RENEWABLE THERMAL COLLABORATIVE

RENEWABLE THERMAL: STATE OF THE TECHNOLOGIES

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RENEWABLE THERMAL COLLABORATIVE

RENEWABLE THERMAL: STATE OF THE TECHNOLOGIES

November 9, 2020

Speakers

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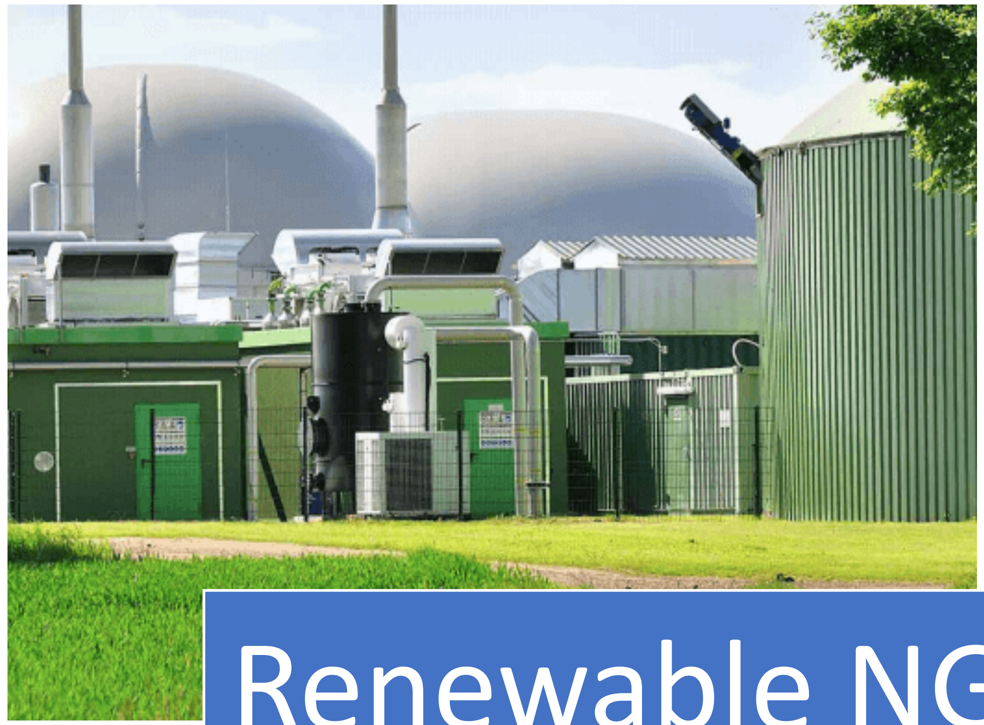
Manager of Industrial Systems and Fuels Analysis Group
National Renewable Energy Laboratory

Parthiv Kurup
Concentrating Solar Power Cost and Systems Analysis
National Renewable Energy Laboratory

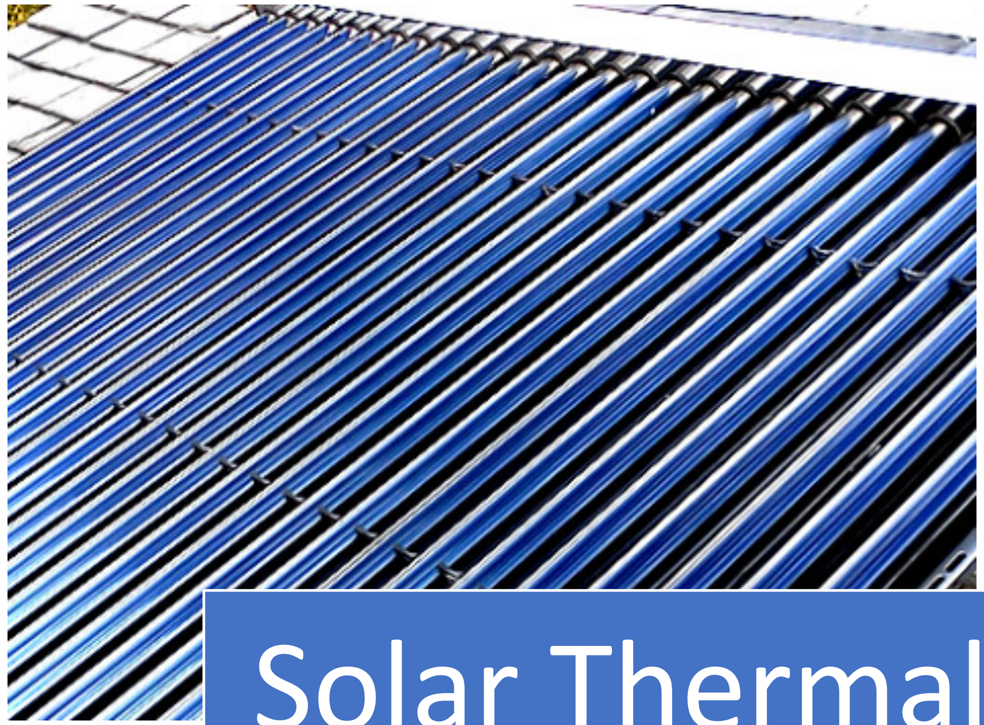
Renewable Thermal Technologies – An Overview

Electrification

Hydrogen



Renewable NG



Solar Thermal

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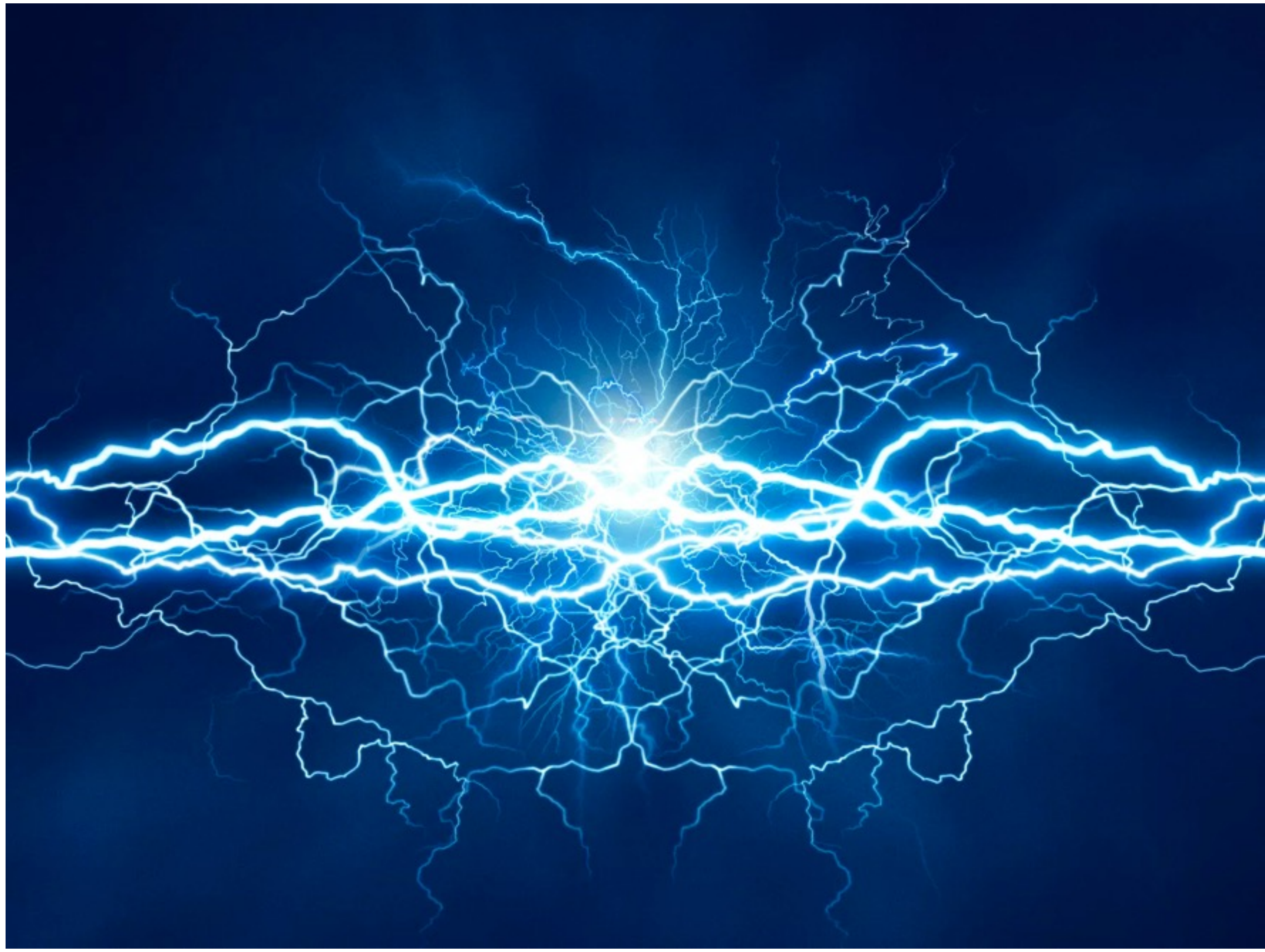
Electrification of Industry



Presenters:

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Plenary Session

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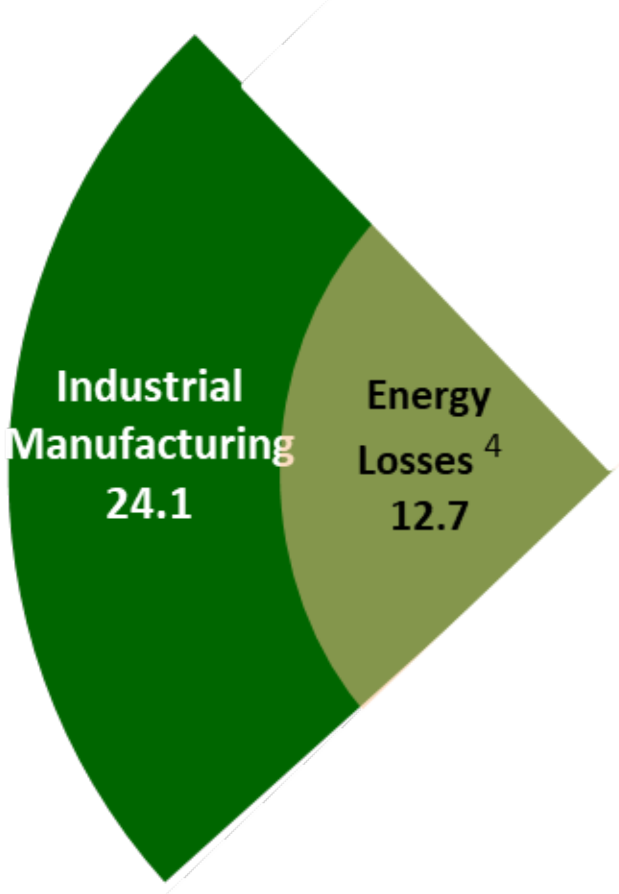
Energy Use in the U.S



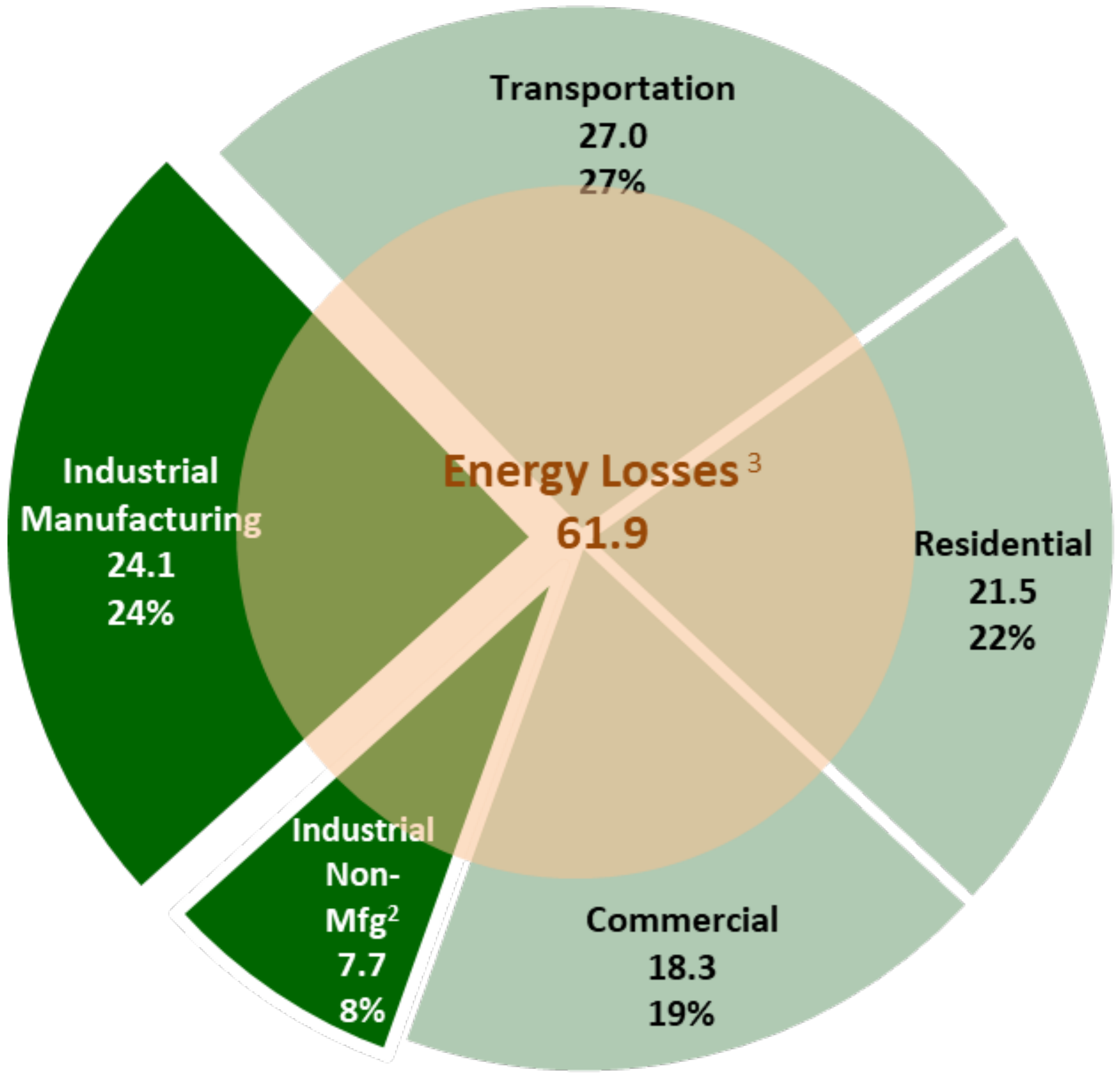
Data for 2014

More efficient manufacturing reduces energy losses

and…

More efficient manufacturing enables technologies that improve energy use throughout the economy:

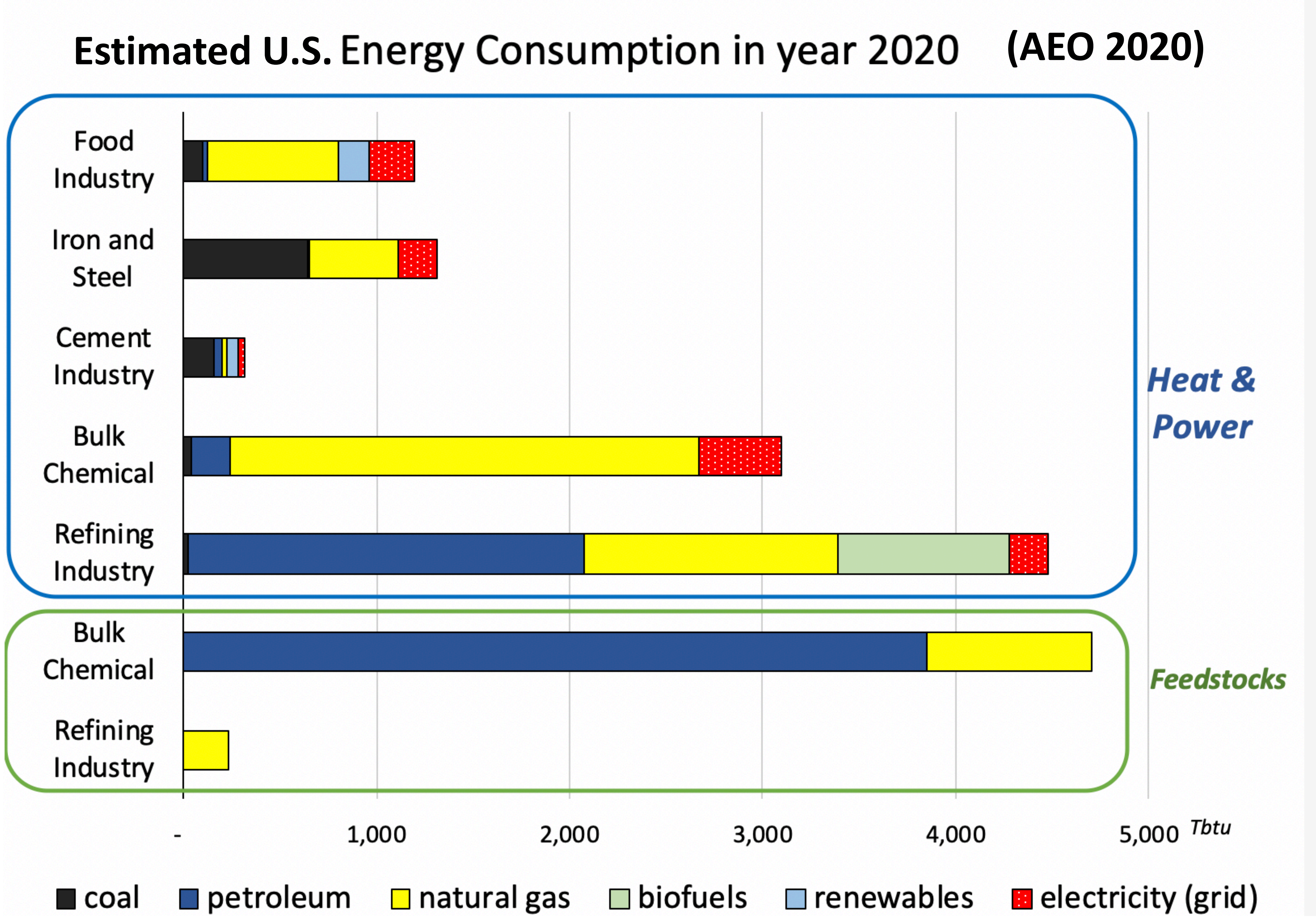
- Transportation
- Buildings
- Energy Production and Delivery



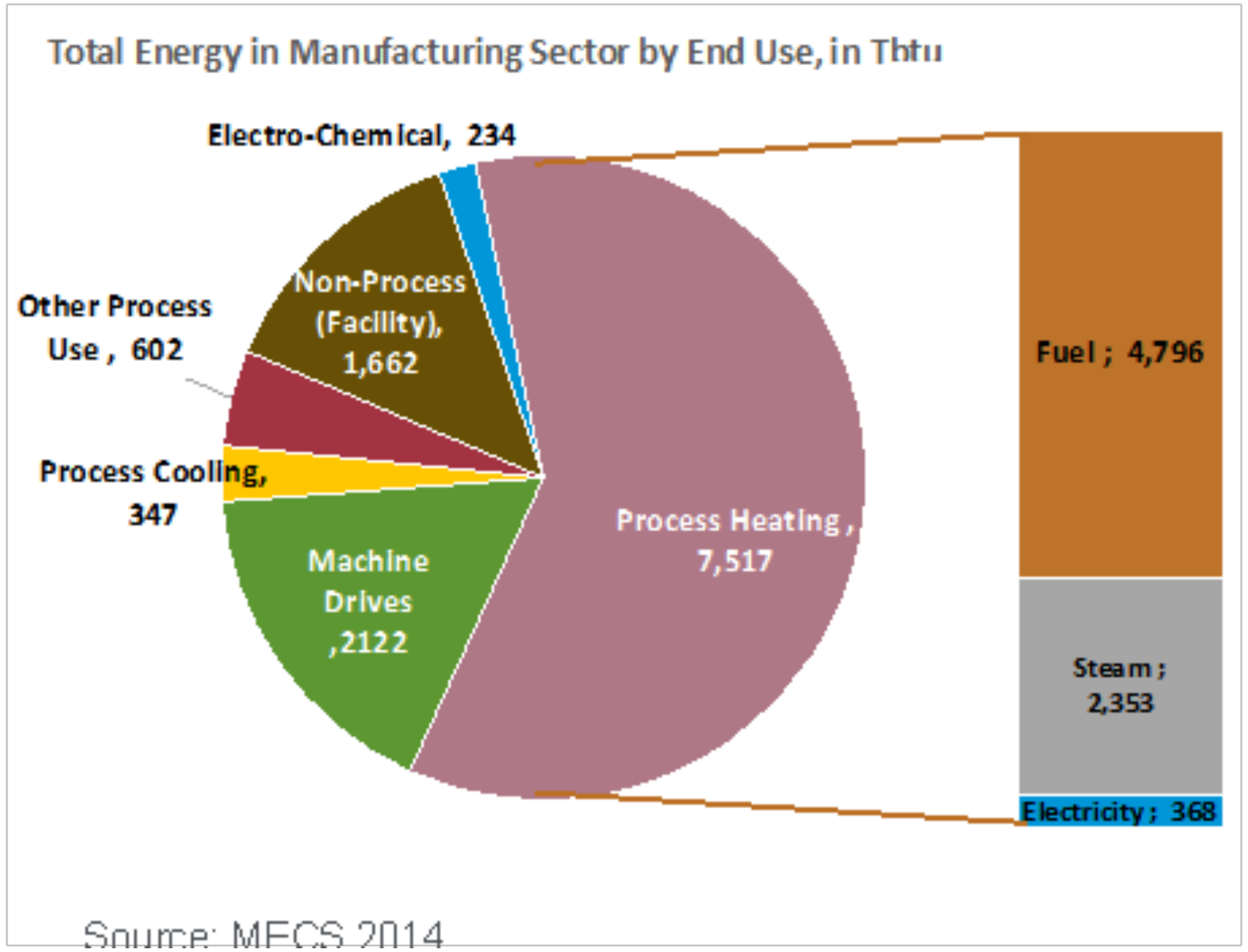
U.S. Energy Economy by Sector
98.5 quadrillion Btu, 2014 [1]

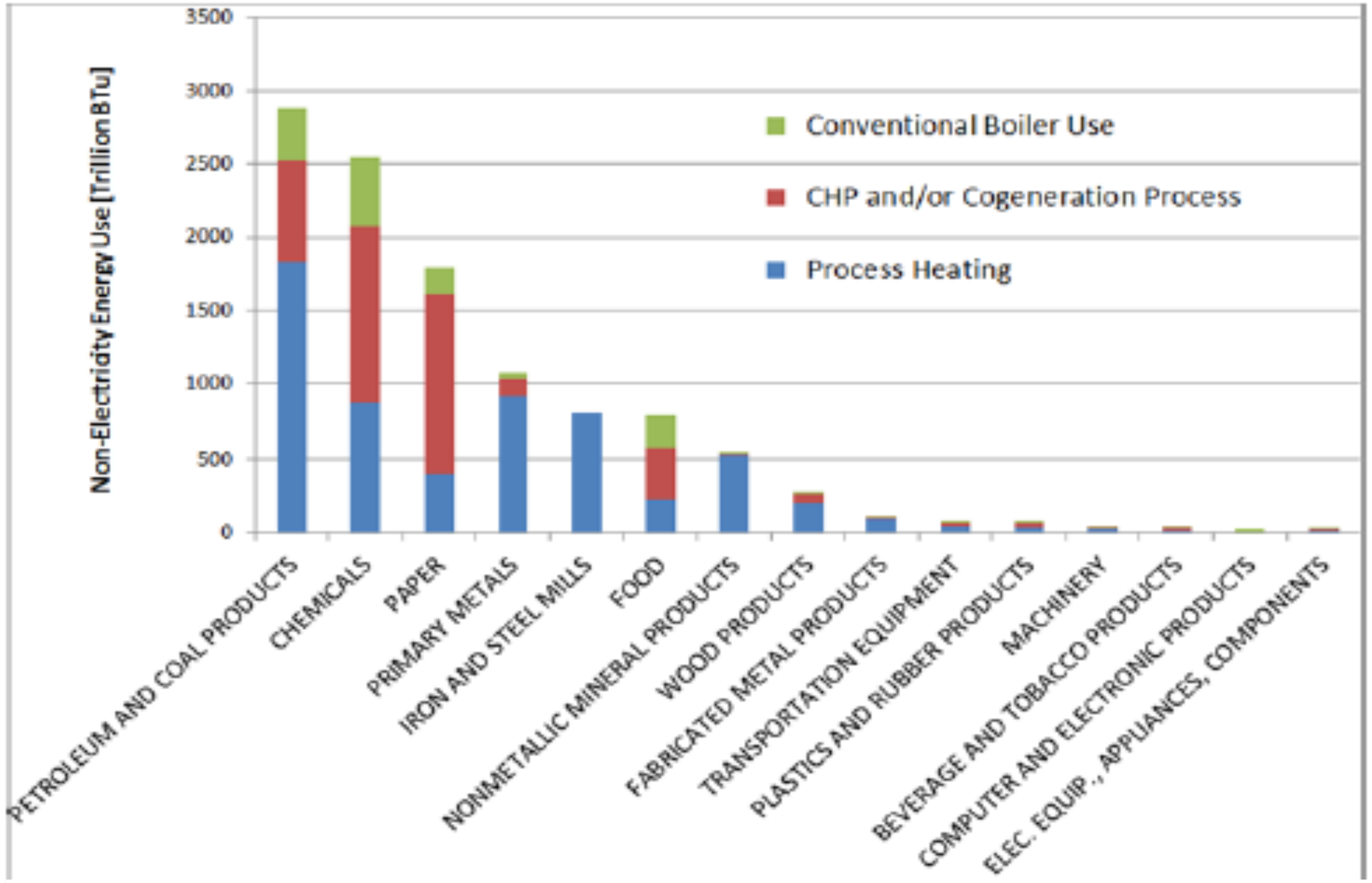
Source: Cresko 2020

U.S. Industrial energy use



U.S. Industrial energy use





Breakdown of non-electric fuel use by industry sector in U.S. (EIA 2017)

0)

Source: DOE Energy Information Administration's Manufacturing Energy Consumption Survey (MECS) data for 2014.

Industrial heat demand profile

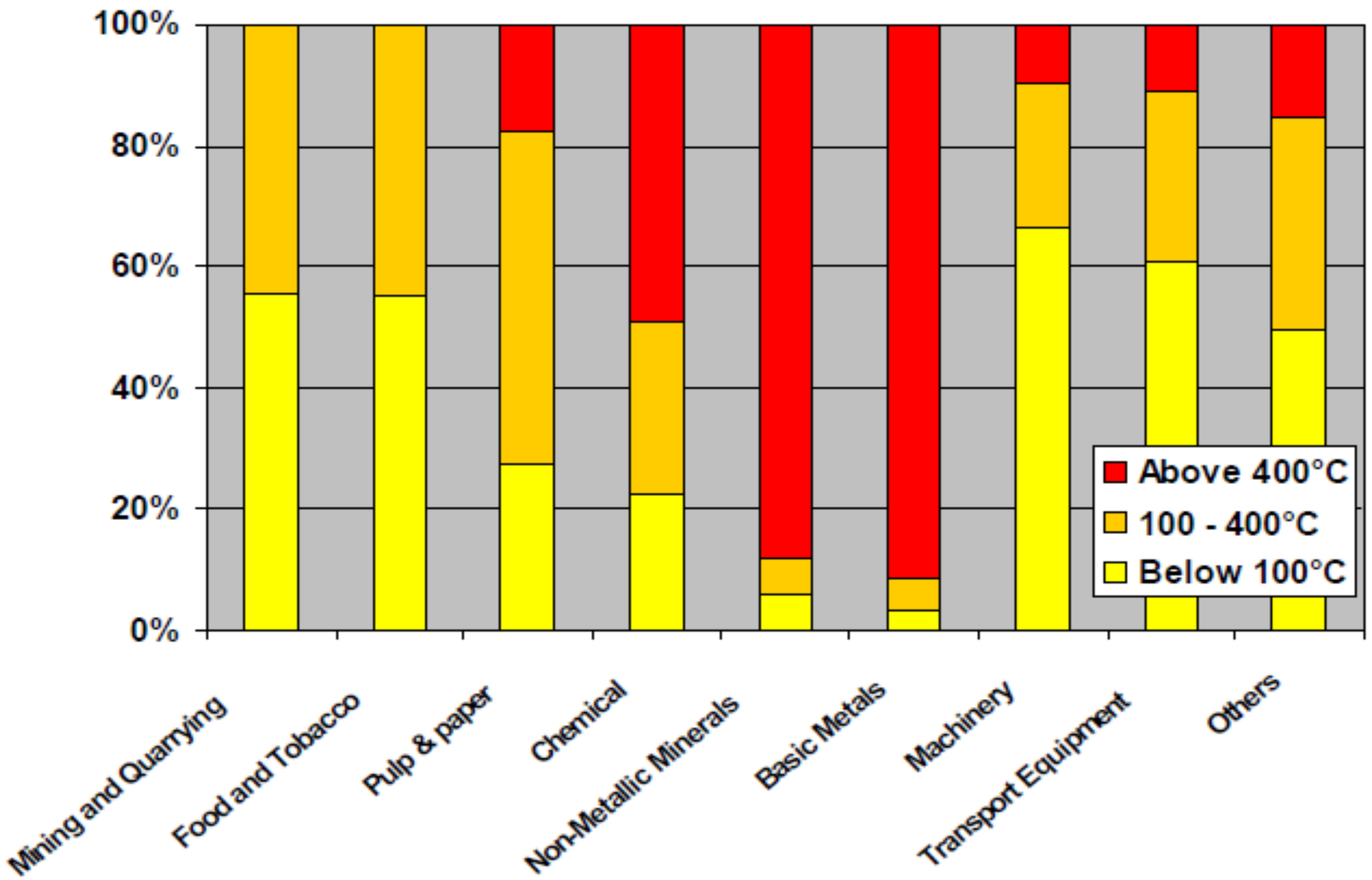


Figure: Share of industrial head demand by temperature in selected industries

Source: Caludia et al., 2008

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Industrial process heat temperature requirement

Industrial Sector	Unit Operations	Temperature Range	
		Celsius	Fahrenheit[62]
Food	Drying	30-90	90-210
	Washing	60-90	150-210
	Pasteurizing	60-80	150-190
	Boiling	95-105	220-140
	Sterilizing	110-120	250-270
	Heat Treatment	40-60	110-150
Beverages	Washing	60-80	150-190
	Sterilizing	60-90	150-210
	Pasteurizing	60-70	150-170
Paper Industry	Cooking and Drying	60-80	150-190
	Boiler Feed Water	60-90	150-210
	Bleaching	130-150	190-330
Metal Surface Treatment	Treatment, Electroplating, etc.	30-80	90-190
Bricks and Blocks	Curing	60-140	150-310
Textile Industry	Bleaching	60-100	150-230
	Dyeing	70-90	170-210

Industrial Sector	Unit Operations	Temperature Range	
		Celsius	Fahrenheit[62]
	Drying, De-greasing	100-130	230-290
	Washing	40-80	110-190
	Fixing	160-180	350-390
	Pressing	80-100	190-230
Chemical Industry	Soaps	200-260	430-550
	Synthetic Rubber	150-200	330-430
	Processing Heat	120-180	270-390
	Preheating Water	60-80	150-190
Plastic Industry	Preparation	120-140	270-310
	Distillation	140-150	310-330
	Separation	200-220	430-470
	Extension	140-160	310-350
	Drying	180-200	390-430
	Blending	120-140	270-310
Flour By-Products	Sterilizing	60-90	150-210
All Industrial Sectors	Pre-heating of Boiler Feed Water	60-90	150-210
	Industrial Solar Cooking	55-180	140-390
	Heating of Factory Buildings	30-80	90-190

Source: RTC 2018

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Industrial Electrotechnologies

Commercial	Emerging
Electric boilers	Electric infrared heating
Heat pumps	UV heating
Induction heating	Electric Induction melting
Radio frequency heating	Plasma melting
Electric arc furnaces	Electrolytic reduction
	Microwave heating

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Industrial Electrification Study

Partners: Renewable Thermal Collaborative and Global Efficiency Intelligence

Supported by: Energy Foundation

Project Goal: Accelerate electrification in the industrial sector.

How:
- We are conducting bottom up subsector, systems, and technology-level analysis and developing a Technology Action Plan (TAP) for scaling up electrification in industry.
- The RTC, GEI and RTC industrial partners will promote this Action Plan with key stakeholders, including:
  - Industrial companies
  - Electric utilities
  - Policy makers and regulators
  - Key opinion leaders

Bottom-up analysis method

Step1
- Detailed analysis of existing heating system

Step2
- Selection of suitable electrification technology

Step3
- Process integration assessment with new electrified heating technology

Step 4
- Calculation of changes in energy use and GHG emissions and cost implications

No.	Industry
1	Aluminum casting
2	Ammonia
3	Methanol
4	Recycled plastic
5	Paper (from virgin pulp)
6	Recycled paper
7	Container Glass
8	Textile
9	Steel
10	Cement
11	Beer
12	Beet Sugar
13	Milk powder
14	Wet corn milling
15	Soybean oil
	Electrification of all industrial boilers

Electrification of Container Glass industry in the U.S.

Conventional System Process				All Electric Process	
Heating Equipment	Electrical Demand (kWh/tonne)	Thermal Demand (kWh/tonne)	Process steps	Electrical Demand (kWh/tonne)	Heating Equipment
Electrically-powered mixer/crusher	161.0	0.0	Mixing	161.0	Electrically-powered mixer/crusher
Gas-fired furnace	204.0	1150.0	Melting	860.0	Electric glass melter
Forehearth and forming equipment	26.0	105.0	Conditioning & Forming	104.0	Electric forehearths
Gas-fired Anealing lehr	25.0	210.0	Poat Forming(Annealing)	183.0	Electric Anealing lehr
	416.0	**1465.0**	**Sub-total**	**1308.0**	
	1881		**Total Energy**	**1308**	

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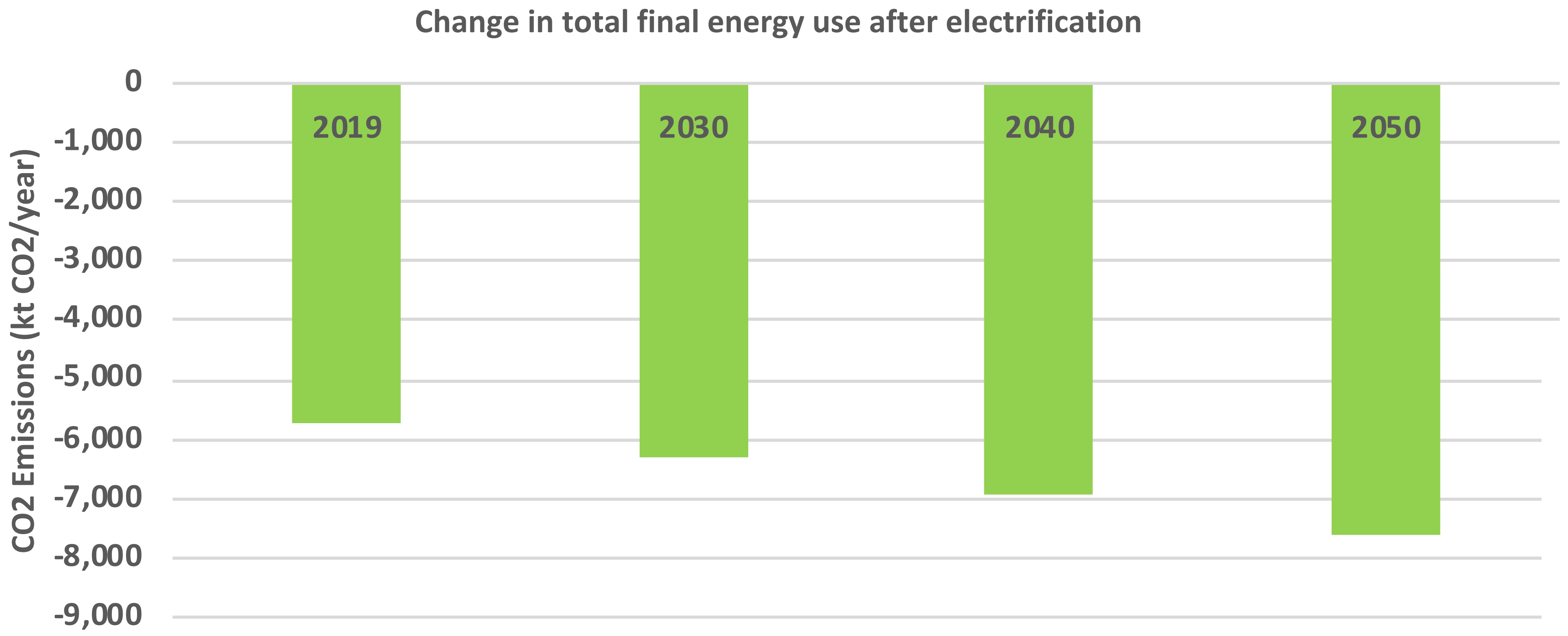
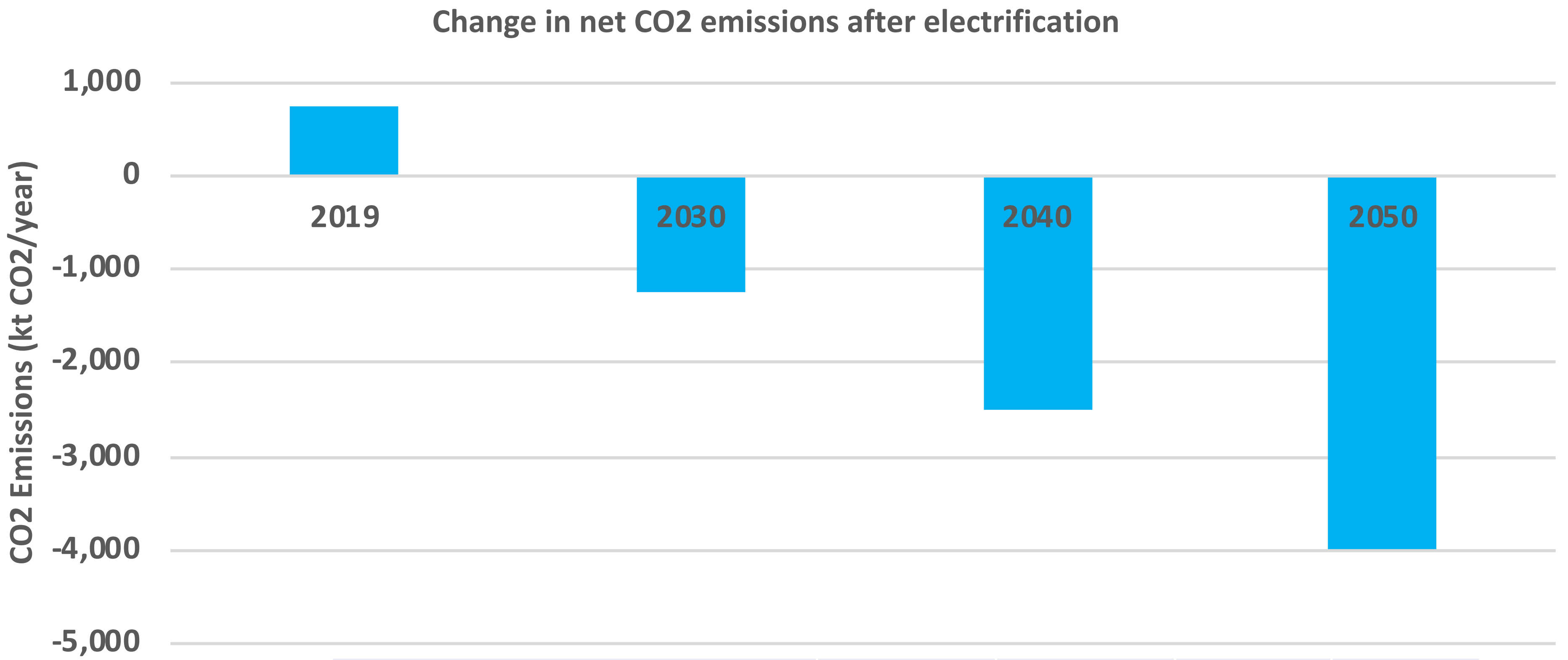
Electrification of Container Glass industry in the U.S.



Note: This is the technical potential assuming 100% adoption rate in the U.S.



	2019	2030	2040	2050
Emission factor for grid electricity in US (kgCO2/MWh)	414	207	103	0

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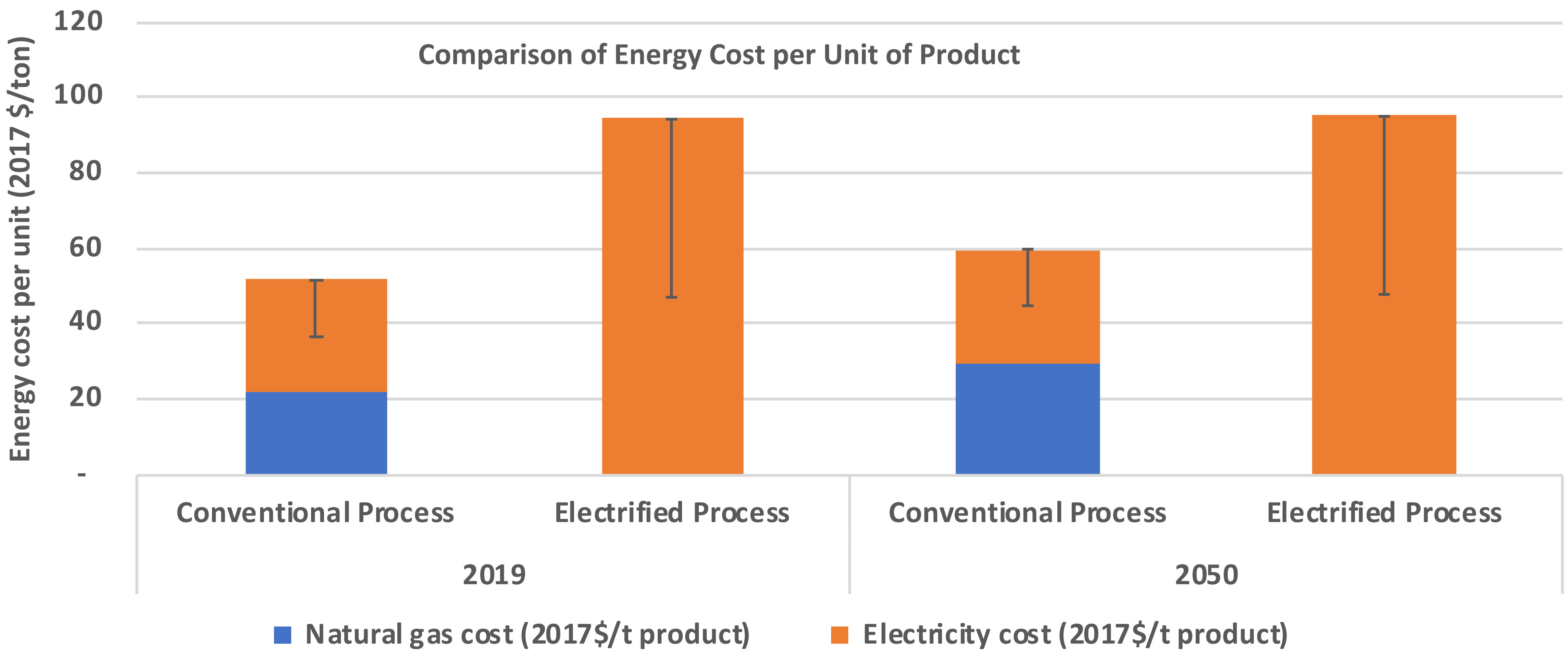
Electrification of Container Glass industry in the U.S.



Note: The error bars show the energy cost per unit of production when unit price of electricity is reduced by 50%.

	2019	2050
Average unit price of **electricity** for industry in U.S. (2017 US$/kWh)	0.072	0.073
Average unit price of **NG** for industry in U.S. (2017 US$/kWh)	0.015	0.020

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Thank You!

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Website: www.globalefficiencyintel.com

The Technical and Economic Potential of H2@Scale within the United States and Discussion of Thermal Opportunity

Mark F. Ruth

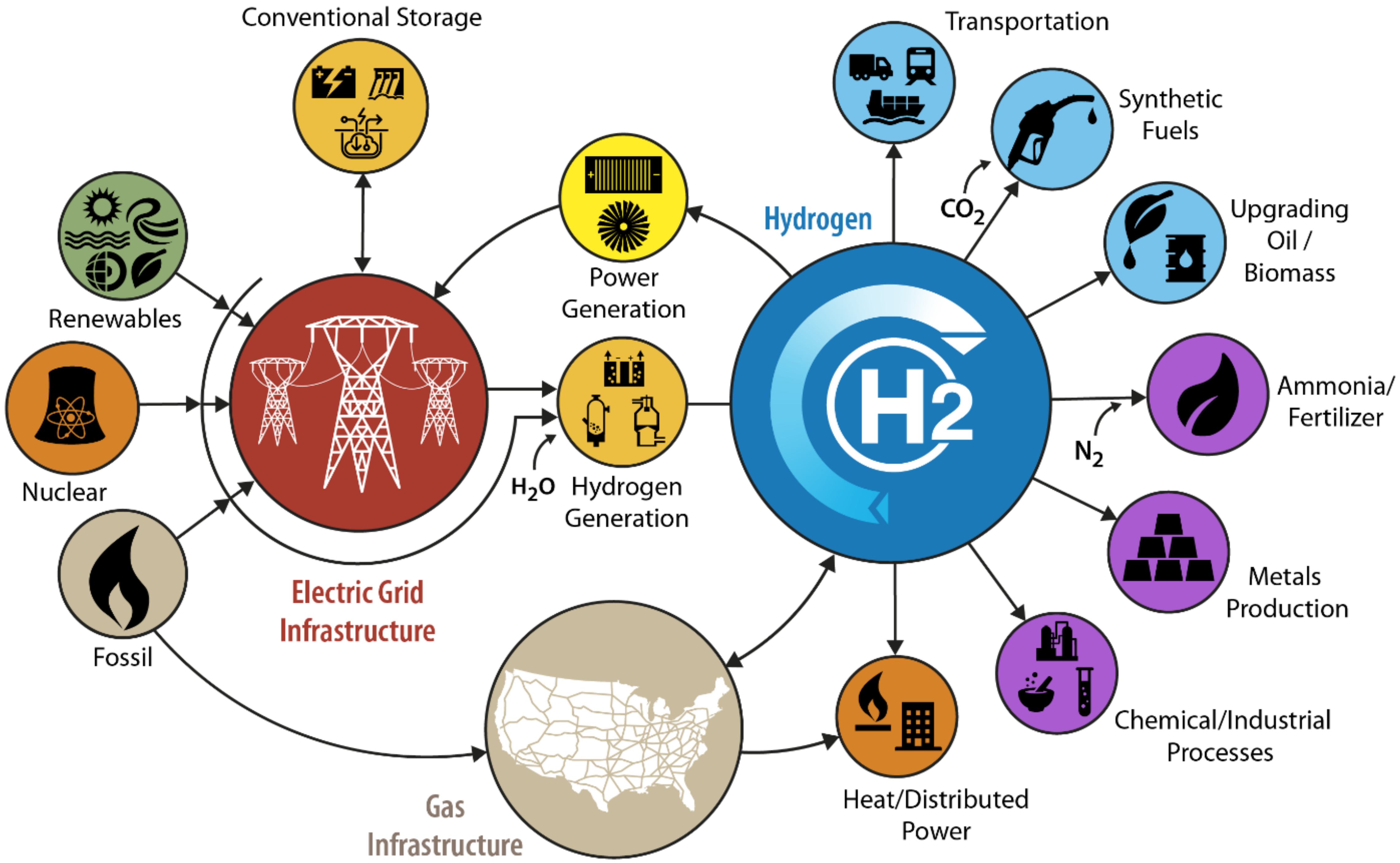
Renewable Thermal Collaborative Summit

November 9, 2020

H2@Scale

DOE initiative focusing on hydrogen as an energy intermediate.

Report on technical and economic potential released October 7:



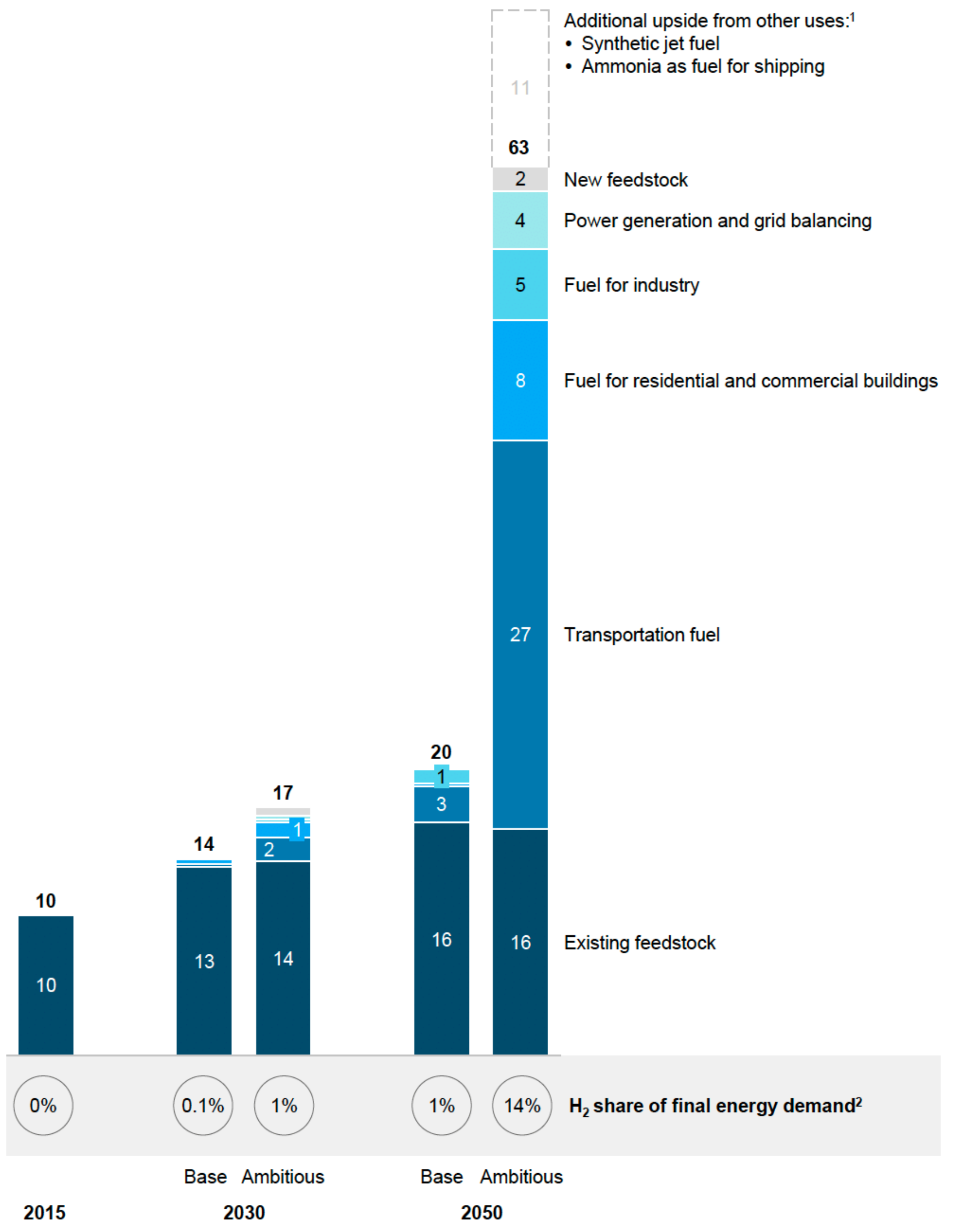
https://www.nrel.gov/docs/fy21osti/77610.pdf

We Identified 106 MMT/yr Hydrogen Serviceable Consumption Potential without Direct Use of Hydrogen for Heating

Exhibit 2

Hydrogen demand potential across sectors – 2030 and 2050 vision

Million metric tons per year



[1] Assuming that 20% of jet fuel demand would be met by synthetic fuel and 20% of marine bunker fuel by ammonia

[2] Demand excluding feedstock, based on IEA final energy demand for the US

Note: Some numbers may not add up due to rounding

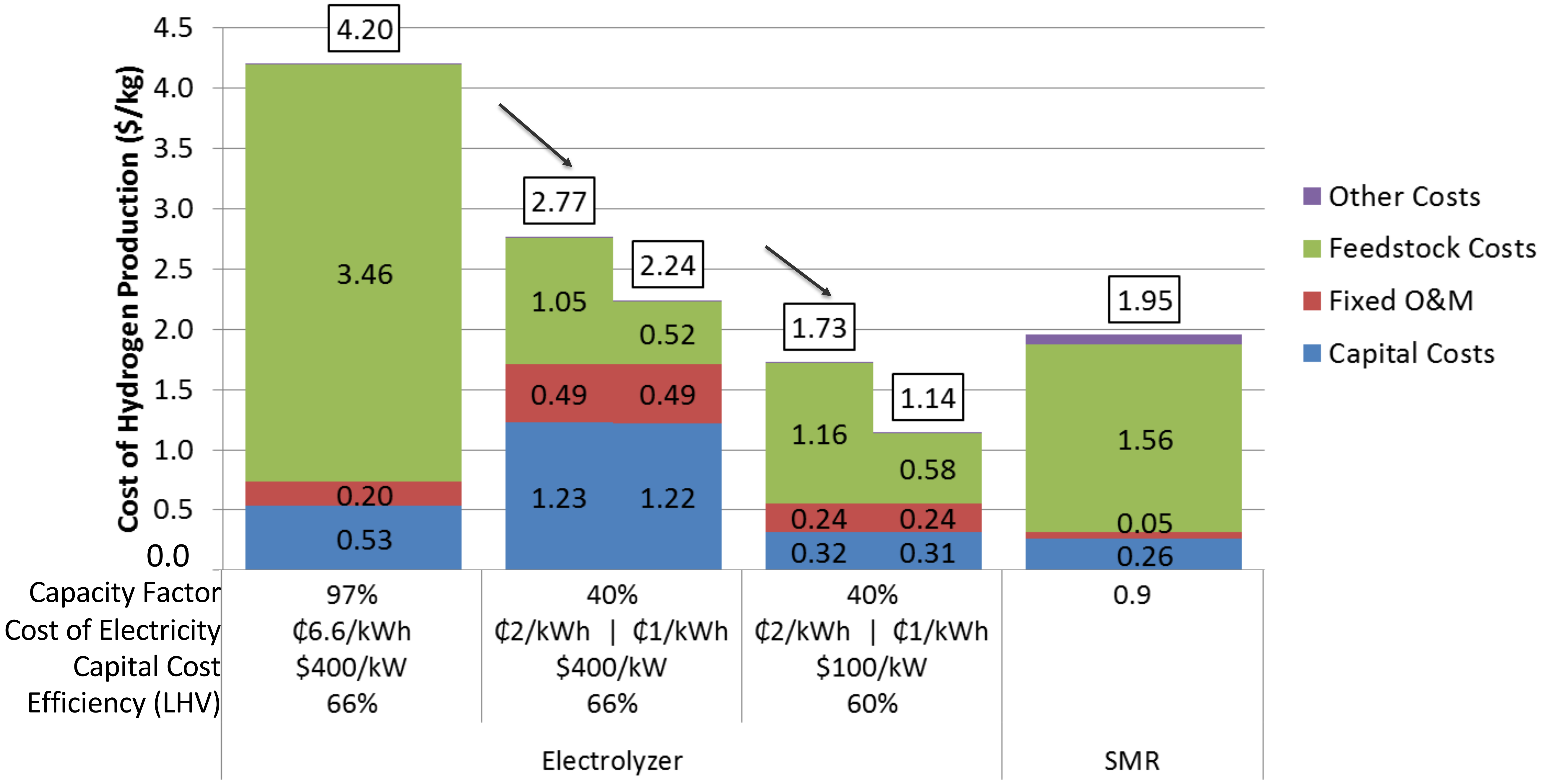
Source: Road Map to a US Hydrogen Economy Reducing emissions and driving growth across the nation. www.ushydrogenstudy.org

Application	NREL's Serviceable Consumption Potential (MMT/yr)	2015 Market for On-Purpose H2 (MMT/yr)	Roadmap 2050 Ambitious Scenario (MMT/yr)
Refineries and the chemical processing industry (CPI) [a]	7	6	8
Metals	12	0	3
Ammonia	4	3	5*
Biofuels	9	0	1*
Synthetic hydrocarbons	14	1	2
Natural gas supplementation	16	0	13
Seasonal energy storage for the electricity grid	15	0	4
Industry and Storage Subtotal	**77**	**10**	**36**
Light-duty fuel cell electric vehicles (FCEVs)	21	0	27
Medium- & Heavy-Duty FCEVs	8	0	
Transportation Fuel Subtotal	**29**	**0**	**27**
Total	**106**	**10**	**63**

* Does not include additional potential upside from other uses

Opportunity for Low-Temperature Electrolysis using Low-Cost Electricity

Potential Levelized Costs of H_2 Production



Availability of low-cost electricity can help enable low-cost H_2 production, even at low capacity factors.

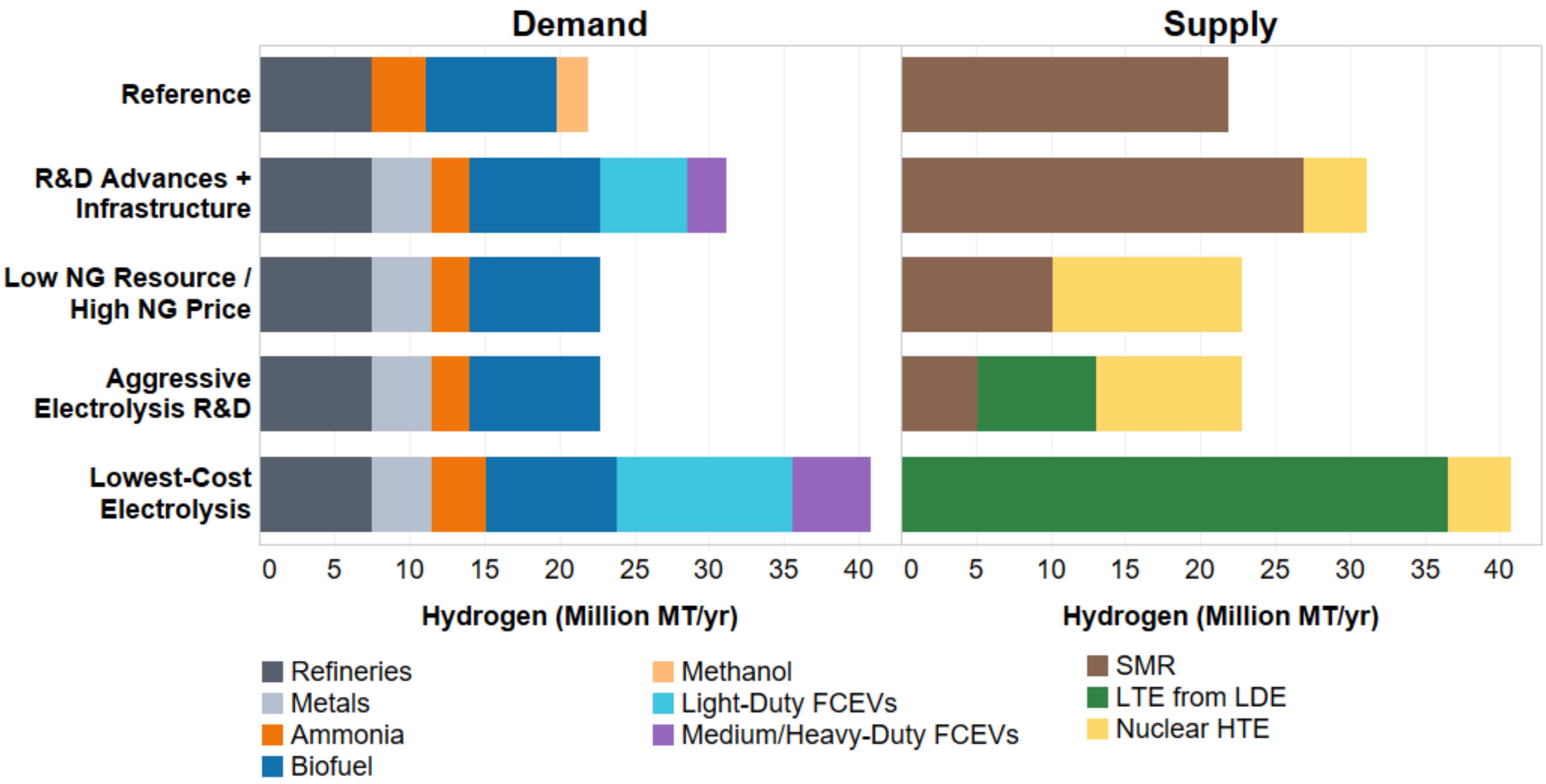
Source: Bryan Pivovar & Josh Eichman

SMR: Steam methane reforming of natural gas

Economic Potential: Limitations and Caveats

- **Market equilibrium methodology and market size estimates in 2050**
  - **Transition issues such as stock turnover are not considered**
- **New policy drivers, such as emission policies, are not included either for hydrogen or the grid**
- Technology and market performance involve many assumptions about adjacent technologies
  - In all but the non-reference scenario, the assumption is that R&D targets are met
- Demand analysis is limited to sectors that could be forecast for the foreseeable future
  - Hydrogen use to convert biomass based market size equal to 50% of aviation demand
  - Hydrogen for industrial heat is not included
  - Single hydrogen threshold price for fuel cell vehicle market estimates
- Estimates of delivery costs were standardized and without location specificity
- Potential long-term production technologies (e.g., photo-electrochemical) not included
- Economic feedback impacts are not considered
- Competing technologies (both for markets that use hydrogen and for resources to generate hydrogen) are addressed in a simplified manner only

Economic Potential Results



The economic potential of hydrogen demand in the U.S. is 2.2-4.1X current annual consumption.

SMR: Steam methane reforming of natural gas
HTE: High temperature electrolysis

LTE: Low temperature electrolysis
LDE: Low-cost, dispatch-constrained electricity

Summary of Key Conclusions

- **Hydrogen's serviceable consumption potential in the U.S. is >10X current annual consumption.**
- **The economic potential of hydrogen demand in the U.S. is 2.2-4.1X current annual consumption**.
  - Range across 5 scenarios developed using a variety of economic and R&D success assumptions
- **Hydrogen for thermal energy will likely need emission or other drivers to penetrate U.S. markets**

Thank You

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www.nrel.gov

Details are available at:

https://www.nrel.gov/docs/fy21osti/77610.pdf

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Fuel Cell Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

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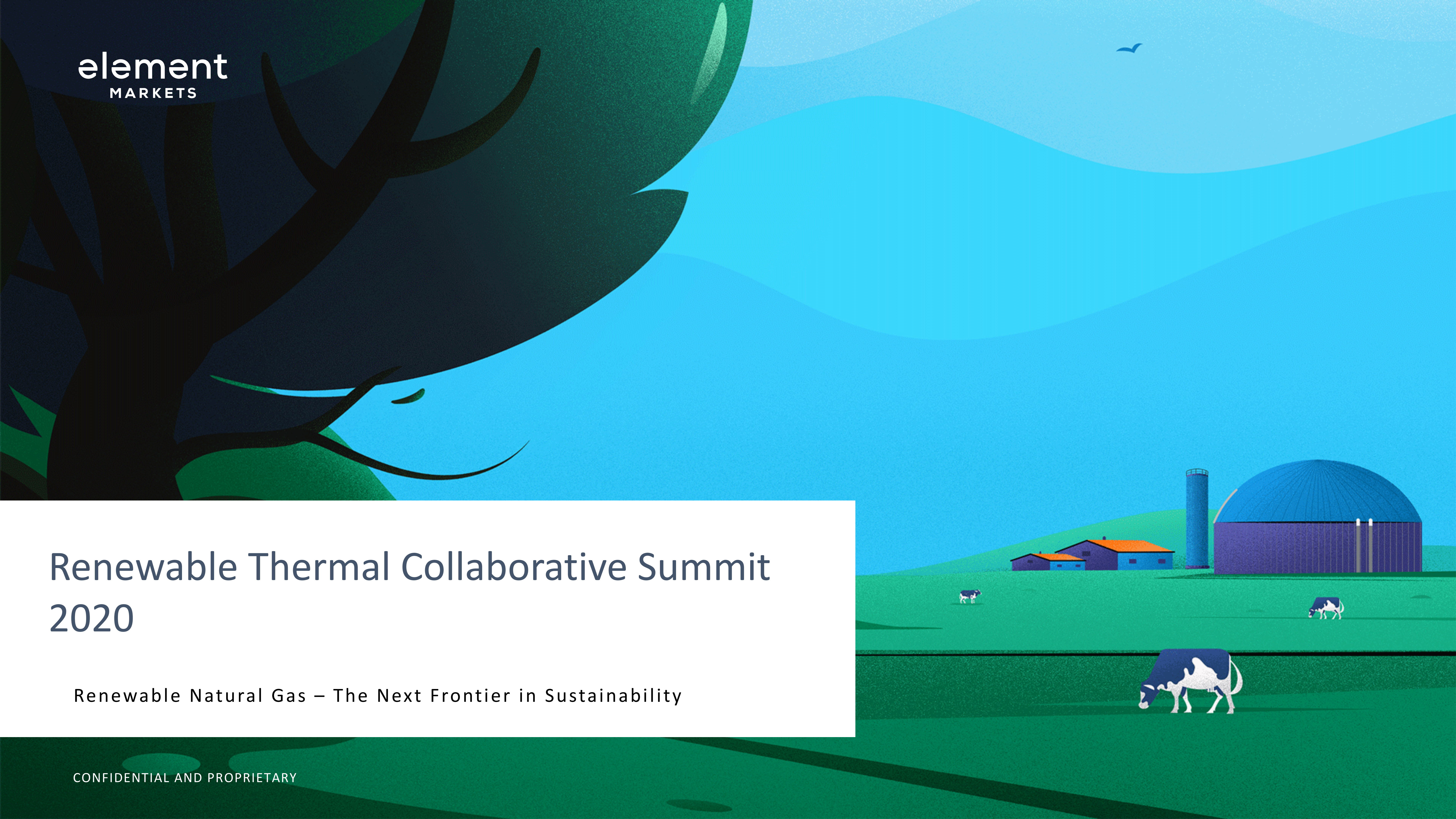

Renewable Thermal Collaborative Summit 2020

Renewable Natural Gas – The Next Frontier in Sustainability

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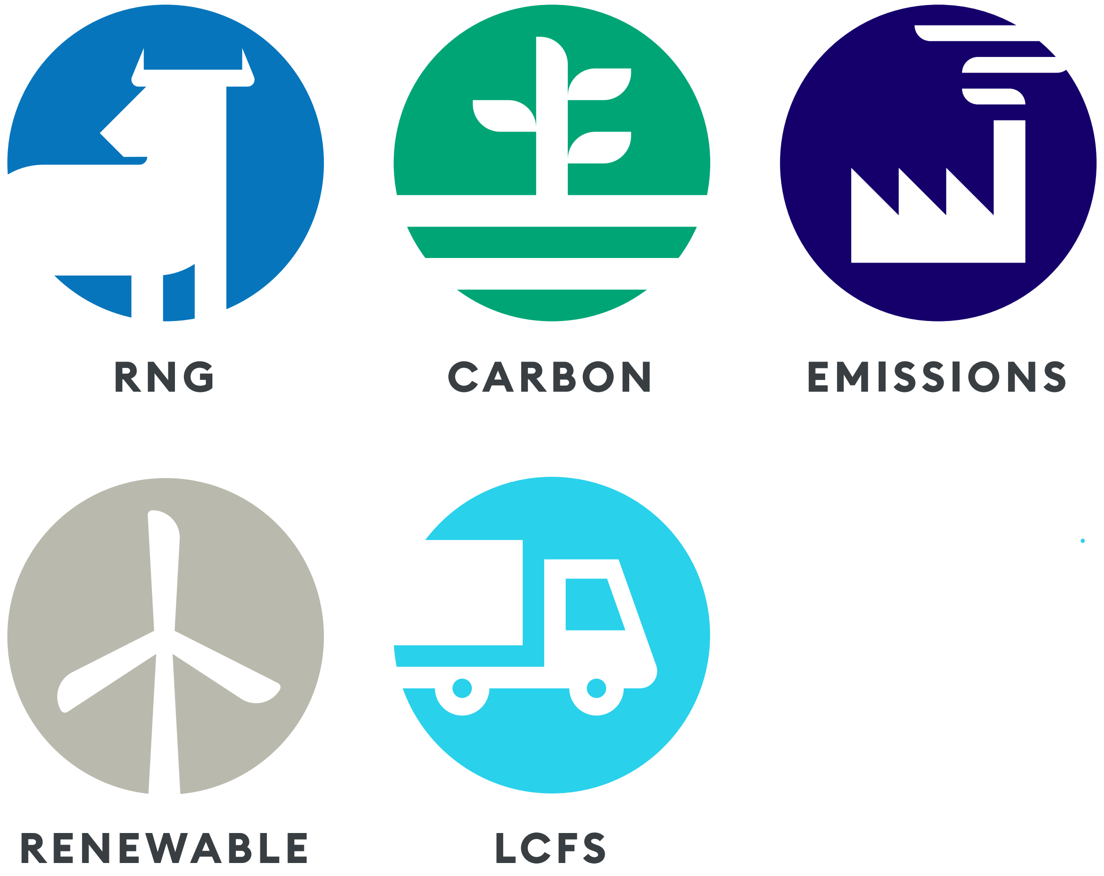
Leading the Clean Energy Revolution



Element Markets is the leading independent marketer of environmental commodities in the U.S., helping clients meet compliance mandates and voluntary targets in a world shifting to renewable and low carbon resources.

- Founded in 2005
- Over $3 billion in environmental commodities transacted
- Customer base of over 800 companies within environmental markets
- Major provider and marketer of carbon credits and renewable natural gas (RNG) for universities, Fortune 100 companies, and municipalities
- Largest independent marketer of RNG in North America representing ~20% of U.S.supply
- Wholesale provider of carbon credits with over 40 million tonnes transacted on behalf of clients
- Generating Low Carbon Fuel Standard (LCFS) credits since 2014 with over 30 Tier II pathways
- Leading marketer of Emissions Reduction Credits in the U.S.

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Element Markets Business Lines: Renewable Natural Gas

Our Renewable Natural Gas team partners with farmers, landfill operators and wastewater treatment plants to generate renewable fuel and bring it to market for utilities, fleet operators and voluntary buyers seeking to capture the benefits of cleaner energy.

- Largest independent marketer of renewable natural gas (RNG) in North America
- Recognized leader in ultra-low carbon intensity ("CI") fuels
- Upstream assets include offtake from over 20 production facilities and over 35 active pathways under either the RFS or LCFS programs
- End markets include RNG-to-transportation, RNG-to-electricity and voluntary buyers of RNG
- Experienced, solutions-oriented team with a relentless appetite for innovation and client service

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Understanding Renewable Natural Gas

Renewable natural gas (RNG) is classified as methane gas captured from eligible sources that is cleaned and upgraded to pipeline specification and injected into the common carrier pipeline. Eligible sources include:

Landfill Gas

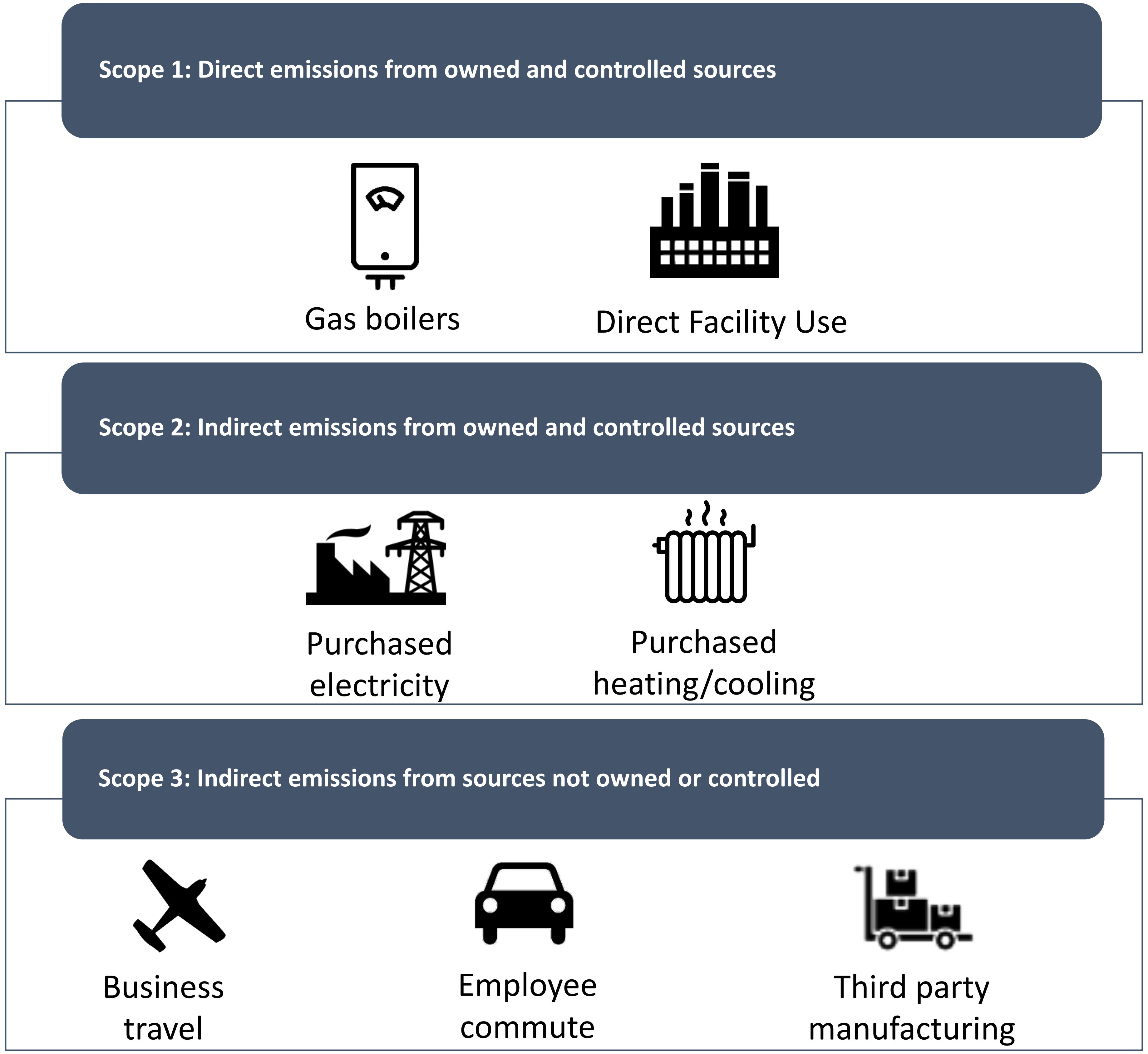
Wastewater Treatment Facilities

Anaerobic Digesters (Swine or Dairy Projects)

RNG is represented in units of MMBtu or Dekatherms and the majority of RNG is consumed for compliance purposes under the Renewable Fuels Standard (RFS) and Low Carbon Fuel Standard (LCFS)

Deriving Value from RNG in the Voluntary Space

Scope 1 Emission Reductions represent the next frontier for sustainability initiatives



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Menu of Environmental Products: RNG for Scope 1 Emissions Mitigation

Scope	Example Sources	Mitigation Measures	Reporting/Registry Options
1 Direct emissions from owned & controlled sources	• Gas boilers • Natural gas use at the facility	Carbon offsets (local/global)	• Climate Action Reserve (CAR) • American Carbon Registry (ACR) • Verra
		Renewable natural gas	• Renewable Thermal Certificate (RTC) solution • Physical delivery of RNG
2 Indirect emissions from owned and controlled sources	• Purchased electricity • Purchased heating/cooling	Renewable Electricity Certificates (RECs) applied electricity purchases (available in North America / Europe)	• Green-e Energy Program
3 Indirect emissions from other sources	• Business travel • Employee commute • Third party manufacturing	Carbon offsets (local/global)	• CAR, ACR, or Verra

RNG Compliance Markets: RFS and LCFS Markets

Renewable Fuel Standard (RFS)

- Federal program administered by the EPA
- Established in 2005 and requires renewable fuel to replace petroleum-based transportation fuels
- Renewable Identification Numbers (RINs) are primary driver
- Renewable natural gas (cellulosic biofuel) generates 11.727 RINs per 1 MMBtu of gas

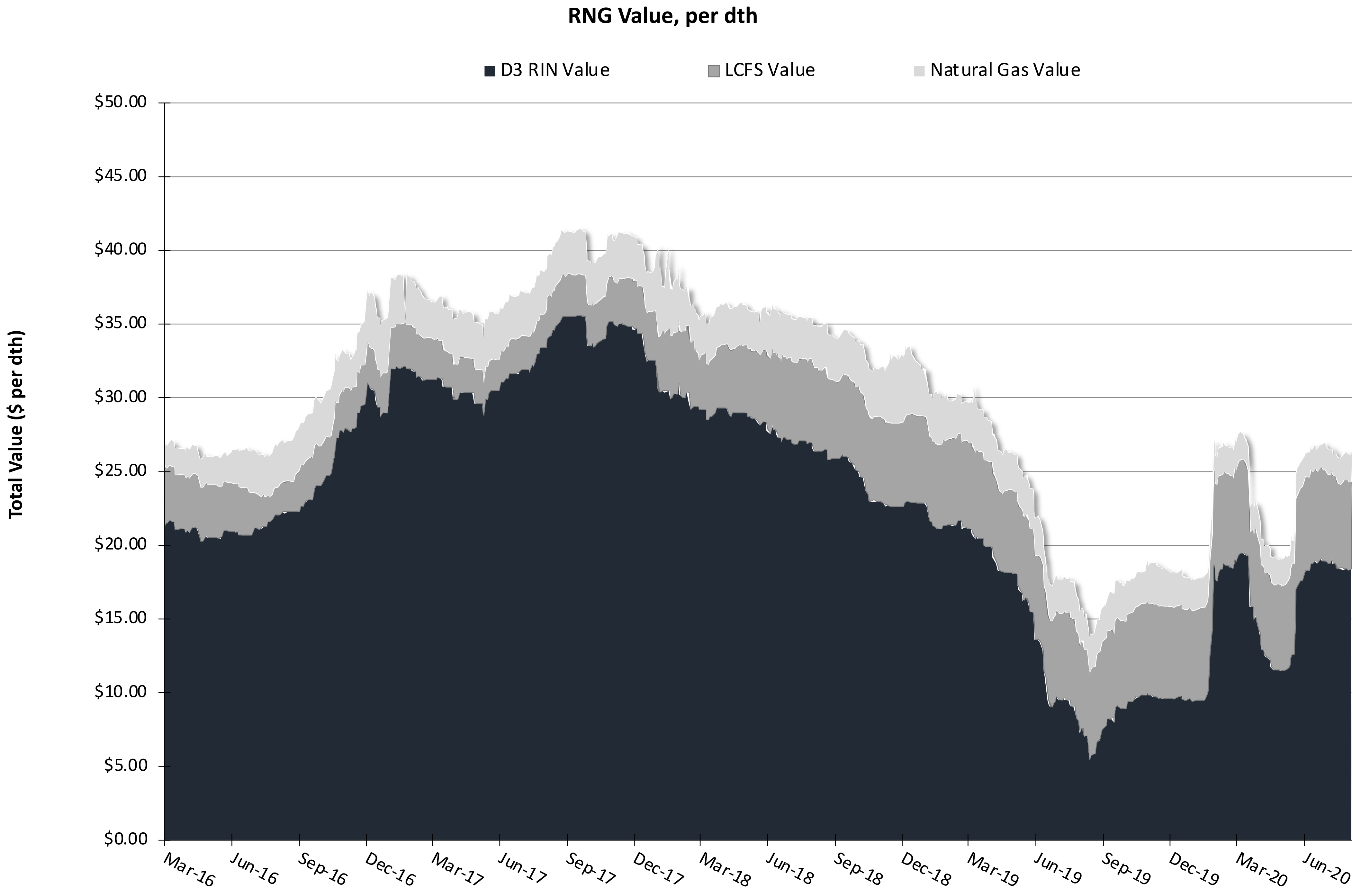
Low Carbon Fuel Standard (LCFS)

- Transportation fuels program originating in California and spreading to Oregon and other states
- Administered by the California Air Resources Board (CARB)
- Carbon Intensity (CI) scores drive credit generation process
- Different sources of RNG yield varying amounts of LCFS credits based on CI scores

Combined Value of RNG in Transportation Markets

RNG supply is constrained by demand from RFS and LCFS markets with current RNG prices yielding **$26 (landfill gas) to over $100 (swine gas) per MMBtu**. RNG benefits from the stacking of environmental commodities (RINs and LCFS credits).

Long term deals trade lower than current annual market creating opportunity for sustainable buyers.



Green-e Thermal RECs: Scope 1 Mitigation Solution

The Renewable Thermal Collaborative, M-RETs, and the Center for Resource Solutions are all working to launch a robust system for renewable thermal certificates (RTCs)

RTCs represent the following*:

1 dekatherm of renewable thermal generation

May include verified carbon intensity data and track full or partial carbon lifecycles

Include serial number, account, project, feedstock, vintage, location, quantity

Tracking system prevents double-counting and provides assurance to buyers of voluntary RNG

*Source: M-RETS

element MARKETS

Thank you.

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Co-President

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3200 Southwest Freeway, Suite 1310
Houston, TX 77027

Emissions House of the Year
Energy Risk Magazine,
2020, 2018, 2014, 2010

Environmental Products House of the Year Energy Risk Magazine, 2019

Energy Risk Environmental Rankings:

- #1 U.S. Regional Greenhouse Gas Dealer
- #1 U.S. Voluntary GHG Credit Dealer
- #2 Renewable Energy Credit Dealer

Best Trading & Advisory Company in North American Renewable Identification Numbers
Environmental Finance Magazine

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Framework for Hybrid Renewable Thermal Systems (RTES)

Parthiv Kurup, Sertaç Akar, Colin McMillan, Josh McTigue, and Matt Boyd

Renewable Thermal Collaborative Virtual Summit

V3, November 9th 2020

Material includes unpublished preliminary data and analysis that is subject to change - not for distribution, quotation, or citation

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- Purpose of Presentation
  - To provide information on developing framework and selecting technologies for Industrial Process Heat (IPH)
  - Not to convey findings or conclusions to take away or inform activities
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Content

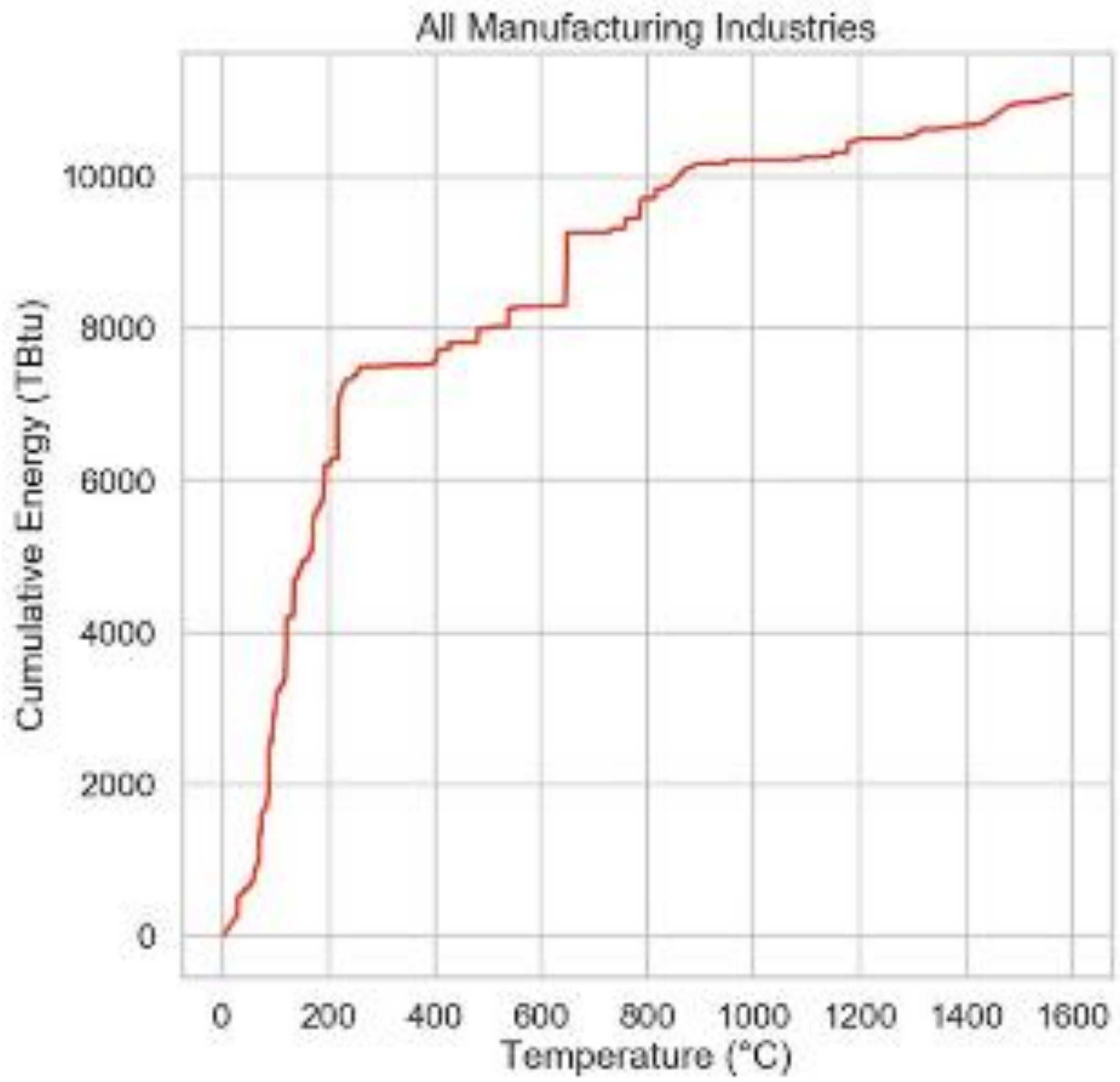
1 Introduction

2 Framework

3 Modelled Scenarios and Hybrid RTES

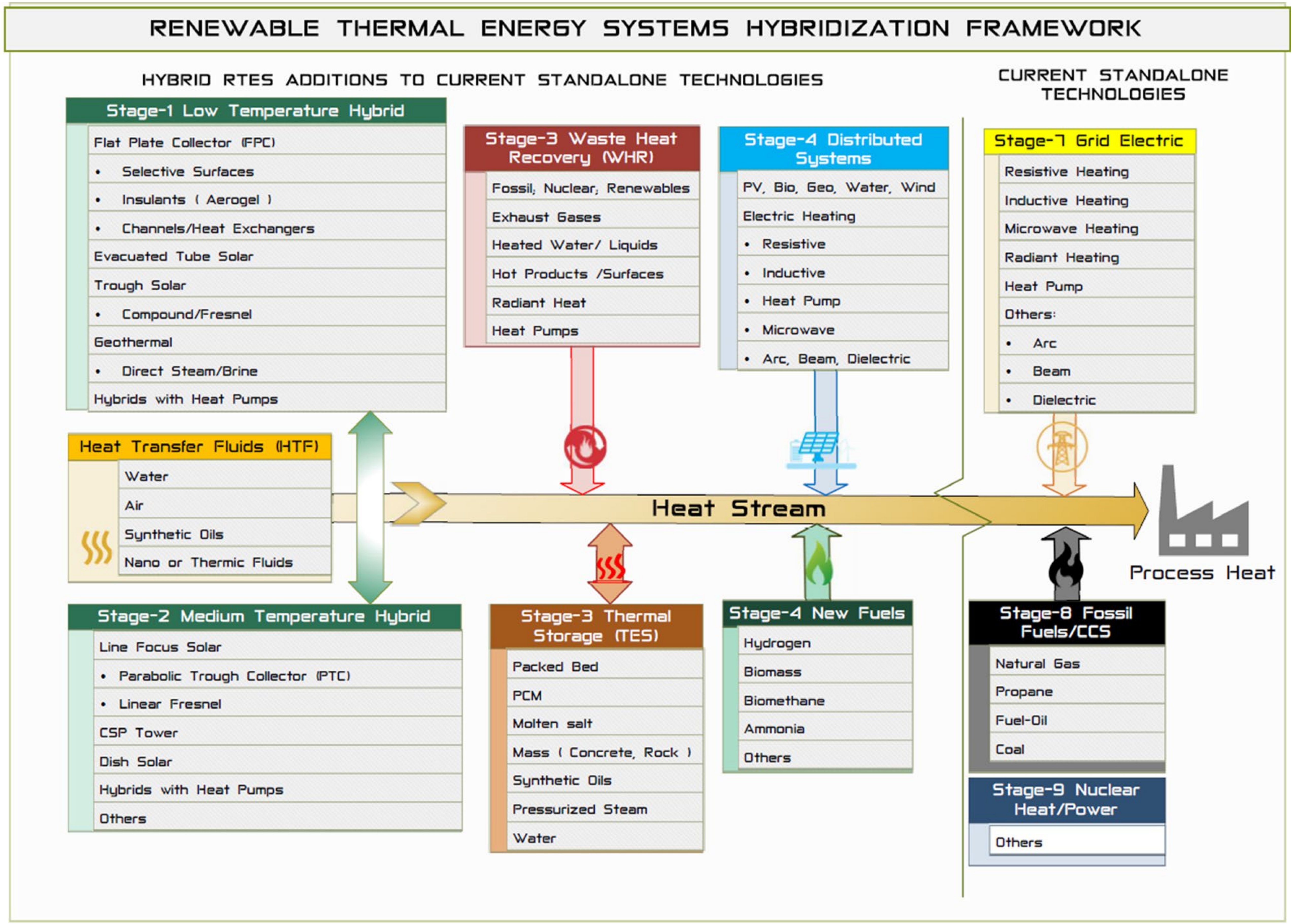
1. Introduction

- **IEA estimated that 32% of total global energy is consumed by industry**
  - In the U.S., ~2/3 of process heat is used for applications below 300°C
- **Hybrid renewable energy systems (RTES) solutions and thermal energy storage (TES) are important for the dispatch of heat, at optimal times needed by the demands of buildings and industrial applications**
  - In Denmark, hybrid RTES solutions are being deployed and are cost competitive with the current regional NG costs
- **The National Renewable Energy Laboratory (NREL) System Advisor Model (SAM) is a well-established tool for modeling solar heat systems:**
  - Flat plate collectors (FPCs) with glazed and evacuated tube
  - Linear Fresnel collectors (LFCs)
  - Parabolic trough collectors (PTCs).
- **SAM (2020.2.29) can do single system modelling very well but it is not yet capable of hybrid RTES modelling at different temperatures or combining technologies such as FPCs and CSP.**



Cumulative process heat demand by temperature in 2014. *Illustration by Colin McMillan, NREL* - https://www.nrel.gov/analysis/solar-industrial-process-heat.html

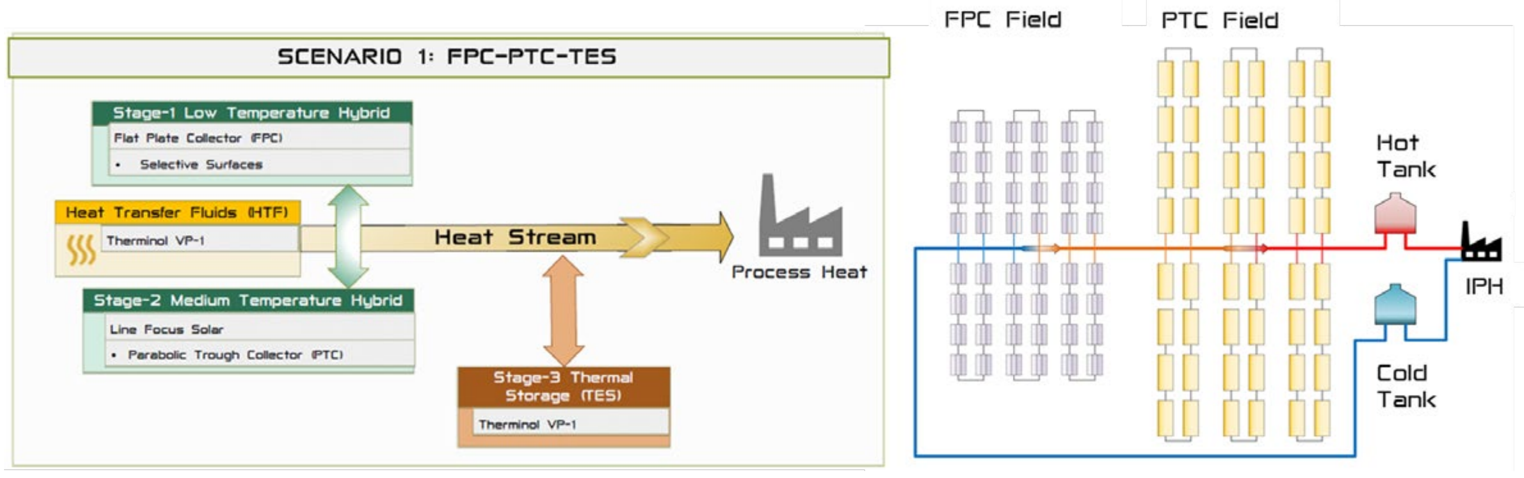
2. Framework



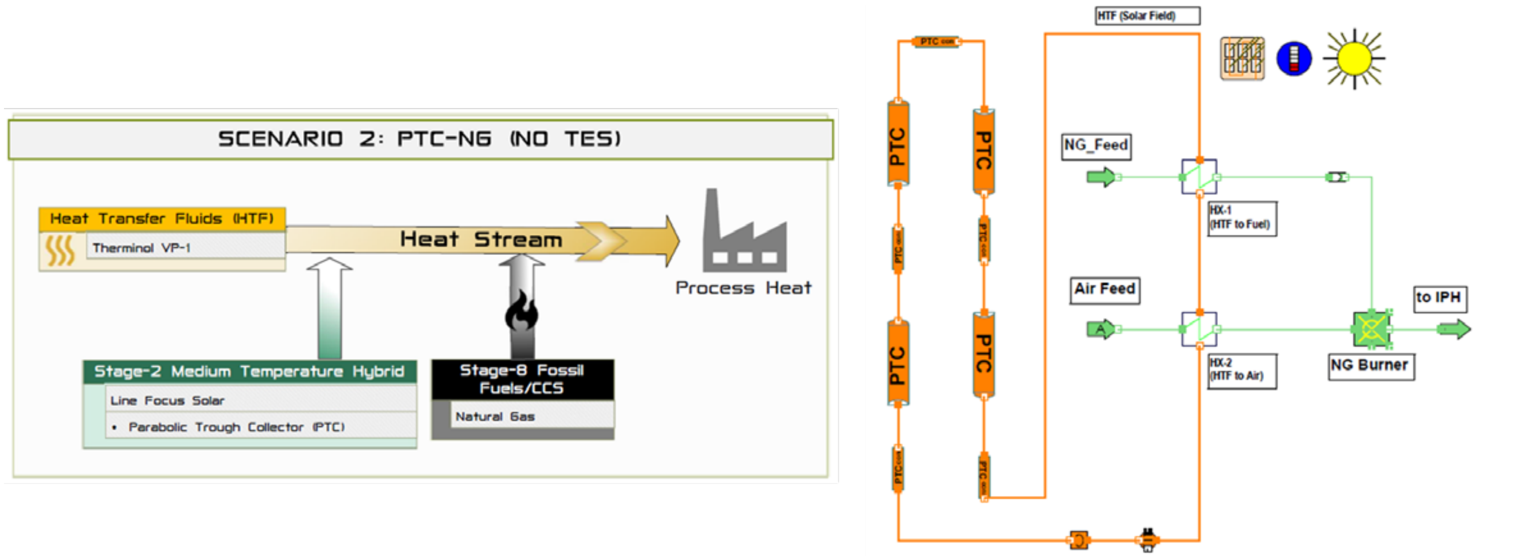
- We have investigated a variety of approaches to hybrid system modeling for RTES at different temperatures or combinations of technologies and developed an initial framework.
- The hybridization framework starts by creating a heat stream and raising the temperature of that heat stream by various combinations of RE technologies and other sources such as fossil fuels, renewably derived fuels, or electric heating in multiple stages, with options for TES and/or waste heat recovery (WHR).
- **Vision**: to create or further modify a Decision Support tool that helps the end-user ascertain potential yield, technology options and costs

Full Papers: Kurup et al. 2020, "Hybrid Solar Heat Generation Modelling and Cases", and Akar et al. 2020 "Renewable Thermal Hybridization Framework for Industrial Process Heat Applications" to be published

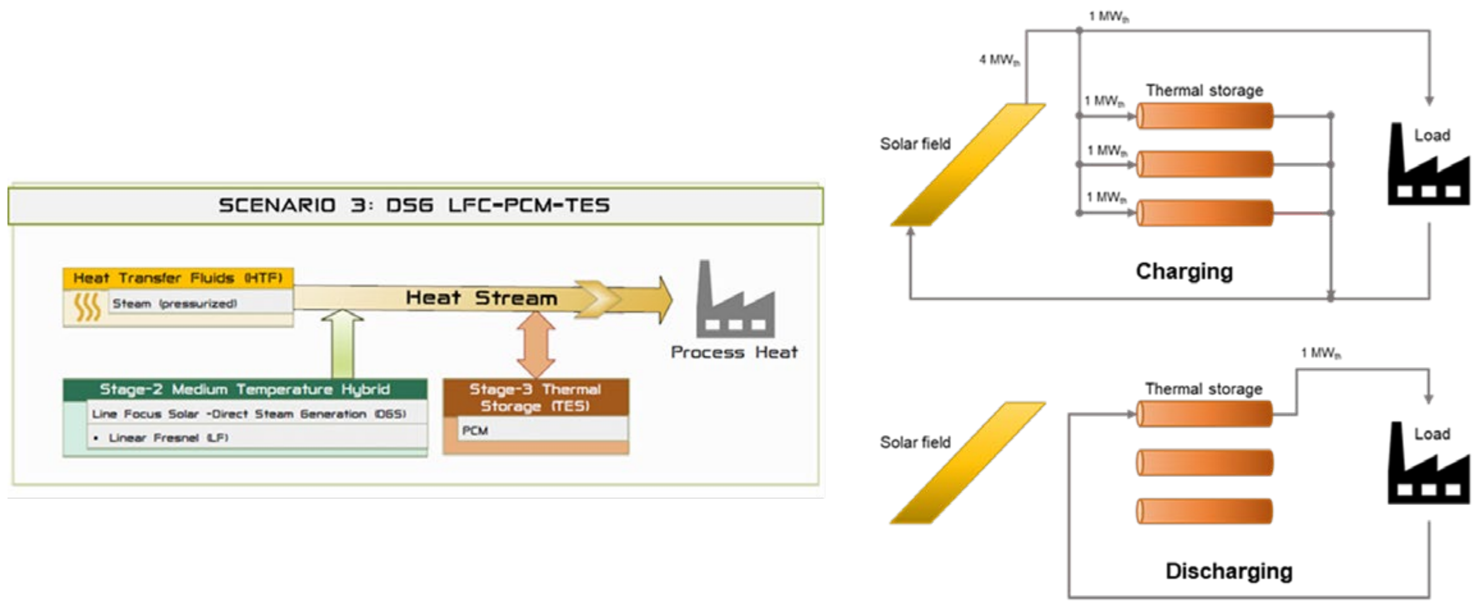
3. Modelled Scenarios



The first scenario is designed to pre-heat the HTF (Therminol VP-1) through a Flat Plate Collector (FPC) system to reach 150°C, and then send it to a Parabolic trough Collector (PTC) system to reach an exit temperature of 300°C for an IPH application.



The second scenario is designed to use a PTC solar field to heat an air and/or fuel stream of a natural gas (NG) burner system. This is expected to be suitable for hybridization of existing industrial systems that use NG burners today.

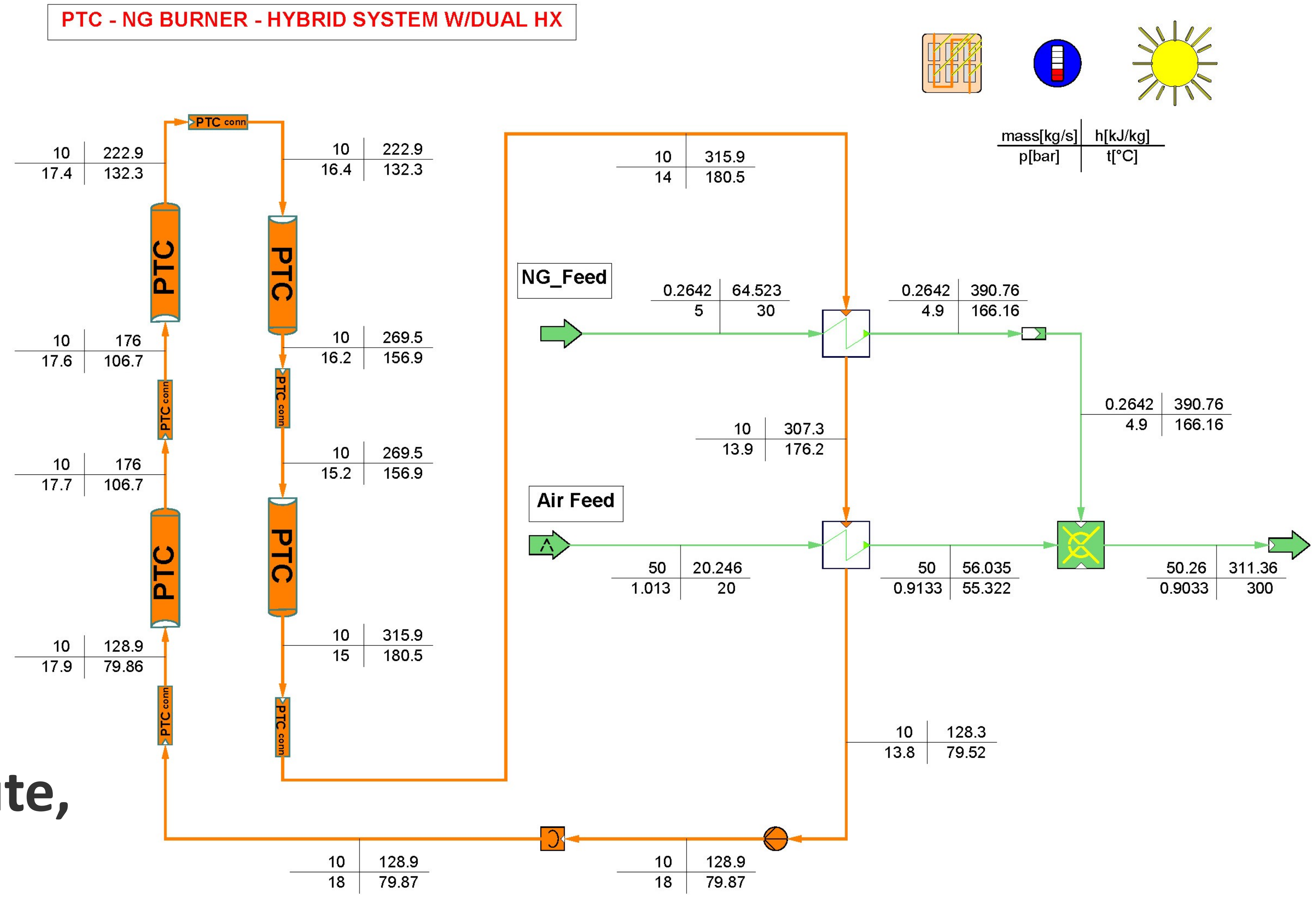


The third scenario uses direct steam generation (DSG) linear Fresnel collectors (LFCs) coupled with TES which uses phase change materials (PCMs) to improve the system's flexibility and capacity factor. PCMs store energy in the latent heat of the phase change and can thus achieve relatively high energy densities.

Scenario 2:Parabolic Trough Collectors (PTCs) with an HTF and NG burner

PTCs with an HTF and NG burner

- A fully operational PTC system has been modelled with a variable HTF temperature.
- The PTC system is designed to operate with a 24% capacity factor and providing a maximum outlet temperature between 180 °C and 300 °C
- 26% NG offset is possible, without TES, with 24% capacity factor



Preliminary Results—Do Not Distribute, Quote or Cite

Heating from solar field	No Heating	180 °C	200 °C	250 °C	300 °C
NG mass flow (kg/s)	0.301	0.264	0.256	0.242	0.223
Change in NG mass flow (%)	0.00%	-13%	-15%	-19%	-26%

Thank You!

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Thank you for attending this session.

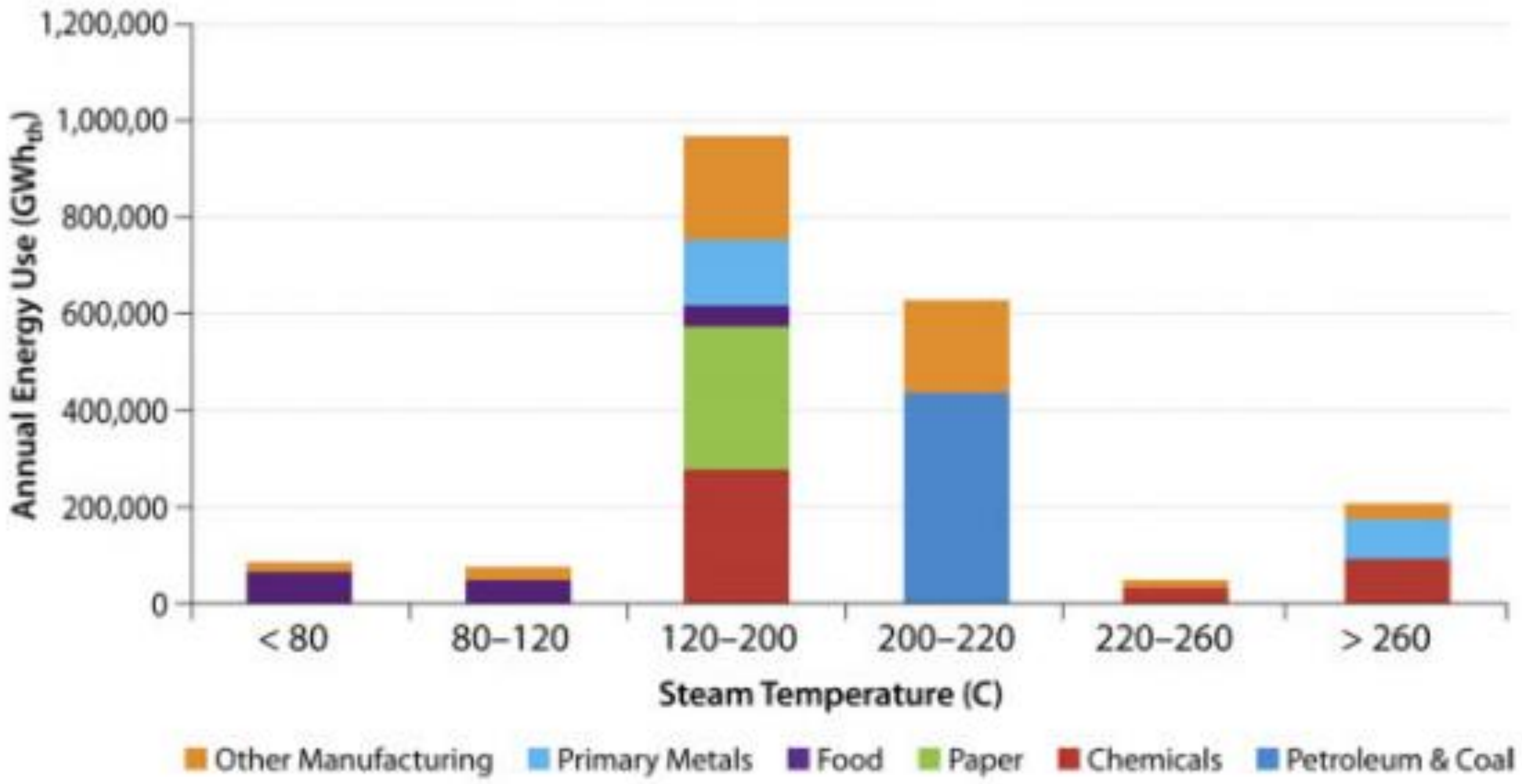
Please join us for the technology breakout sessions.

Return to the Attendee Portal and to “State of the Technologies.” Here you will find the Zoom links to different breakout rooms.

Each breakout session will last 16 minutes. Once the 16 minutes is up, switch to another breakout session room by going back to the Attendee Portal.

Backup

Industrial Steam Use in the U.S.



⇨ **120-220 °C steam is target for Solar IPH**

Full report: Kurup and Turchi 2015, "Initial Investigation into the Potential of CSP Industrial Process Heat for the Southwest United States", found here - https://www.nrel.gov/docs/fy16osti/64709.pdf

Data from Fox, Sutter, and Tester, "The Thermal Spectrum of Low-Temperature Energy Use in the United States." 2011

Sample Technologies for IPH

Temp. Range	Technology	HTF of Choice	Applications/Comments
< 80°C	Flat plate (e.g. Evacuated) Non-tracking compound parabolic (CPC) Solar pond PV Heat Pump	Air Water/glycol	Hot water Space heating
80 to 200°C	Waste heat pumps Parabolic Trough Linear Fresnel	Water/steam	Hot water or steam for IPH
200 to 300°C	Parabolic Trough Linear Fresnel	Mineral oil	Direct heat or steam for IPH Vacuum-jacket receivers become necessary to minimize heat loss
300 to 400°C	Parabolic trough Linear Fresnel	Synthetic oil	Direct heat or steam for IPH
400 to 550°C	Parabolic trough Linear Fresnel	Steam or Molten salt	Electric power
> 550°C	Heliostat/central receiver Parabolic dish Resistive heating e.g. PV Microwave/Induction heating e.g. PV	Steam or Molten salt	Electric power

Future Work

- **FPCs and PTCs with TES**
  - Use of different HTFs like mineral oil or unpressurized water (i.e. Tårs plant)
  - Connecting the FPC Field to PTC field by a HX for a better pressure and temperature control
  - Adding more capital cost estimates for both FPC and PTC system and improving the SAM financial models to reflect a real hybrid case project economics
  - Potentially releasing the hybrid add-on to the SAM public version

- **PTCs with an HTF and NG burner**
  - Adding economic analysis to optimize the RTES in a cost-effective hybrid scenario.
  - Investigating other alternative scenarios to compare effectiveness of use of hybridization and systems costs.
    - TES addition to the PTC system,
    - Co-operation of PTC and NG burner in two separate heat streams
    - Waste heat recovery with a recuperator after NG burner
  - Adding optimized dispatch model by using hourly DNI data as an input.

- **DSG LFCs and phase change material (PCM) storage**
  - Detailed dispatch model and system size optimization
  - Investigating other PCMs such as Lithium nitrate, sodium nitrate-potassium nitrate
  - Adding cost analysis