Waste Biomass

Renewable Thermal Technology

RENEWABLE
THERMAL
COLLABORATIVE

Technology Overview

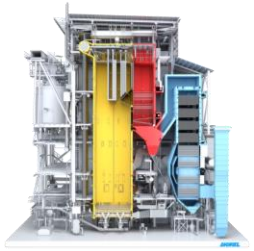
Description of technology

- Biomass is currently the largest source of renewable industrial heating in the US and worldwide, particularly in the wood, and pulp & paper sectors
- Direct combustion of solid biomass is the primary focus of this fact base, rather than conversion to liquid biofuels or gaseous fuels (i.e., pyrolysis)
- Biomass combustion typically produces steam, which drives electricity production or provides process heating
- Alternatively, air is heated by biomass combustion, which provides heat for drying applications

Types of equipment

- There are two major systems for biomass combustion heating:
  - Fixed bed combustion
  - Fluidized bed combustion

Fixed bed wood chip and pellet boiler1



Bubbling fluidized bed boiler2

Note: Example equipment not exhaustive

1. Hurll Nu Way; 2. Andritz

Technical characteristics

- **Temperature range:** Up to 1,000 ºC
  - Fixed bed boilers: 800-1,000 ºC
  - Fluidized bed boilers: 760-870 ºC
- **Heat flux:** High
  - Dependent on biomass combustion system and heat transfer configuration
- **Heated materials:** Most materials are applicable
- **Emissions:** CO2 and other particulate emissions at point of combustion but theoretically carbon neutral
- **Technical maturity:** High maturity
  - Biomass combustion widely deployed in wood and pulp & paper industries for power generation and process heating applications

Biomass combustion industrial heating is useful for most low to medium temperature process applications

Key properties of biomass combustion heating include:

- 1,950 ºC max. temp.
- High heat flux
- Heats all materials

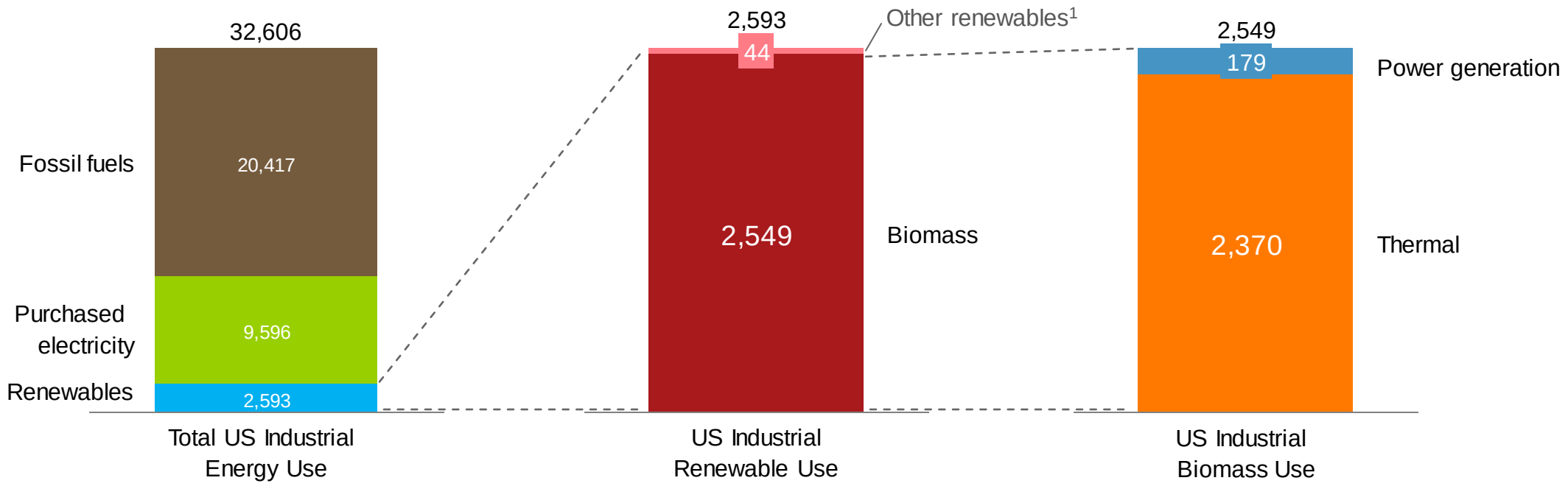
These properties align with requirements for several process heating applications.

Industry Sector	Process Heating Applications						Relevant Equipment
Refineries	Distillation	Reactors					Boiler, process heater
Chemicals	Distillation	Drying	Reactors				Boiler, process heater, furnace, air heater
Iron & steel	Pelletization	Hot rolling	Basic oxygen furnace	Blast furnace			Boiler, furnace
Food	Drying	Pasteurizing	Boiling	Sterilizing	Washing	Cooking	Air heater, boiler, oven
Paper	Stock steaming	Drying	Wood processing	Evap. & chem. prep.	Lime calcination		Air heater, boiler, oven, furnace
Cement	Pre-heating & treating	Melting furnace	Forming	Annealing	Kiln combustion		Furnace

Not applicable | Potentially applicable | Currently deployed

Note: Since RNG has been blended into the existing natural gas distribution network, all potentially applicable process heating applications are denoted as "currently deployed"

Biomass constitutes around 8% of US industrial energy consumption and >98% of total industrial renewable energy use – most of which is for thermal applications



1. Includes hydroelectric, solar, wind, and geothermal
Note: Fuel consumption includes non-thermal and non-combustion uses; Source: EIA Monthly Energy Review 2018

Combustion of biomass for thermal energy is currently widespread in sectors with readily available fuels from production wastes or other feedstocks

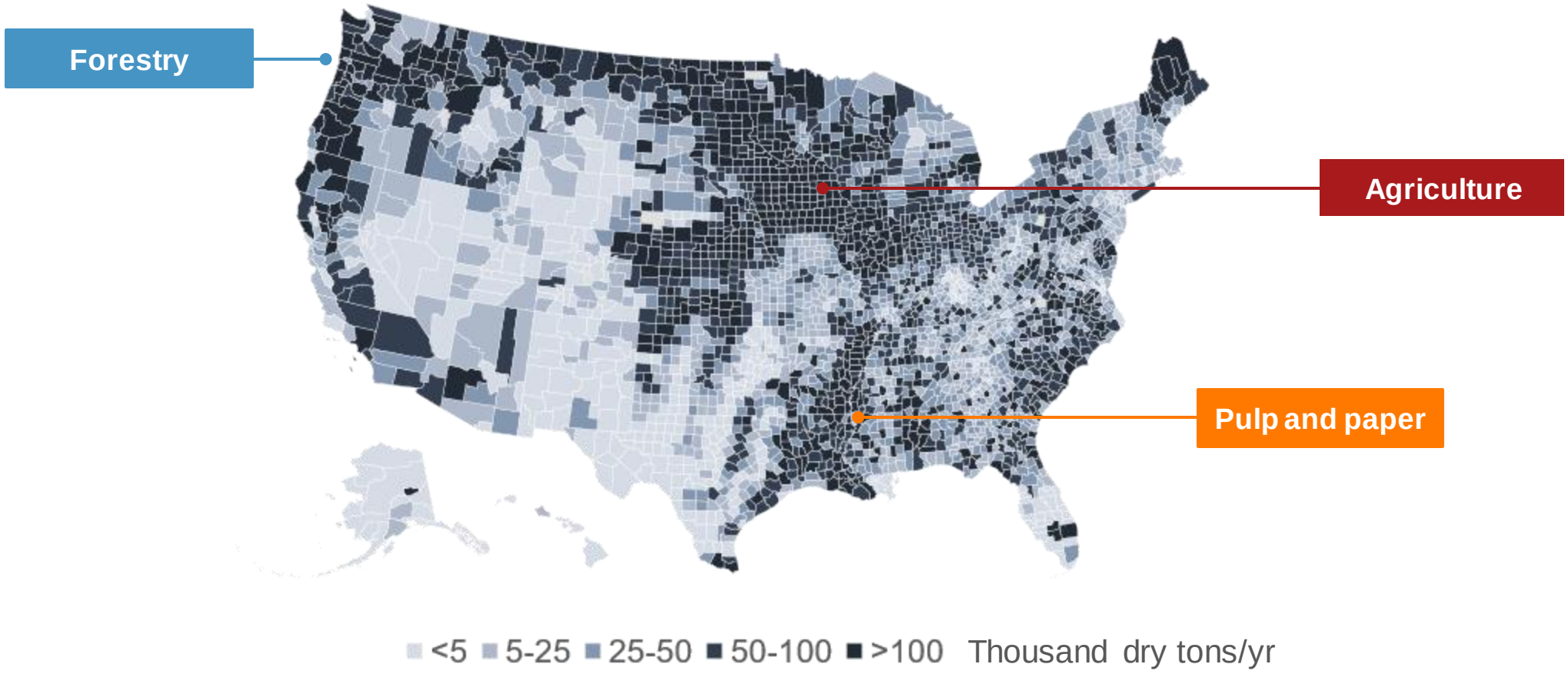
Factors for current utilization of biomass

- On-hand supplies of biomass waste or byproducts
- Low-cost fuel relative to alternatives
- Elimination of waste materials
- Potential net zero-carbon emissions

Current sectors with high biomass usage

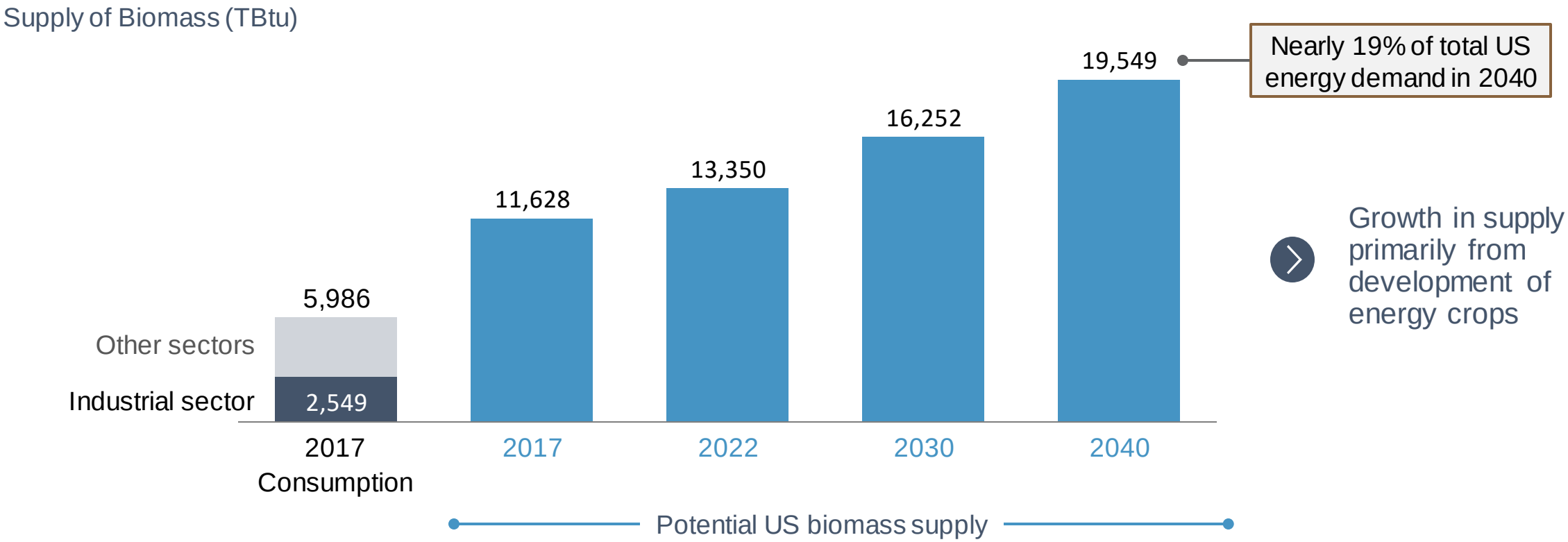
- Forestry and lumber
- Pulp and paper
- Food and agriculture

Biomass supply in the US today is predominantly concentrated in the Midwest, South, and the Pacific Northwest due to the agriculture and forestry sectors



Source: NREL Biofuels Atlas;

Current consumption of biomass is a fraction of total potential, especially with the growth of energy crop cultivation



Note: Assume biomass has average heating value of 8,200 Btu/lb (16.4 MMBtu/ton) from EIA
Source: DOE, US EIA

Biomass energy comes from four major feedstock categories

Energy crops

- Herbaceous
- Woody

Wastes

- Food processing wastes
- Wood processing wastes
- Municipal solid waste

Agricultural

- Crop residues

Forestry

- Forest residues and thinnings
- Whole-tree biomass

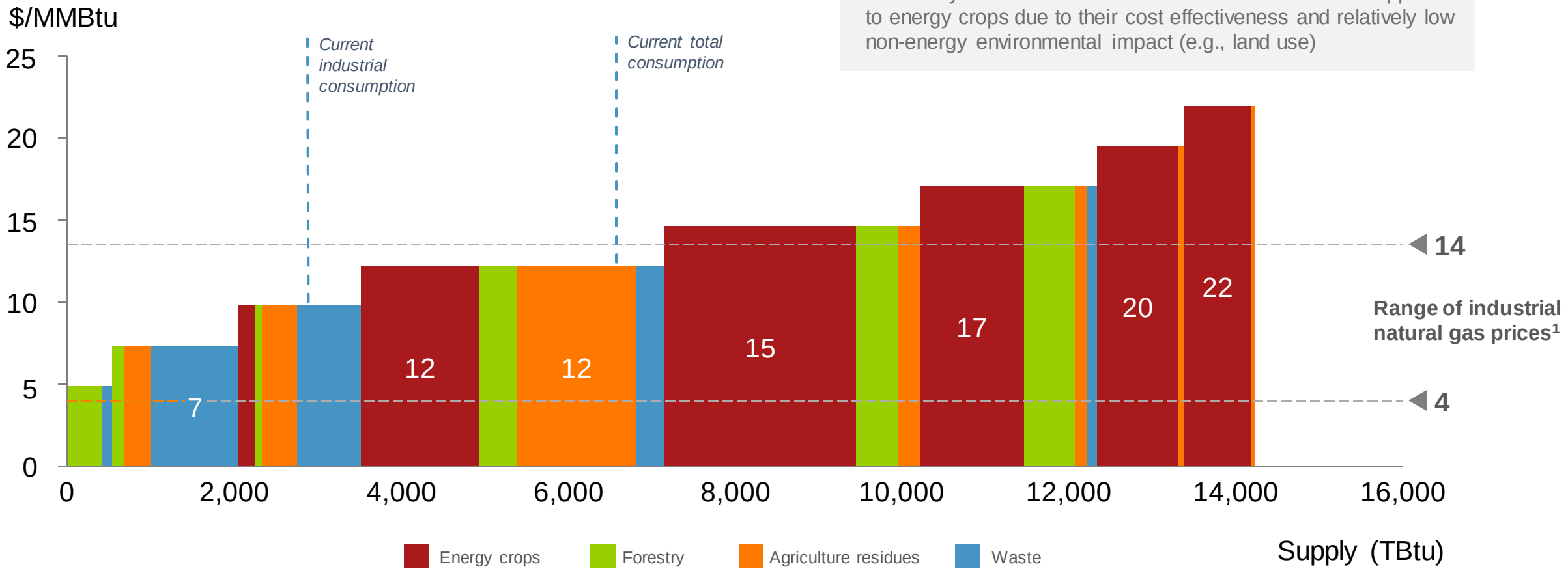
Increasing level of current usage in industrial heating

Note: Algae is not included due to its nascent nature and primary use as a feedstock for liquid biofuels

Large supplies of biomass feedstocks in all four categories are within range of economic viability in the next decade

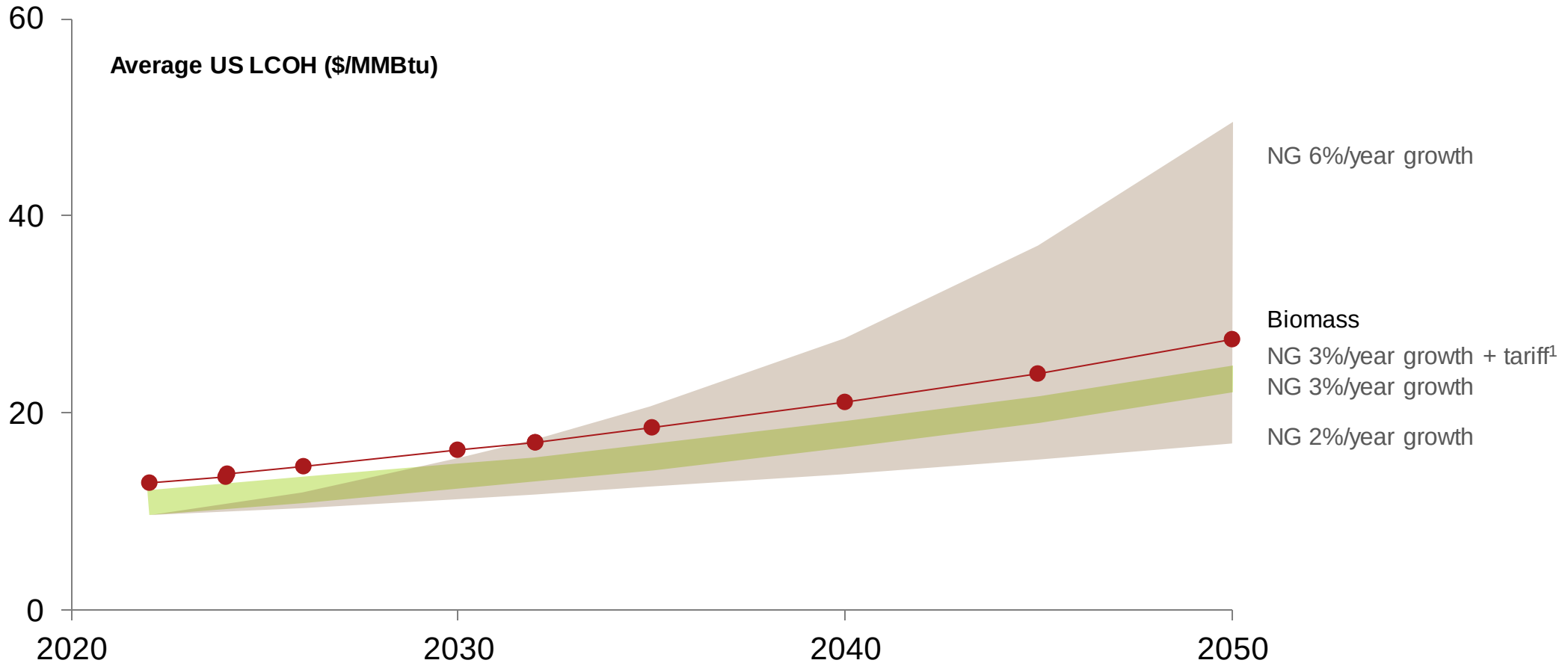
Potential Supply of Biomass by Feedstock Type (TBtu) in 2030

This analysis focuses on waste biomass feedstocks as opposed to energy crops due to their cost effectiveness and relatively low non-energy environmental impact (e.g., land use)



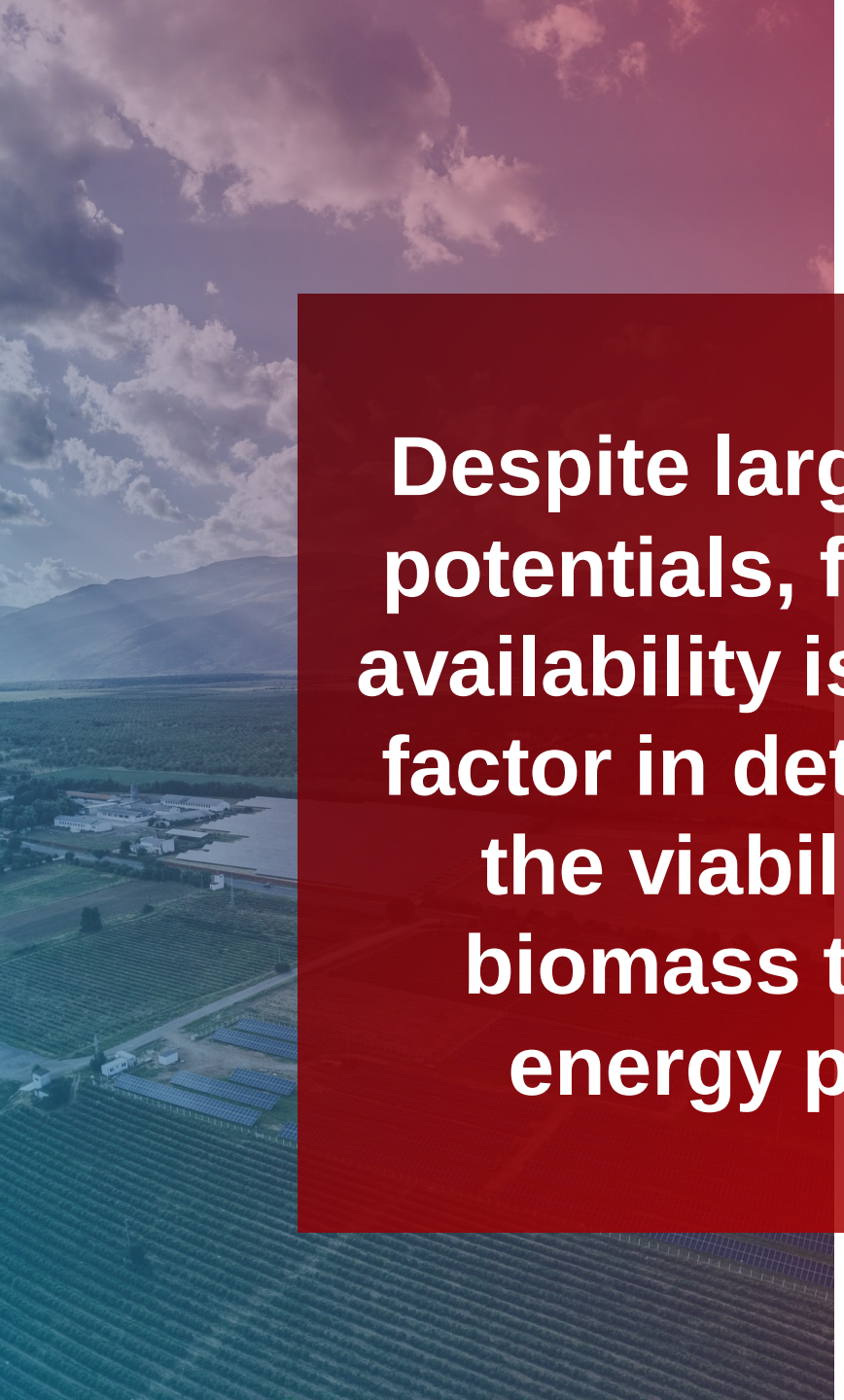
1. EIA May 2022 end-user prices; Notes: Assume biomass has average heating value of 8,200 Btu/lb (16.4 MMBtu/ton) from EIA. Biomass supplies beyond $90/ton ($5.5/MMBtu) were excluded. Prices adjusted from roadside to final sales prices; Source: DOE

Depending on feedstock constraints, biomass is expected to be comparable in cost relative to natural gas in the next 30 years



1. Based on $51/tonne CO2 social cost of carbon

Notes: Subsidized are shown in plots, subsidized and unsubsidized LCOHs are within 5%. Subsidies may further reduce biomass producer costs and consequently LCOH by <10%.



Despite large supply potentials, feedstock availability is a critical factor in determining the viability of a biomass thermal energy project

Important questions to determine the feasibility of biomass for industrial heating include:

- What is the transportation distance and cost for the feedstock?
- Does the feedstock require collection, or is it a waste or byproduct at a processing plant?
- Is the feedstock a waste that would incur disposal costs if not used for bioenergy?
- What processing steps are required to prepare the biomass feedstock for combustion?
- What combustion technology is suitable?

Biomass for industrial heating may compete with other biomass applications, which could lead to constrained supply and increased prices

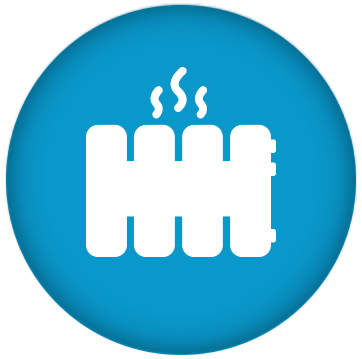
Non-energy uses

Pulp & paper feedstock

Power generation

Electricity production

Building heating



Space and water heating

Transport

Liquid biofuel production

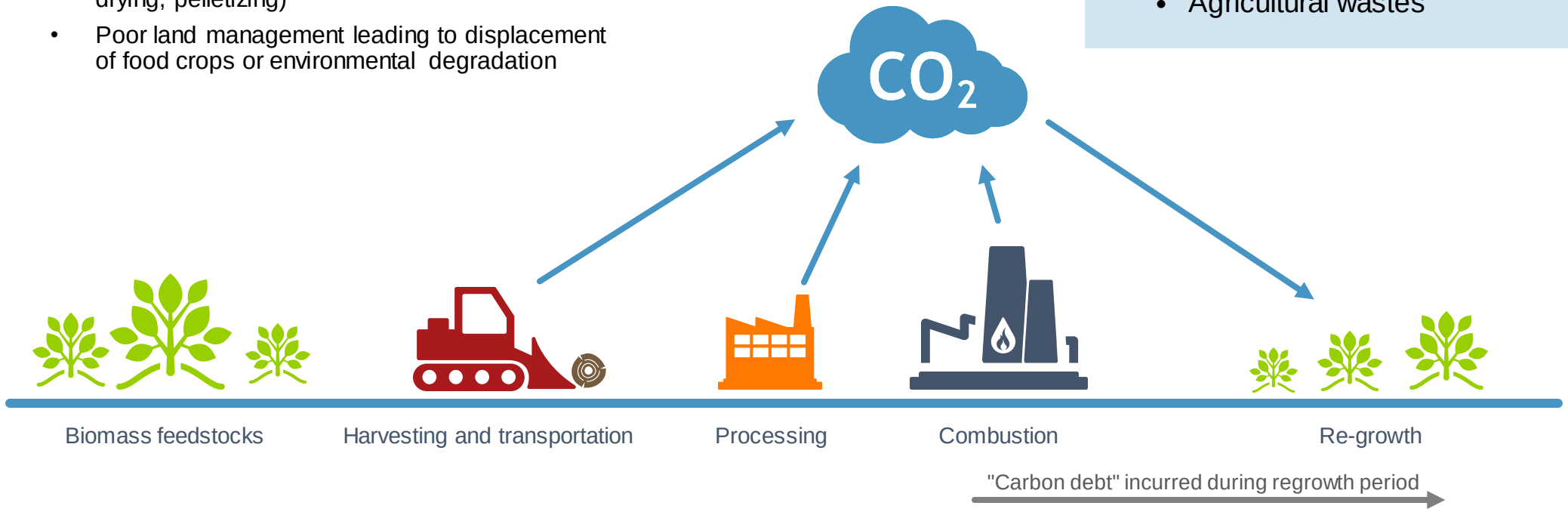
Mature applications → *Emerging applications*

Carbon neutrality of biomass is contentious and overall carbon footprint can range significantly depending on feedstocks, transportation, and processing

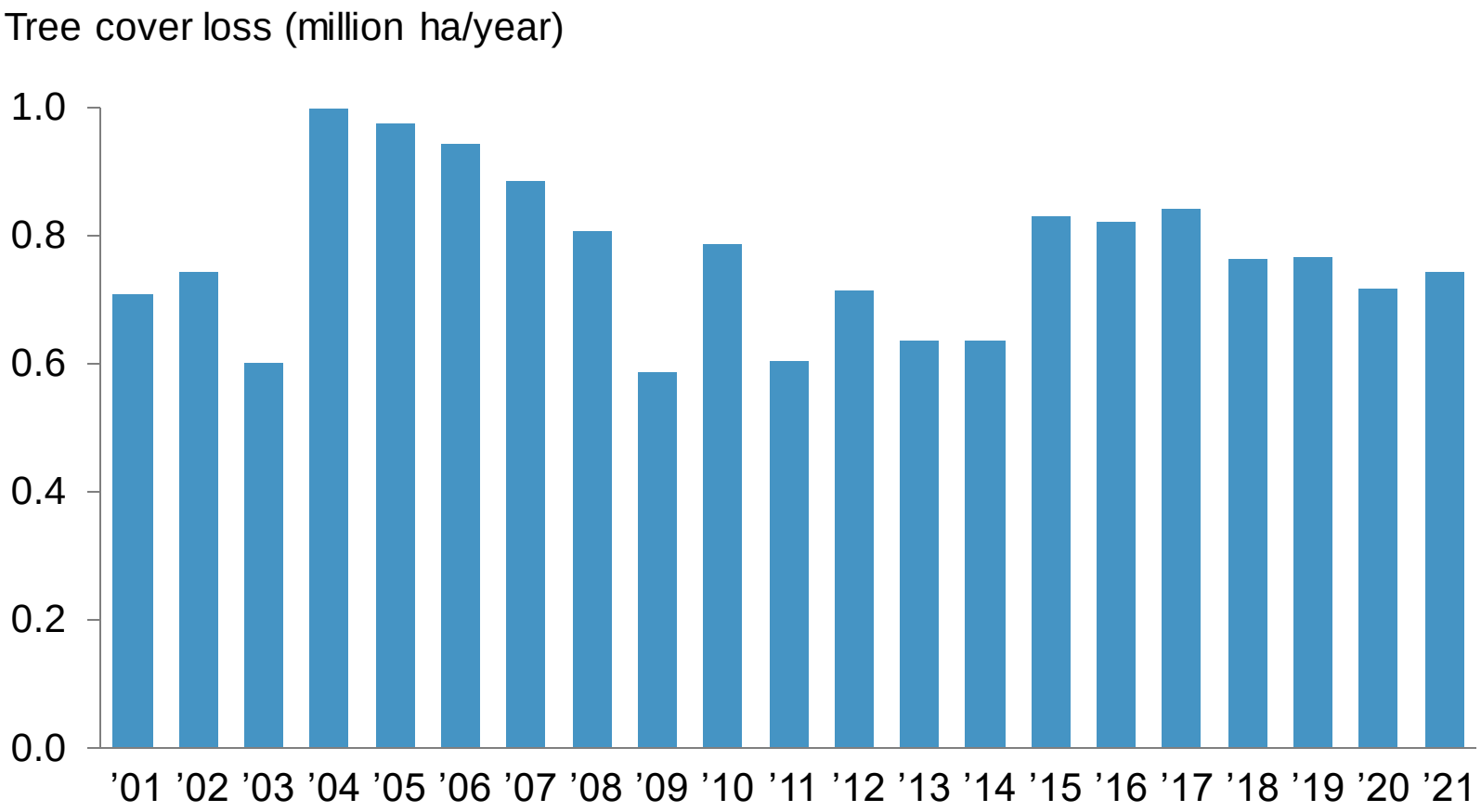
- Biomass combustion is theoretically carbon-neutral due to natural carbon sequestration during plant growth

- However, several factors may increase the overall carbon footprint
  - Emissions during harvesting and transportation
  - Emissions during processing steps (e.g., chipping, drying, pelletizing)
  - Poor land management leading to displacement of food crops or environmental degradation

The best source of biomass is **waste or byproduct biomass**
- Pulp and paper wood wastes
- Forestry residuals
- Agricultural wastes



US has lost over 16% of its tree cover in last 20 years; majority of biomass consumed by paper sector is unlikely to be sustainable or net zero



- From 2001 to 2021, US lost 44.3 million ha (16%) of tree cover
- This deforestation is equivalent to 17.4Gt of CO_2e emissions
- Due to changing climate conditions, the forest sector will likely become a net emitter by 2040[1]

1. USDA Integrated Projections for Agriculture and Forest Sector Land Use, Land-Use Change, and GHG Emissions and Removals
Source: Global Forest Watch, USDA

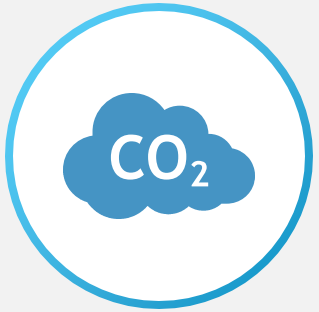
Biomass combustion industrial heating is a mature technology with many advantages, but faces several key barriers to adoption

Advantages

Renewable resource and theoretically carbon neutral

Dispatchable thermal energy supply

Low fuel costs depending on location and feedstock type



Can be paired with CCS for potential negative emissions

Barriers

High transportation costs constrains geographic applicability

Agricultural biomass displaces food production

Biomass combustion creates air pollutants (e.g., VOCs, NOx, PM)

Carbon released during combustion may not be recaptured for decades

Disclaimer

This document has been prepared in good faith on the basis of information available at the date of publication without any independent verification. The drafters do not guarantee or make any representation or warranty as to the accuracy, reliability, completeness, or currency of the information in this document nor its usefulness in achieving any purpose. Readers are responsible for assessing the relevance and accuracy of the content of this document. It is unreasonable for any party to rely on this document for any purpose and the drafters will not be liable for any loss, damage, cost, or expense incurred or arising by reason of any person using or relying on information in this document. To the fullest extent permitted by law, the drafters shall have no liability whatsoever to any party, and any person using this document hereby waives any rights and claims it may have at any time against BCG with regard to the document. Receipt and review of this document shall be deemed agreement with and consideration for the foregoing.

This document is based on a primary qualitative and quantitative research. It does not provide legal, accounting, or tax advice. Parties responsible for obtaining independent advice concerning these matters. This advice may affect the guidance in the document. Further, the drafters have made no undertaking to update the document after the date hereof, notwithstanding that such information may become outdated or inaccurate. The drafters have used data from various sources and assumptions provided to the drafters from other sources. The drafters have not independently verified the data and assumptions from these sources used in these analyses. Changes in the underlying data or operating assumptions will clearly impact the analyses and conclusions.

This document is not intended to make or influence any recommendation and should not be construed as such by the reader or any other entity.