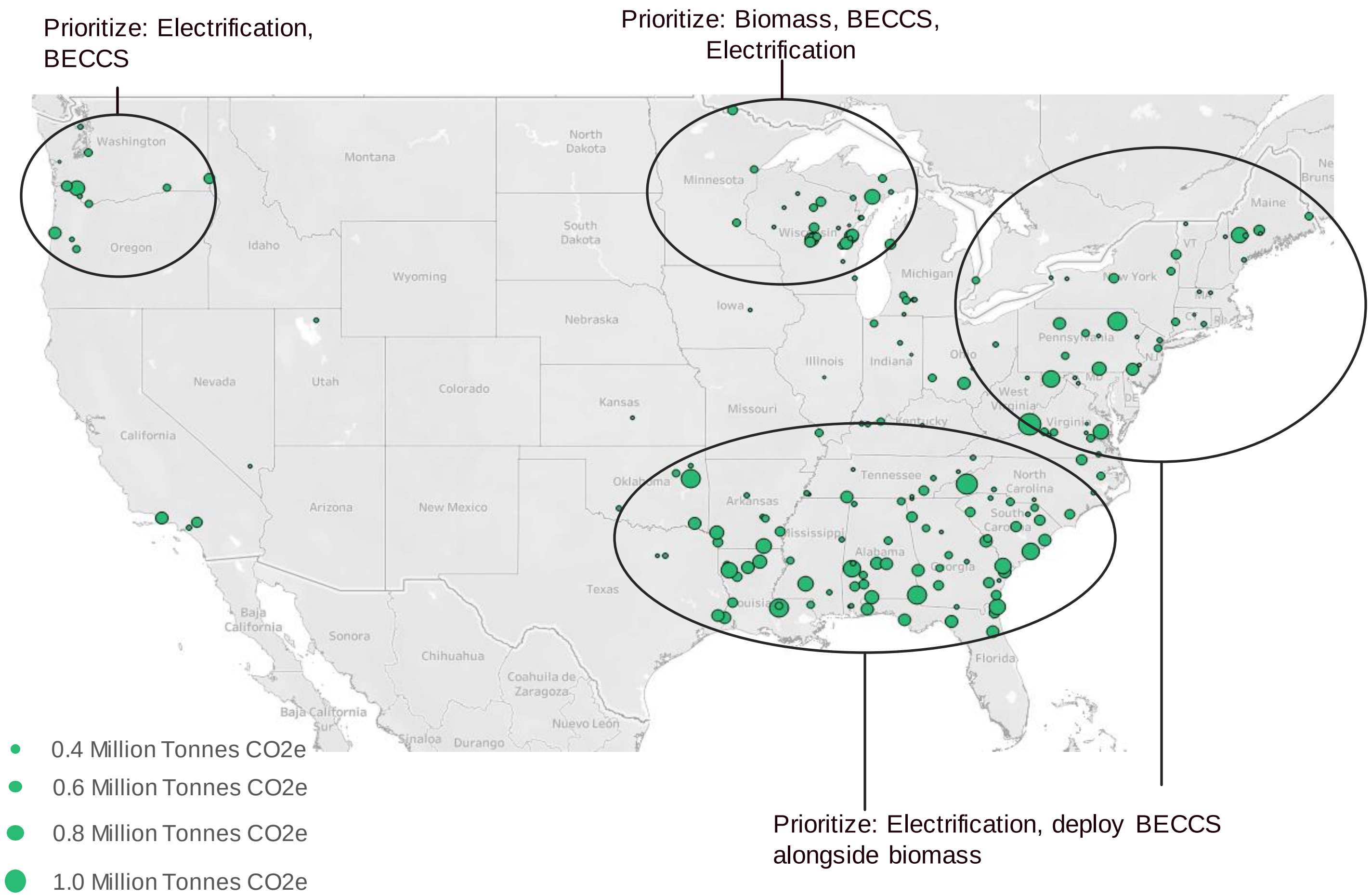
Average US LCOH ($/MMBtu)

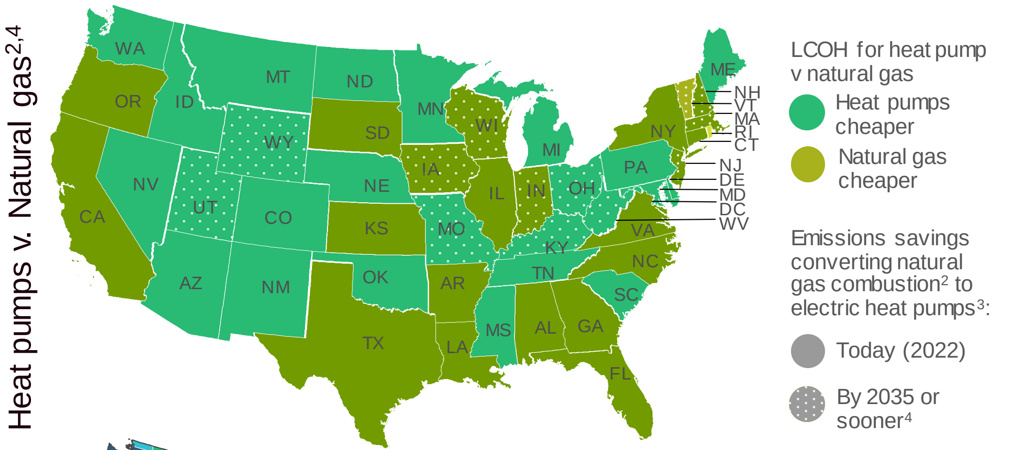


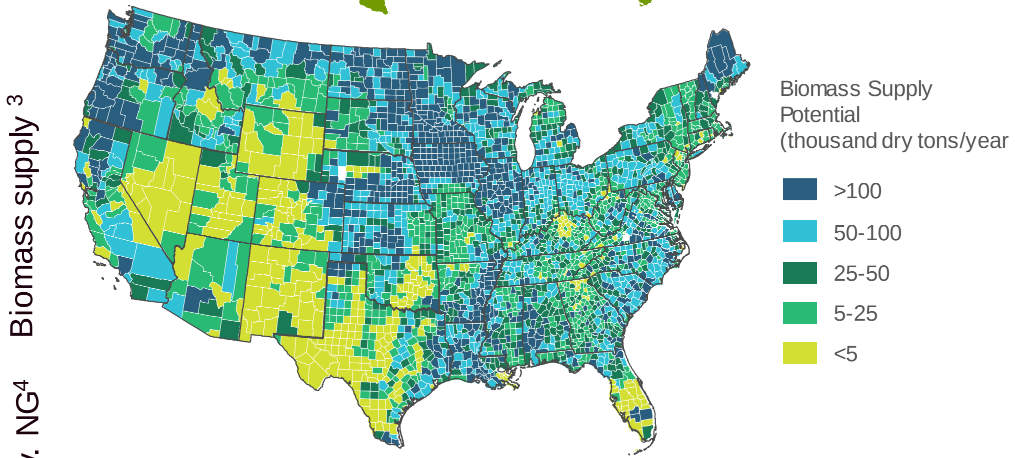
1. LCOH compares project lifetime costs against lifetime energy produced; costs include capital expense of equipment, fuel costs, and maintenance expense assumptions over the usable life of the energy asset. Electricity and natural gas pricing is based on national weighted average wholesale industrial end user electricity and natural gas prices for the past 1 year as of June 2022 industrial electricity modeled to grow at 2% per year. Electric heat pumps, electric resistive, and natural gas heating efficiencies modeled at 300%, 99%, 75%, respectively. Includes Inflation Reduction Act incentives 2. Combined with natural gas combustion; includes $85/tonne 45Q tax credits from IRA 3. Uses weighted average US natural gas price for the past twelve months as of June 2022 (excludes Hawaii); assumes 75% combustion efficiency Source: EIA; EPA; Inflation Reduction Act; BCG analysis

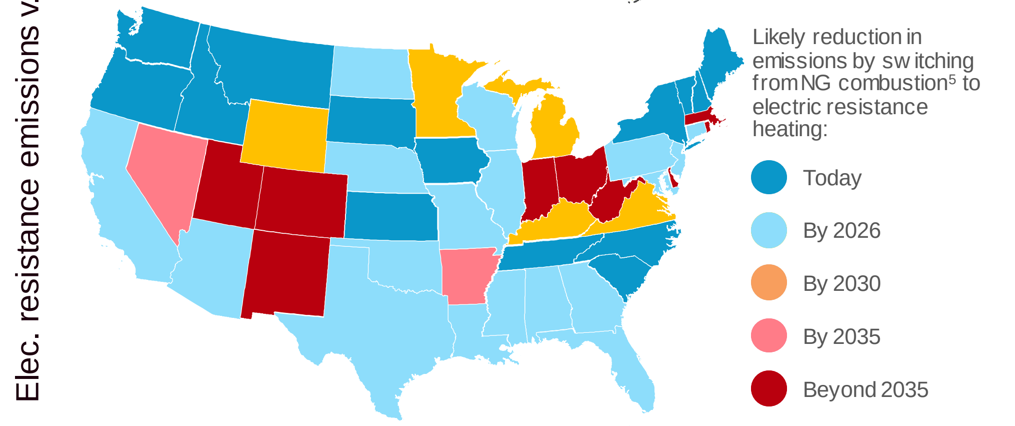
Heat pumps appear cost effective and reduce emissions in ~45 states today

US Paper Sector thermal emissions by zip code[1]









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. NREL Biofuels Atlas 4. US EPA GHGRP (2019); US EIA; State Renewable Portfolio Standards; IEA ETSAP Industrial Combustion Boilers Fact Sheet; BCG analysis 5. Calculated using 85% efficiency for natural gas boiler 6. Calculated using a conservative COP of 3

Decarbonization pathways

Coal & Petroleum
Displace at accelerated pace

Natural Gas
Displace with renewable fuels

Electrification
Deploy heat pumps <130ºC; expand to ~200ºC by 2030+; deploy electric resistance where feasible

Biomass
Continue to use as fuel; increase efficiency of use; deploy CCS against biogenic emissions

Electric Resistance + Thermal Storage
Deploy as/where inexpensive intermittent renewable electricity is available

CCS on Biogenic Emissions
Capture biogenic emissions from combustion of biomass and black liquor

2022 → 2050

	Considerations	Target First Movers
Electrification	State electricity grid emissions intensity for elec. resistance	States with inexpensive electricity, or high NG price
Biomass	Availability and sustainability of wood waste and byproducts	Current pulp and paper manufacturers
Electric Resistance + Thermal Storage	Grid or PPA supports emissions savings, viable economics	Ability to procure inexpensive intermittent electricity
CCS on Biogenic Emissions	Potential to produce 100 million tons of negative emissions (annually)	Regions with paper clusters and adequate geology for storage or location for transport of carbon

Biomass combustion constitutes the majority of thermal energy with the remainder fueled by natural gas and petroleum — **fossil fuels can be displaced with electrification and increased use of waste biomass**

Combustion of biomass and black liquor appears to generate biogenic emissions of **100+ million tonnes** of CO2e annually – CCS should be evaluated across the sector to identify economically viable opportunities for BECCS to create negative emissions (using IRA 48Q tax credits of $85/tonne)

Thermal decarbonization pathways

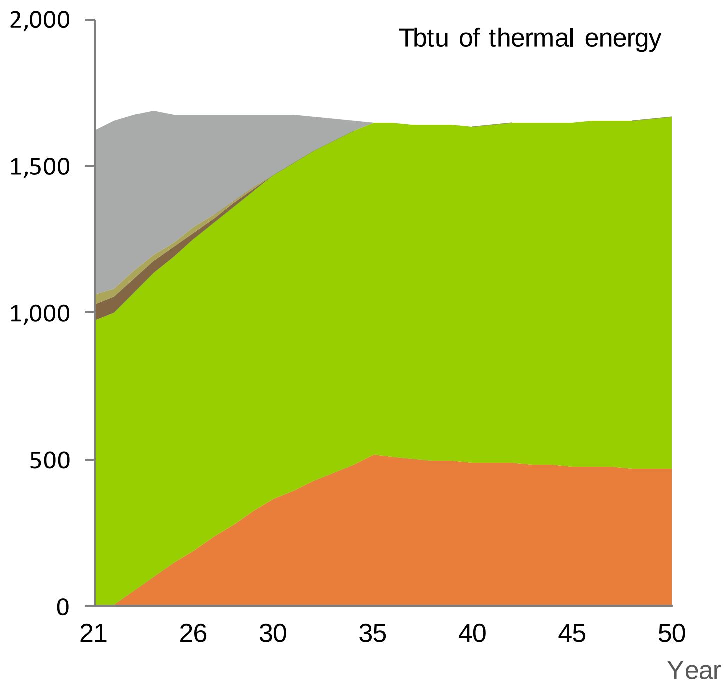
94% of industrial heat is in low (75%) and medium (19%) temperature ranges, which can be **decarbonized on an accelerated timeline** with electrification and heat pumps

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

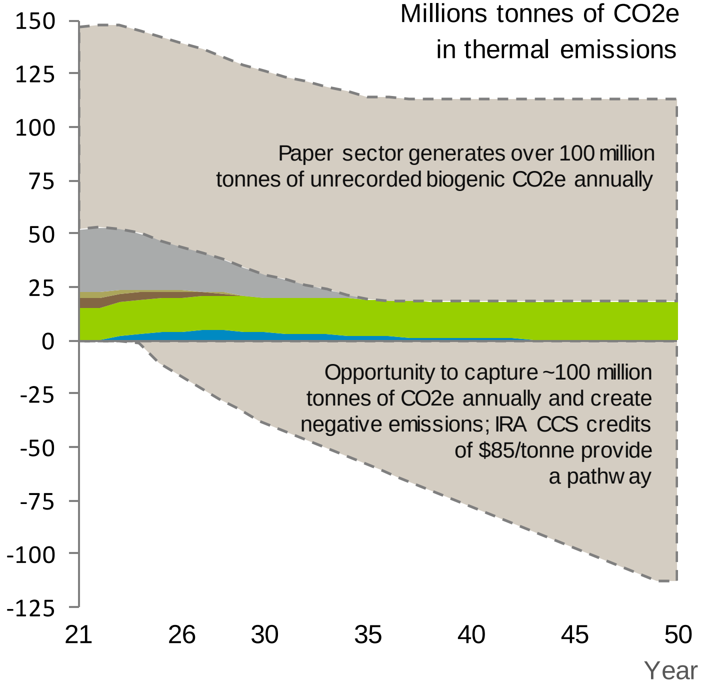
The sector generated 111 million tonnes of biogenic CO2e3,4 in 2018 primarily due to combustion; while these emissions are unreported, there is an opportunity for the sector to capture this carbon, which would equate to a ~15% reduction in total industrial thermal emissions.

Bio-energy with carbon capture and sequestration (BECCS) should be evaluated and deployed using the Inflation Reduction Act carbon capture credits of $85/tonne of carbon; these credits may allow a portion of the total biogenic emissions to be captured cost effectively today. Given mid-long term cost efficiencies in CCS technology, these biogenic emissions could become "n the money"

Thermal energy consumption[1]



Thermal emissions[2]



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

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