# Chemicals

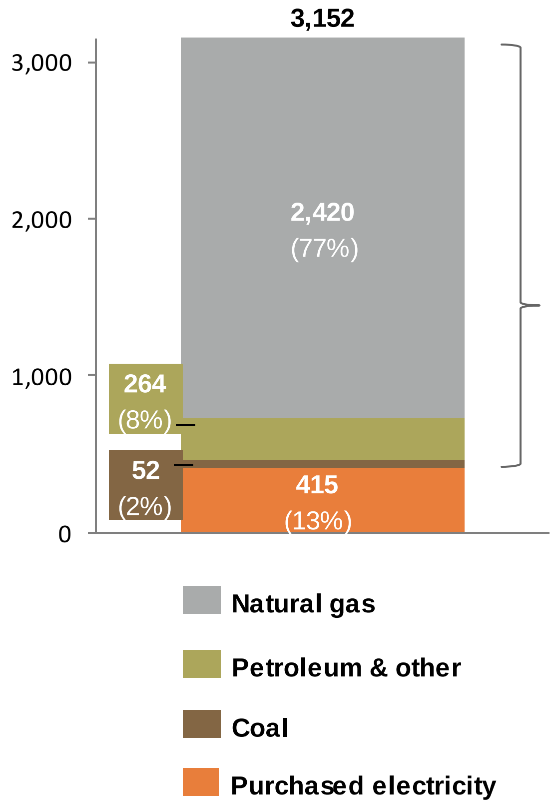
Sector Perspectives

RENEWABLE
THERMAL
COLLABORATIVE

# 77% of energy consumption is driven by natural gas and 74% of thermal emissions are produced at low and medium temperatures

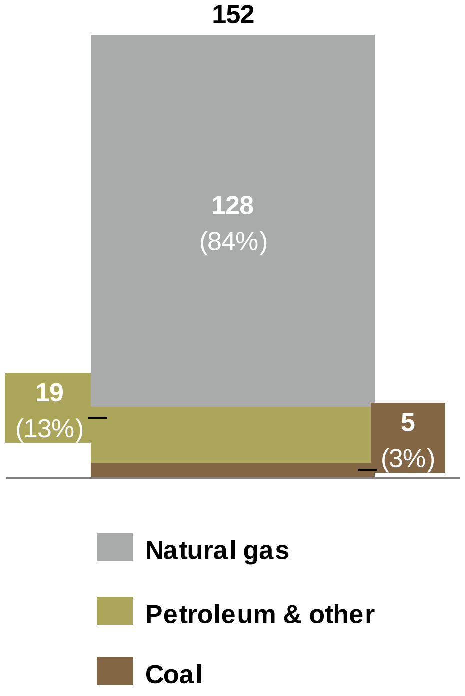
## Total energy consumption (2018)[1]

Trillion Btu



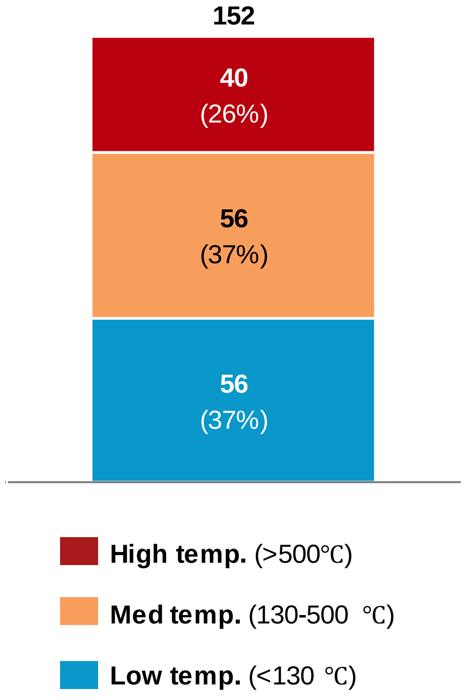

## Thermal emissions (2018)[2]

Million Tonnes of CO2e




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

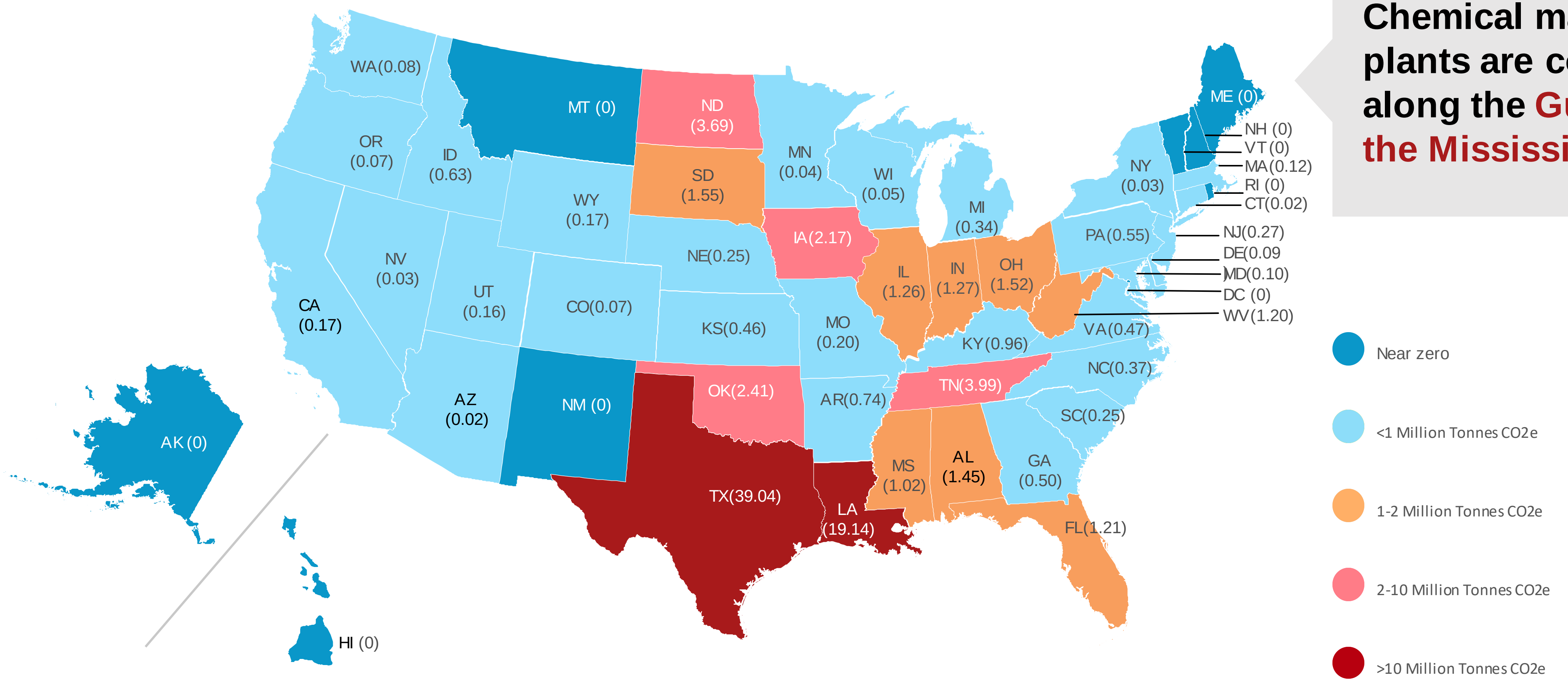
Million Tonnes of CO2e




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) 4. Primarily process byproducts that are combusted as fuels Source: EIA; EPA; NREL; BCG analysis

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

## Chemicals thermal emissions by state (Million Tonnes of $CO_2e$)[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

# ~51% of thermal energy consumption occurs in the distillation and drying temperature ranges; ~26% occurs in the reactor temperature range


## Drying | ~150-200 ºC

**Drying** is used to stabilize solid materials, preventing ice formation, removing unnecessary liquid volume, removing toxic residuals, or creating solid textures. Various dryers are used to remove water from liquids, solids, and gases.

## Distillation | ~100-300 ºC

The **distillation** process separates components of the mixture after the chemical reaction. Heat is applied to separate the various components of the mixture through liquid and vapor phase changes.

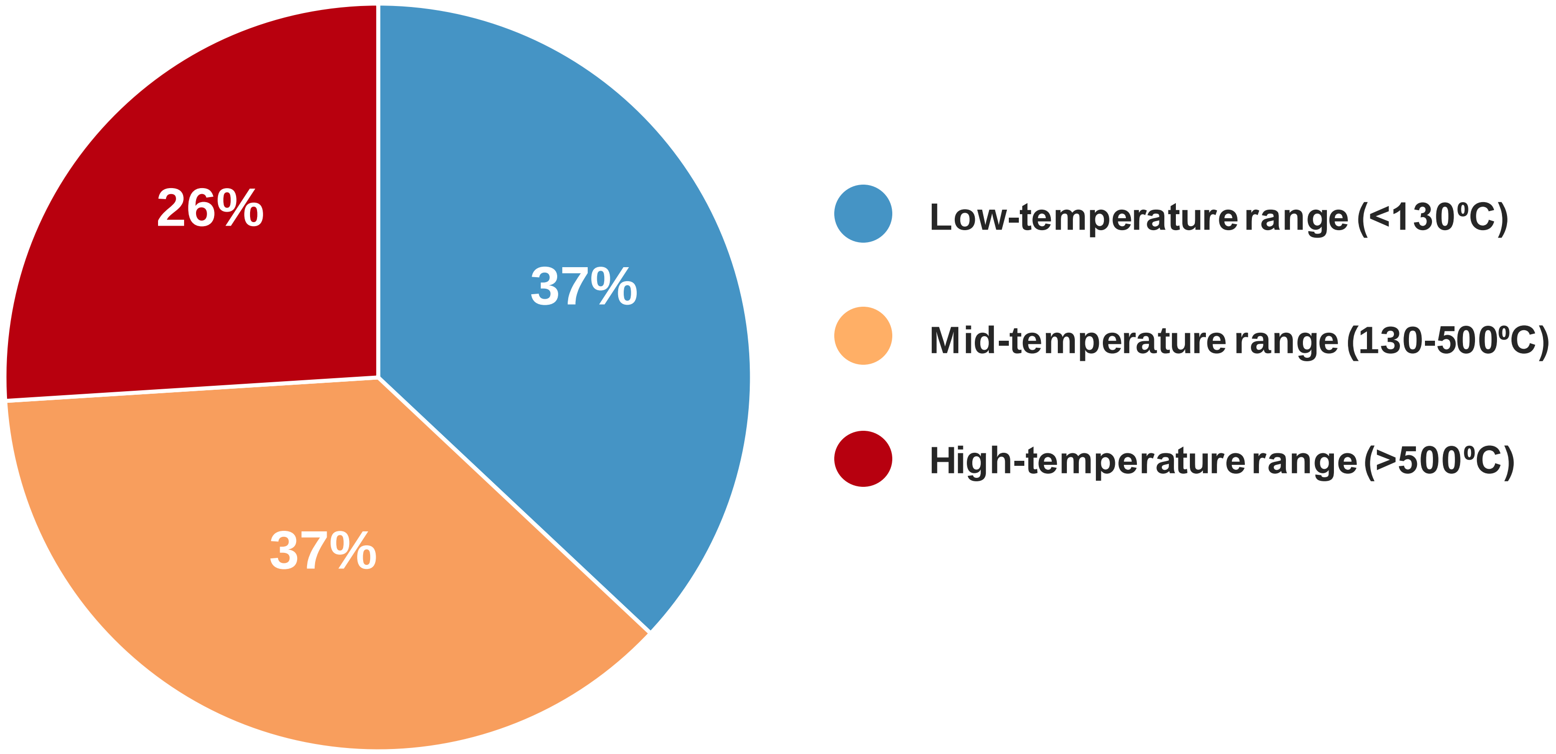
## Reactors | ~500-900 ºC

Chemical products are produced using **reactors** (e.g. steam crackers), which mix reactants using agitation, temperature changes, and pressure changes. Reactors can operate in batches or continuously and can be exothermic or endothermic.

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

**74% of thermal** emissions are produced at low and medium temperatures

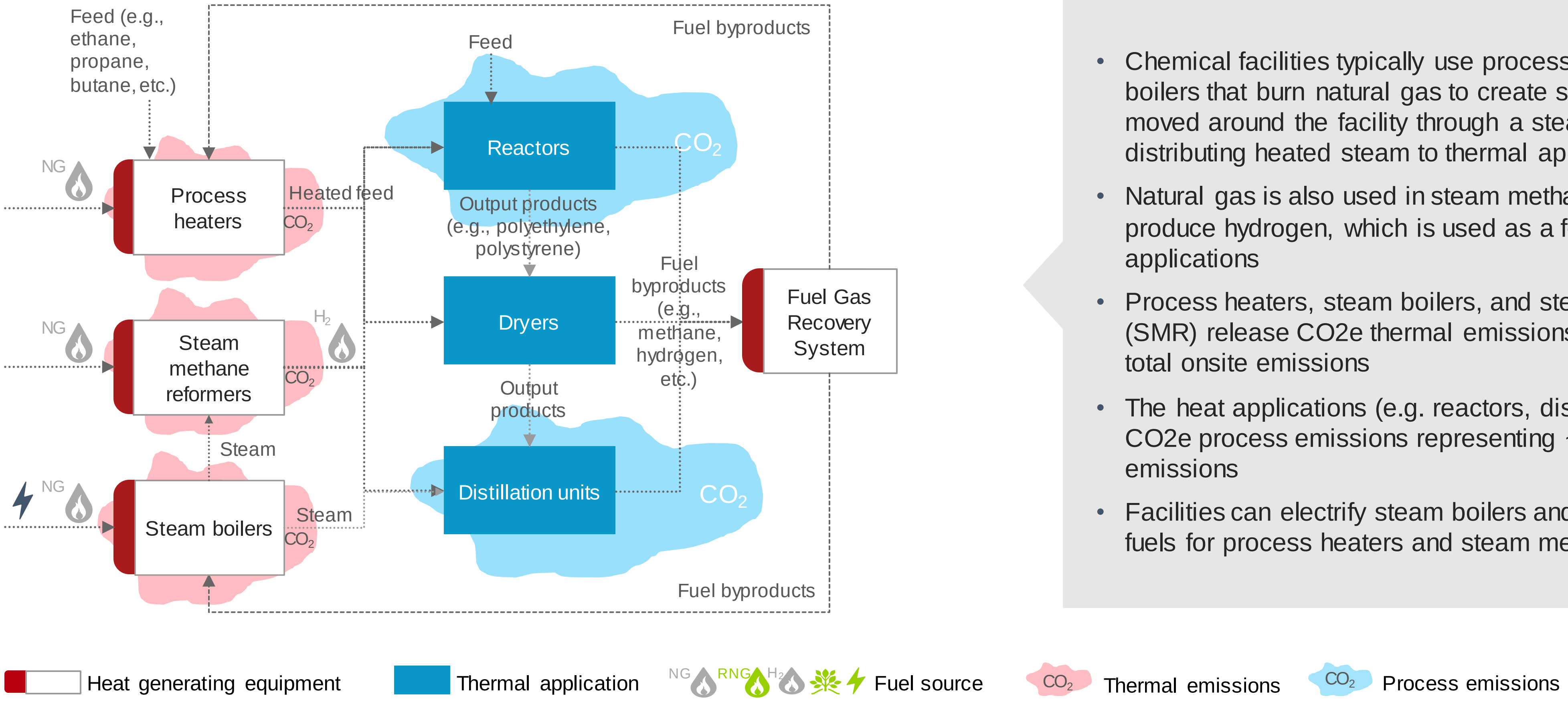
## Thermal energy consumption (TBtu) by heat temperature range (ºC)[1]




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

# Plants typically use natural gas to generate steam heat, which is distributed through steam networks to thermal applications

## Typical chemical plant processes today

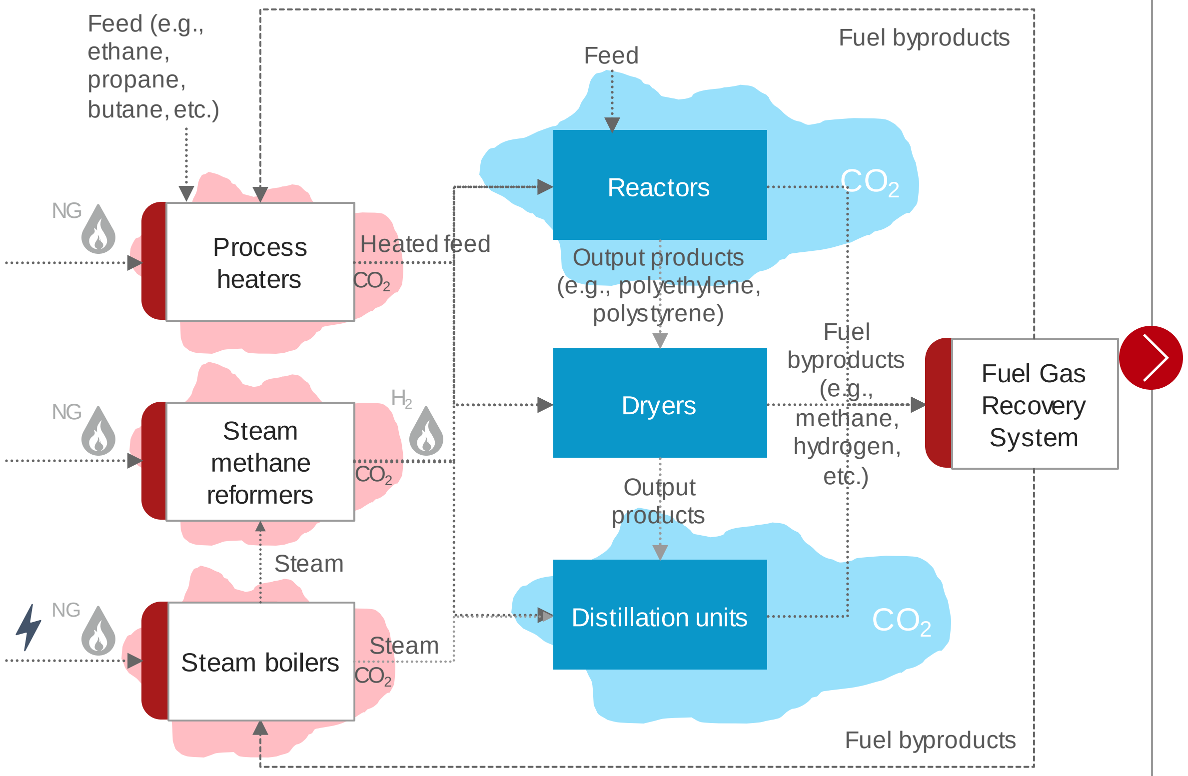



- Chemical facilities typically use process heaters and steam boilers that burn natural gas to create steam heat, which is moved around the facility through a steam network system distributing heated steam to thermal applications
- Natural gas is also used in steam methane reformers to produce hydrogen, which is used as a feedstock in thermal applications
- Process heaters, steam boilers, and steam methane reformers (SMR) release CO2e thermal emissions representing ~45% of total onsite emissions
- The heat applications (e.g. reactors, distillation units) release CO2e process emissions representing ~55% of total onsite emissions
- Facilities can electrify steam boilers and switch to low carbon fuels for process heaters and steam methane reformers

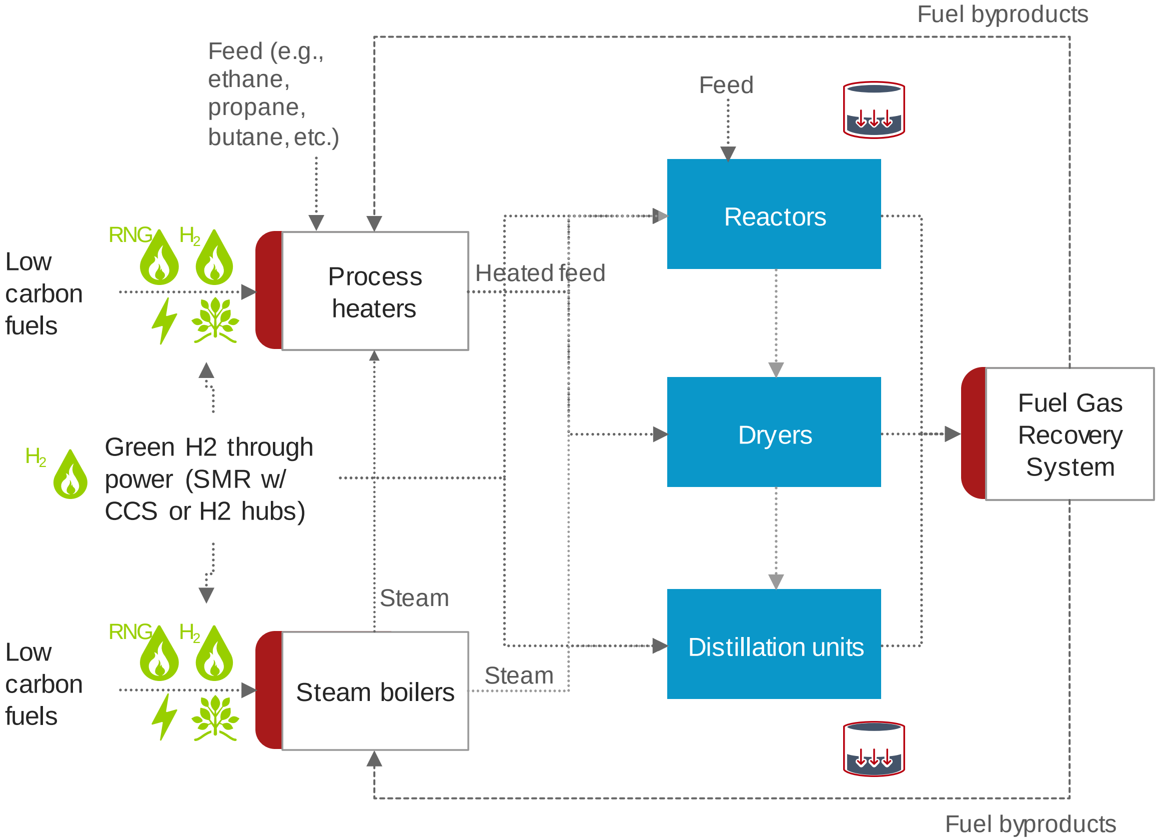
Source: DOE (2022), industry reports and papers, BCG analysis

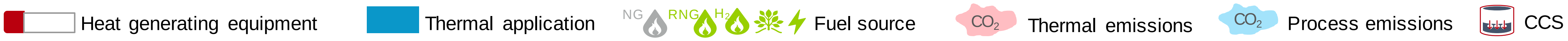
# Electrification and low carbon fuels can reduce thermal emissions; CCS is likely needed to capture the larger process emissions

## Typical chemical plant processes today




## Chemical plant with renewable thermal + CCS



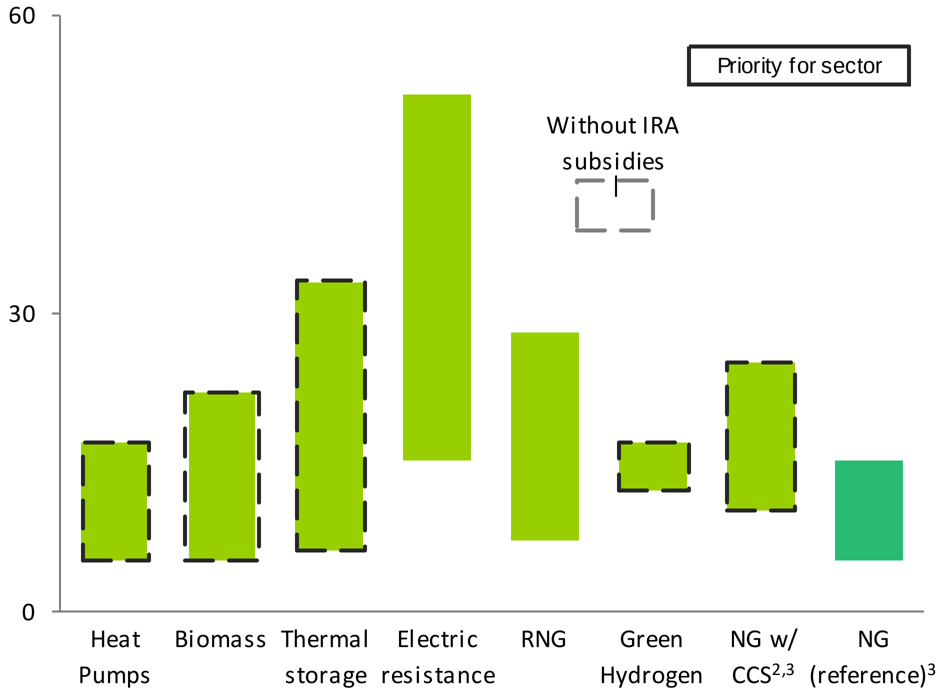




Source: DOE (2022), industry reports and papers, BCG analysis

# Heat pumps, biomass and green H2 are most economic renewable fuel alternatives to natural gas, and have lower cost of heat than NG w/ CCS

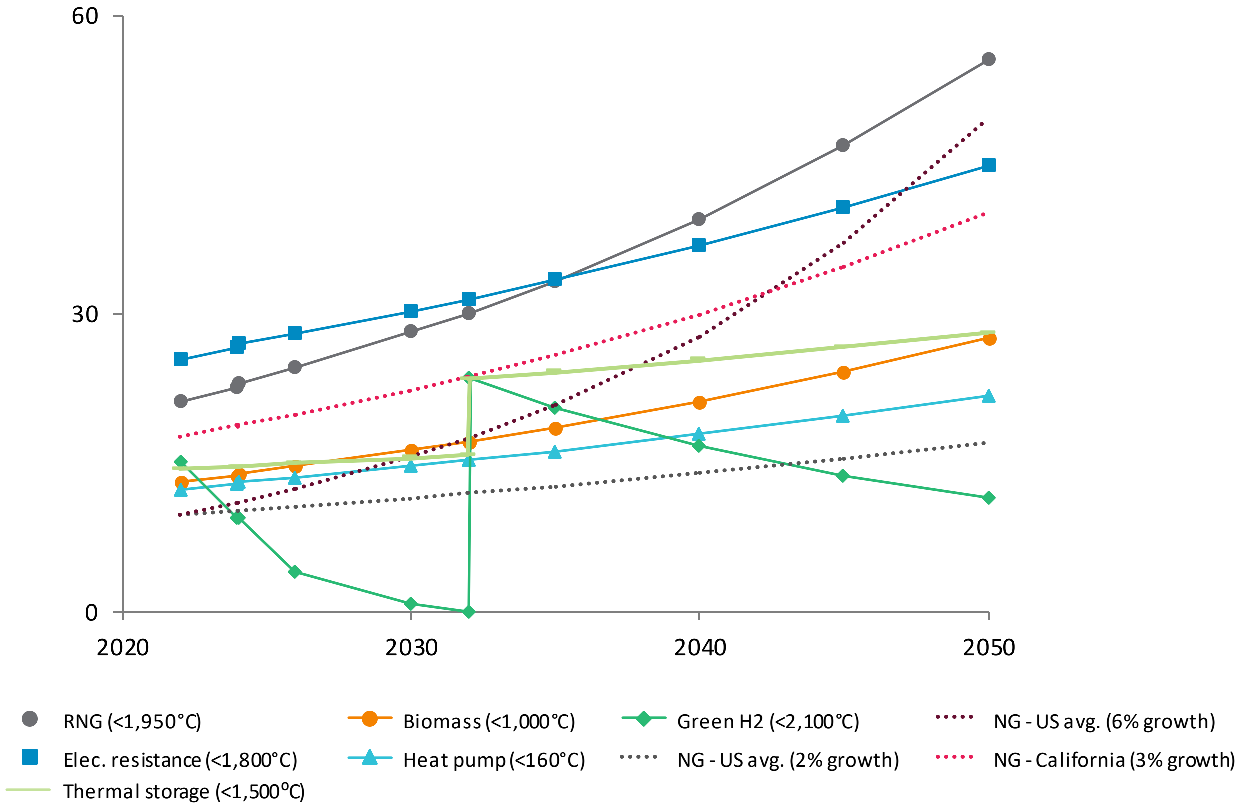
## 2022 LCOH for relevant technologies[1]

($/MMBtu)
($/MMBtu)




## Projected LCOH for relevant technologies[1]

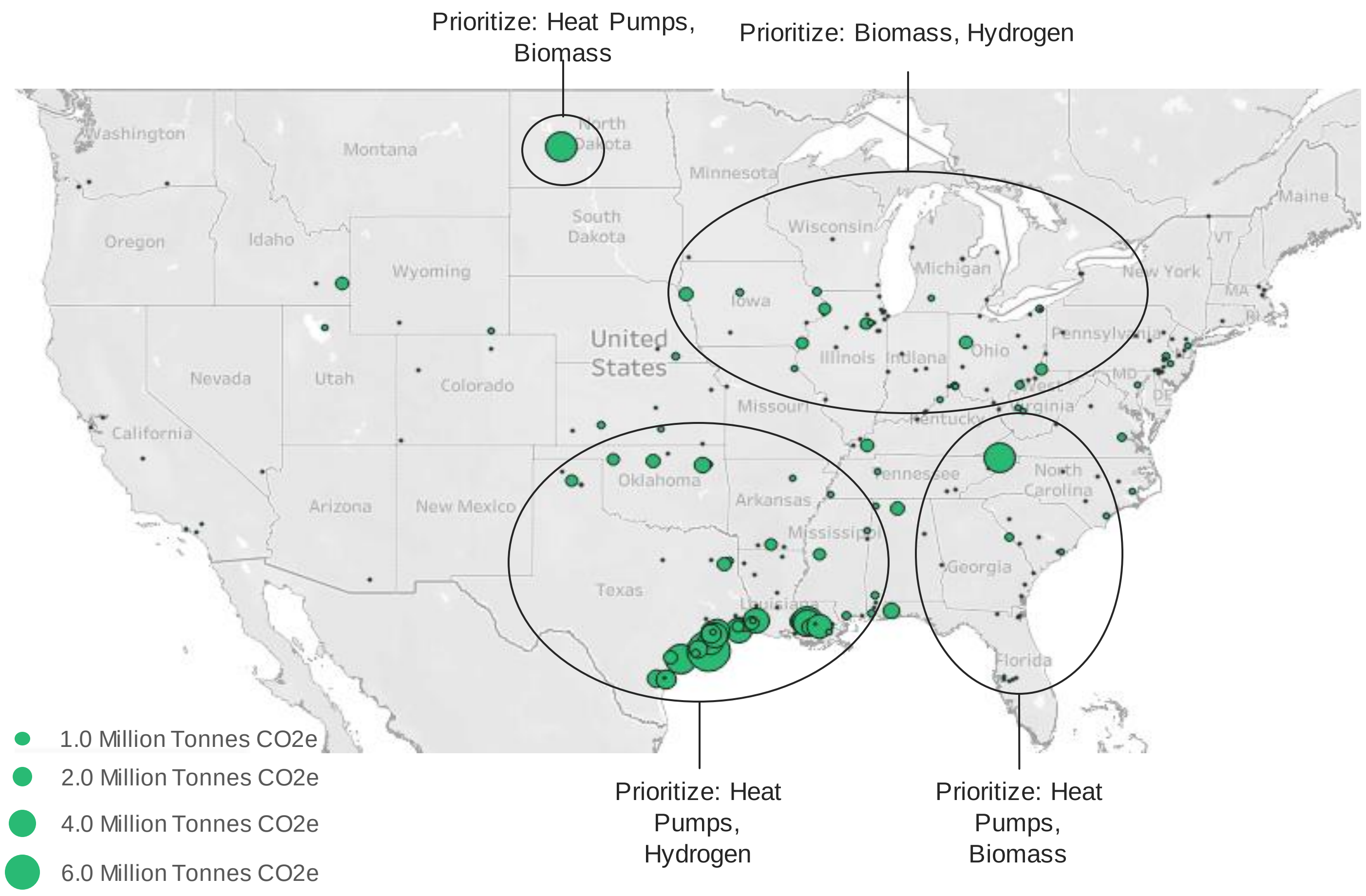
Average US LCOH ($/MMBtu)

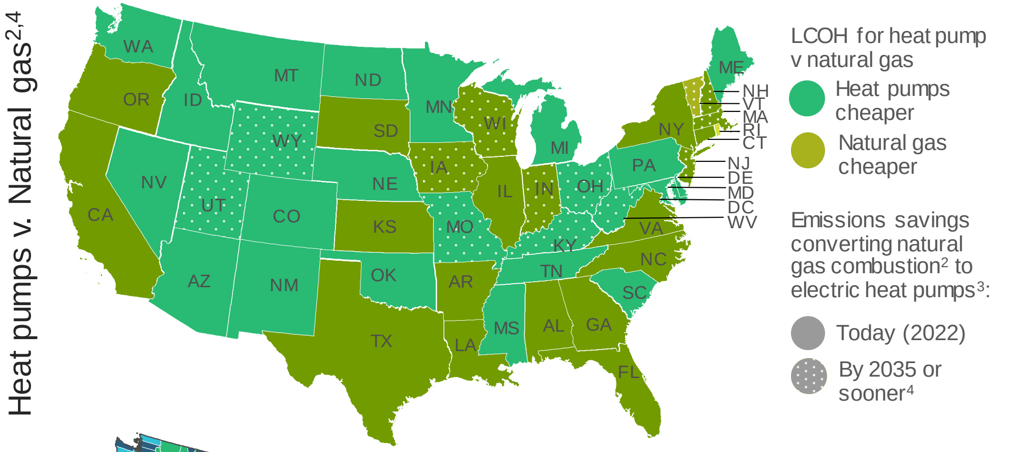


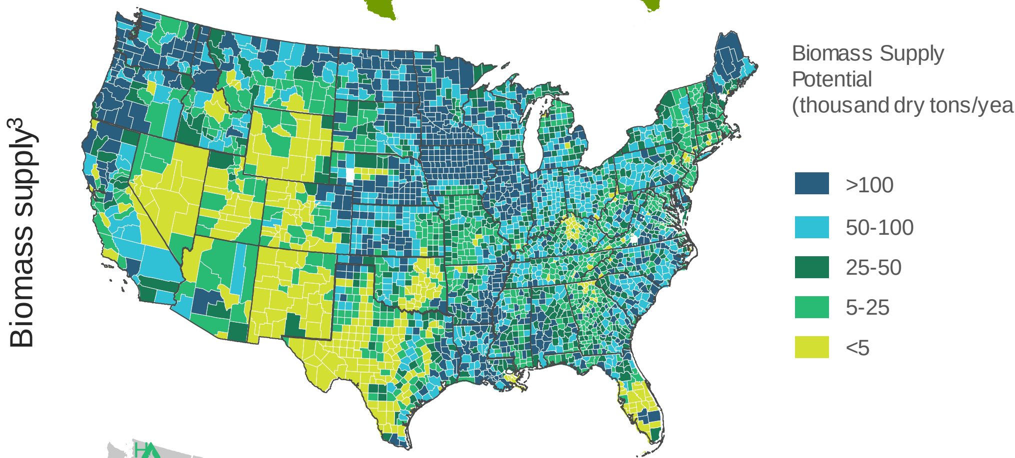

1. LCOH compares project lifetime costs against lifetime energy produced; costs include capital expense of equipment, fuel costs, and maintenance expense assumptions over the usable life of the energy asset. Electricity and natural gas pricing is based on national weighted average wholesale industrial 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

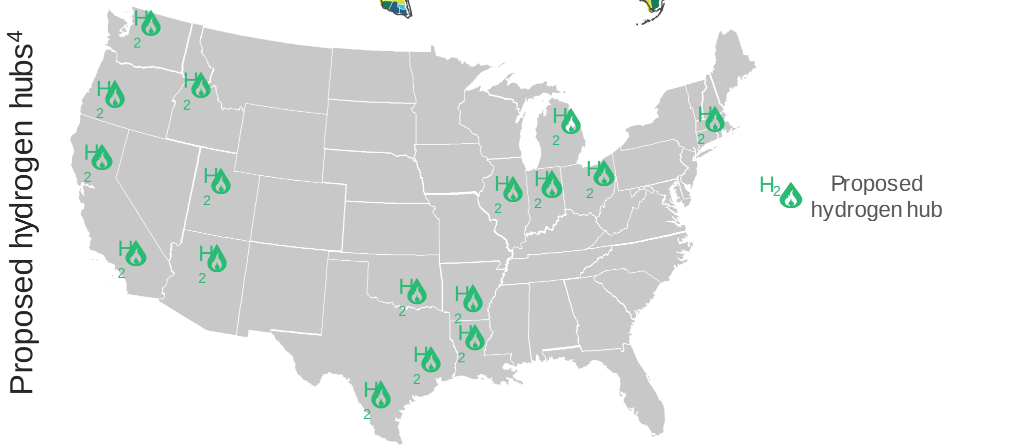
# Hydrogen, biomass, and heat pumps are available in heavy-emissions areas

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




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)

# Decarbonization pathways

**Coal & Petroleum**
Displace at accelerated pace

**Natural Gas**
Displace with renewable fuels

**Electrification**
Deploy electric heat pumps immediately <130ºC and expand to higher temps (up to ~200ºC) in 2030+ timeframe; deploy electric resistance (steam boilers)

**Biomass**
Increase use until feedstock supply constraints are met and green H2 is available

**RNG**
Increase use as blend in NG supply until supply constraints are met and costs are prohibitive

**Hydrogen**
As supplies are available for industrial thermal, ramp up use for high temperature applications

**Electric Resistance & Thermal Storage**
Deploy as inexpensive intermittent renewable electricity is available, and levelized cost of heat for system is lower than natural gas w / CCS

**CCS & Other Carbon Capture**
Capture combustion emissions alongside the larger facility hydrocarbon byproducts (process emissions: ~55% of total emissions)

2022 → 2050

| Considerations | Target First Movers |
|---|---|
| Start with electric heat pumps and steam boilers | States with inexpensive electricity, or high NG price |
| Adequate fuel supply, permitting for new fuel combustion | Local proximity to feedstocks (Midwest, Southeast) |
| Adequate supply of fuel | Regions with grid RNG blending (Midwest, Southeast) |
| Adequate fuel supply, viable economics, government subsidies | Regions with planned H2 hubs and ind. clusters |
| Grid or PPA supports emissions savings, viable economics | Ability to procure inexpensive intermittent electricity |
| Concentration of CO2 in flue gas, government subsidies | Regions with ind. clusters and adequate geology for storage |

The Chemicals sector is heterogeneous with interconnected supply networks, requiring many simultaneous paths to decarbonize thermal emissions. As relevant to their circumstances, each chemicals player can explore these technologies to achieve their decarbonization goals

# Thermal decarbonization pathways

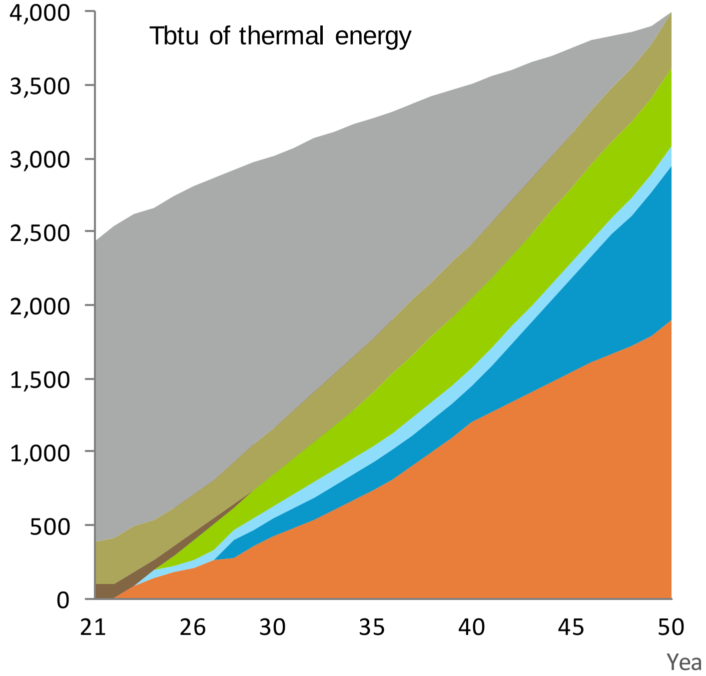
**Use of fossil natural gas is eliminated through 2050**

**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)

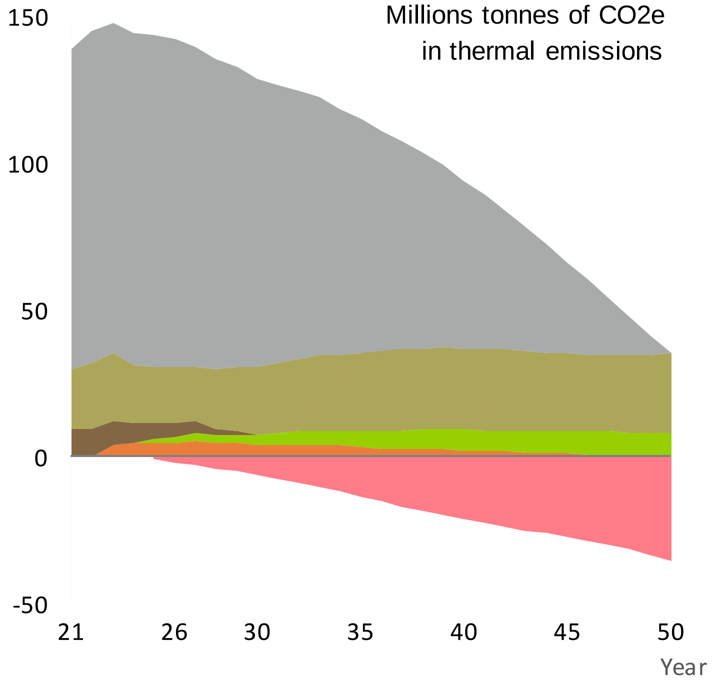
**Electrification** of low and medium temperature applications is deployed beginning immediately; electric grid emissions intensity is lower than fossil NG for heat pumps in nearly all states today; can be deployed against <130ºC processes representing ~37% of total thermal emissions in the sector. As 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 energy consumption[1]




## Thermal emissions[2]




Natural gas | Petroleum & other | Biomass | Clean Hydrogen | CCS
Biofuels & coproducts | Coal | 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 Source: EIA out look; EIA emissions intensity; BCG analysis

# Disclaimer