U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

AMMTO & IEDO JOINT PEER REVIEW

May 16th-18th, 2023

Washington, D.C.

Low Carbon Fuels, Feedstocks, and Energy Sources (LCFFES)

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Industrial Efficiency and Decarbonization Office (IEDO)

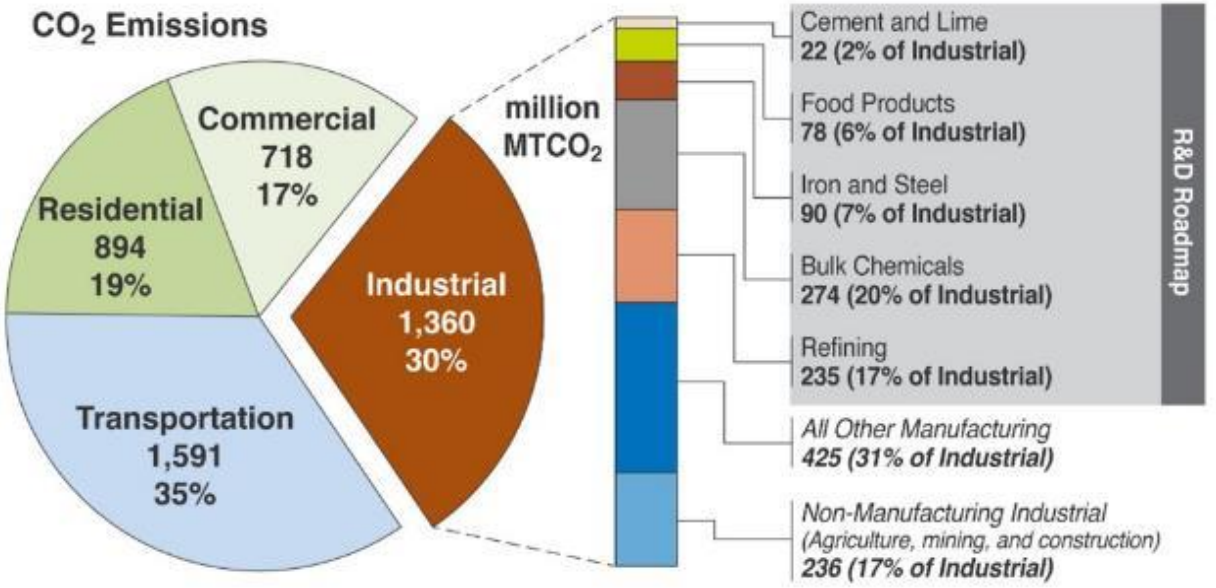
This presentation does not contain any proprietary, confidential, or otherwise restricted information

Industrial Sector Overview

The industrial sector is composed of mature, established facilities with the bulk of emissions from five energy- and emissions-intensive sectors.

- **Common end-uses underpin the diversity of processes and products found within the industrial sector, e.g.,**
  - Process heat (>90% supplied by fossil fuel combustion)
  - Onsite generation of steam and electricity
- **Provides opportunities to address GHG emissions of multiple sectors at once (i.e., cross-sector).**

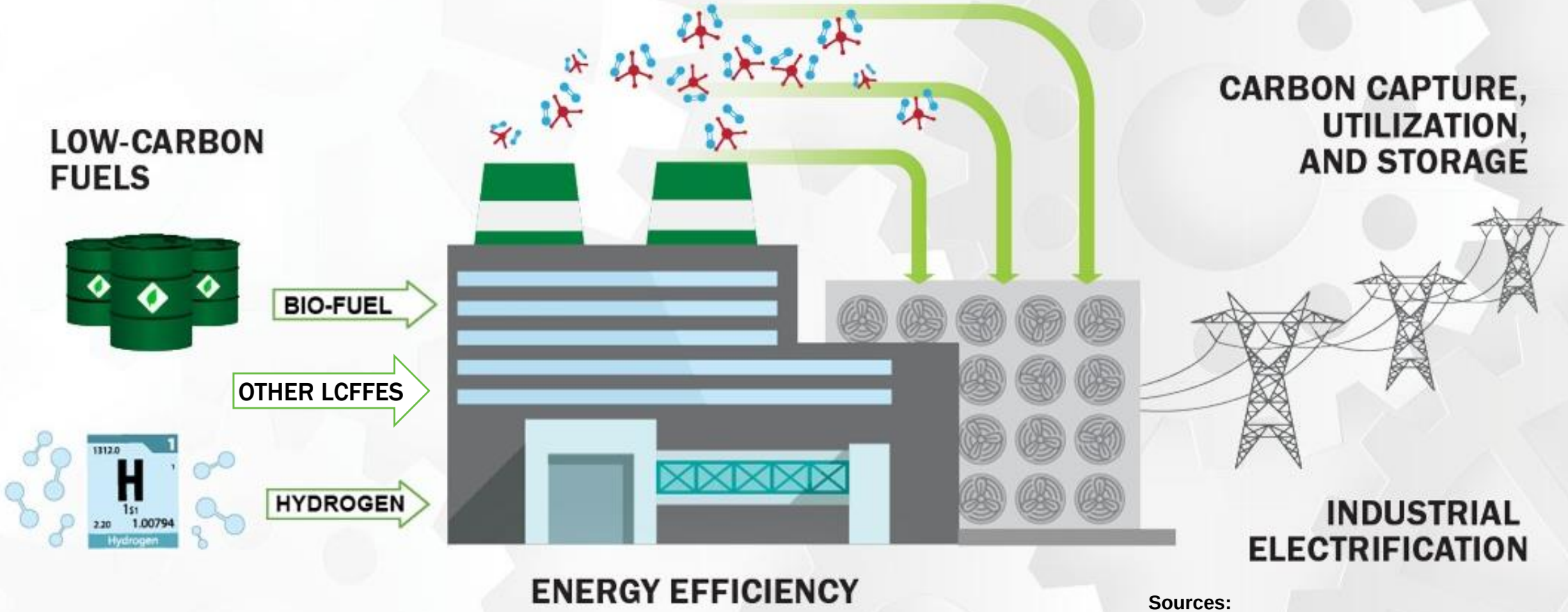
U.S. Energy-related CO_2 Emissions by Sector and Subsector (2020)



Share of the **4,563 million metric tons of CO_2** emitted by the U.S. in 2020 (EIA 2021)

Industrial Decarbonization Roadmap

Four Main Strategies to Decarbonize the Manufacturing Sector



Sources:

(1) DOE Industrial Decarbonization Roadmap, September 2022

Industrial Heat is Essential and Pervasive

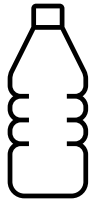
Every major industry subsector uses heat in different ways to make products…

drying
paper, batteries

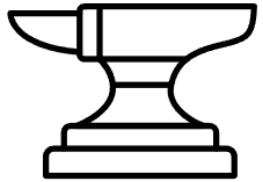
steam
pasteurized food

distillation
high purity chemicals

melting
formed plastics, semiconductors



smelting
iron, copper, aluminum



calcining
cement, lime

Emissions equivalent to over half of U.S. home energy use

3 Pathways to Decarbonize Industrial Heat

Goal: The Industrial Heat Shot™ is a Department-wide initiative to develop cost-competitive industrial heat decarbonization technologies with at least 85% lower greenhouse gas emissions by 2035.

CO_2

85% Reduction

2035

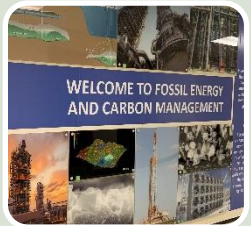
Generate Heat from Clean Electricity

Integrate Clean Heat from Alternative Sources

Innovative Low- or No-Heat Process Technologies

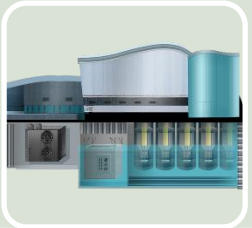
Advanced Materials and Manufacturing Technologies Office

Bioenergy Technologies Office



Fossil Energy and Carbon Management

Hydrogen and Fuel Cell Technologies Office



Nuclear Energy

Solar Energy Technologies Office

Role of LCFFES in Process Heat Decarbonization

Thermal process	Industrial sector							
	Iron and steel	Petroleum refining	Chemical industry	Glass	Aluminum	Pulp and paper	Food processing	Cement
Calcining								
Bonding, curing and forming								
Drying								
Fluid heating								
Heat treating (metal and nonmetal)								
Metal and nonmetal reheating								
Metal and nonmetal melting								
Other heating: processing								
Reactive thermal processing								
Smelting, agglomeration etc								
Steam generation								

Blue = low temperature (<800°F);
Orange = medium temperature (800°F to 1,400°F);
Red = high temperature (>1,400°F).

Integrate Clean Heat from Alternative Sources

Reduce Emissions:
switch to low-emissions heat sources

Alternative for hard-to-electrify applications: high-temperature applications or processes that require direct-fired heating

Examples:
solar thermal, advanced nuclear, geothermal, hydrogen, some sustainable fuels

Sources:
(1) Decarbonization Option for Process Heating, Arvind Thekdi, 2022

LCFFES Background and High-Level Goals

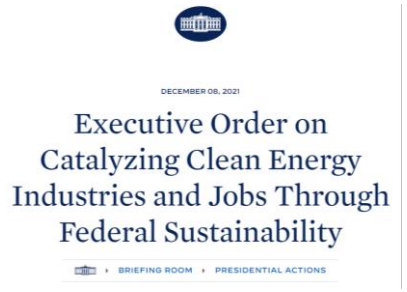
Low-Carbon Fuels, Feedstocks, and Energy Sources is one of the 4 pillars laid out in the DOE Decarbonization Roadmap for reaching net-zero emissions by 2050.

- <u>Potential impact</u>: in combination with LCFFES, reduce emissions by over 100 $MTCO_2$/yr.

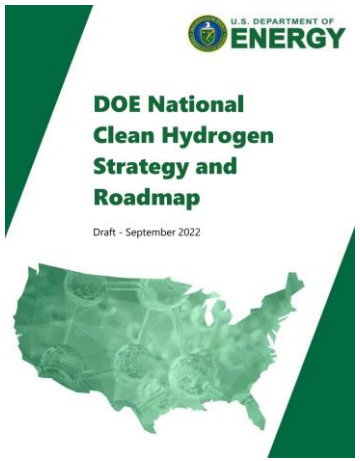
- In alignment with DOE and White House initiatives:

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Industrial Heat™

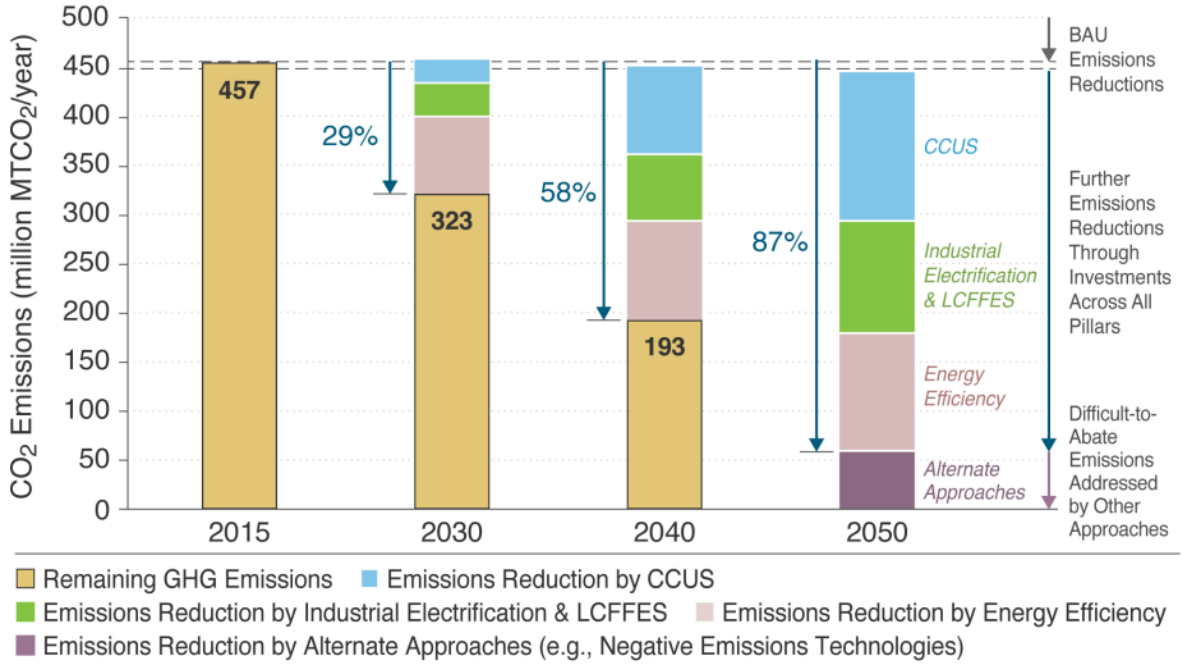
<u>Industrial Heat Shot</u>



<u>White House Buy Clean Initiative</u>



<u>Clean Hydrogen Strategy and Roadmap</u>



Sources:

(1) DOE Industrial Decarbonization Roadmap, September 2022

Challenges and Barriers

Challenges/Barriers	LCFFES Examples
Lack of process equipment to address alternative fuel-specific phenomena	• Biosources: solids handling, pretreatment, and conversion processes required for a diversity of feedstock • Hydrogen: high flame speeds, low flame visibility, high NOx emissions, high moisture content in exhaust
Lack of auxiliary equipment to address industrial infrastructure needs	• Hydrogen: H_2 compressors for lower volumetric energy density; sensors and controls; valves and gaskets for leakage mitigation; new piping materials for corrosion prevention • Renewables: additional infrastructure to support transmission; energy storage requirements for fluctuating energy supply
Industry hesitation towards adopting new energy sources	• Lack of validation with new process equipment/energy inputs • Current facility sensors and controls are inadequate for new energy inputs • Product quality concerns • Potentially high capital costs and longer paybacks
Mitigation of other harmful impacts	• Biofuels: monoculture and water scarcity concerns • Hydrogen: high NOx emissions, higher moisture content in exhaust • Nuclear: radioactive wases posing health and environmental concerns
Inadequate supply chain for materials and fuels	• Hydrogen: sufficient availability of clean H2 to meet industry needs • Biosources: seasonal availability constraints and variability in feedstocks • Renewables: widespread access to key components, materials, and expanded manufacturing capacity needed to support continued transition

Stakeholder Engagement and Analysis to Develop Objectives and Targets

Goal: invest in RD&D that supports adoption and/or use of low-carbon energy sources and feedstocks to achieve an efficient and competitive industrial sector with net-zero greenhouse gas emissions by 2050.

Lab & Industry Input

pre-2023

- ✓Thermal Process Intensification Workshop
- ✓Industrial Decarbonization Roadmap
- ✓Energy Earthshot Lab Ideation Forum
- ✓DOE National Clean Hydrogen Strategy and Roadmap

Planned Stakeholder Engagement

2023+

- ✓ DOE Pathways to Commercial Liftoff: Clean Hydrogen
- May 2023 Cross-Sector Technologies Stakeholder Meeting
- Industrial Heat Earthshot pre-summit forum
- Industrial Heat Earthshot Summit
- Roadmap Extension Project 2.0
- Industrial Technology Innovation Advisory Committee

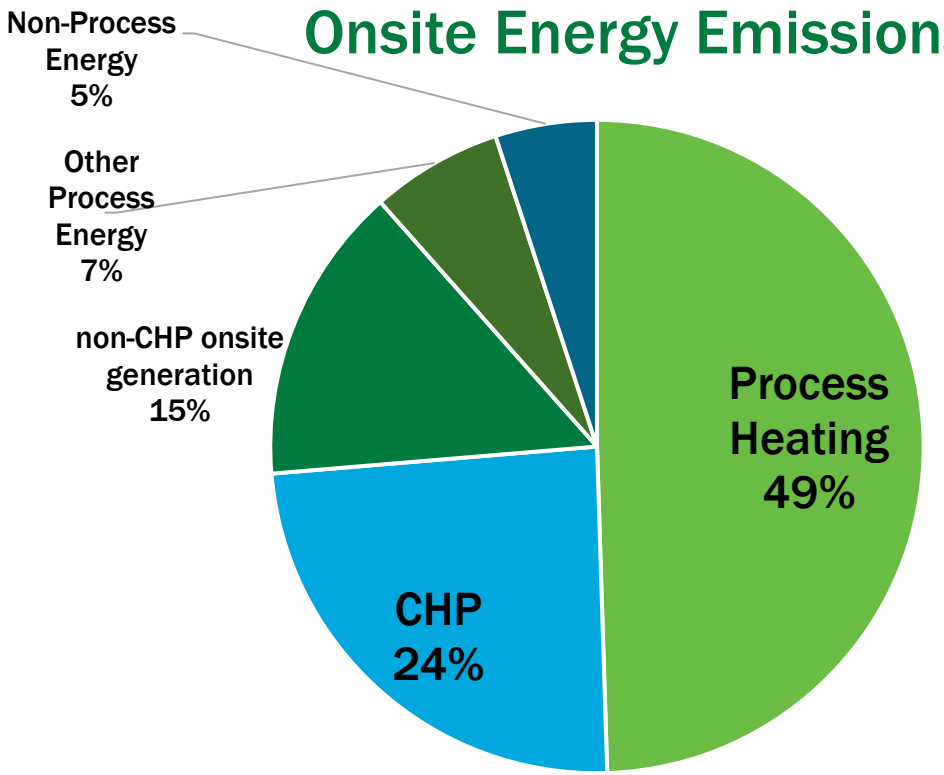
Convening a **diverse** set of stakeholders:

- Industry
- Academia
- National Labs
- Non-Profits
- Utilities
- Labor Groups
- State and Federal Government

Objectives and Targets

- **LCFFES's goal**: invest in RD&D that supports adoption and/or use of low-carbon energy sources and feedstocks

- **Targets**:
  - reduce emissions by 85% for clean fuels and energy sources
  - Validate process parameters and heating profiles as comparable with incumbent
  - Non-GHG emissions reductions comparable to incumbent



Example technical areas of interest:

- Hydrogen and H2-carrier combustion
- Biofuels
- Biomass
- Process byproducts
- Integrating CSP, geothermal, and nuclear into industrial processes

Sources:
(1) DOE Manufacturing Energy and Carbon Footprint, 2018.

Example – Hydrogen combustion

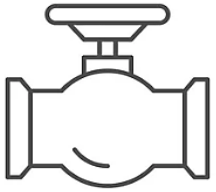
Opportunity:

- Global low-carbon H_2 demand is expected to increases to 200 MMT by 2030
- High flame temperature enables decarbonization of hard-to-electrify industrial process heating applications

Considerations:

- Hydrogen combustion characteristics are different from natural gas, which require investment to accelerate development and testing of combustion system components, while optimizing overall systems from the facility-level perspective.
- Industry needs flexibility in blending: until clean H_2 supply chain is secure, industry needs to be able to use NG- H_2 blends of 0-100%.

Process Equipment: Novel technologies to accommodate unique H_2 combustion phenomena while achieve comparable heating profiles with varying blends



Auxiliary Equipment: New injectors, gaskets, compressors, and valves materials required for H_2 volumetric density, high flame speeds, and high temperatures.

Exhaust Mitigation: Potentially higher NOx and moisture content in H_2 exhaust requires specialized process design and equipment

Sensors and Controls: Air/fuel flow control for variable H_2 supply, advanced exhaust damper controls, leak detection, and system monitoring for safety

LCCFES Portfolio

Congressionally directed activity:

- *Provides up to $55,000,000 for research, development, and deployment to develop and promote the adoption of technologies that can dramatically reduce the greenhouse gas emissions from process heating applications.*
- *The agreement provides not less than $13,000,000 to provide ongoing support for the Combined Heat and Power (CHP) Technical Assistance Partnerships (TAPs) and related CHP Technical Partnership activities, including not less than $5,000,000 for the TAPs and not less than $7,000,000 for related CHP activities*

Total	# Awards	Funding Mechanism	Topic Area	Description
$13.2M	TBD	FY23 MT FOA	Low-Carbon Fuels Utilization R&D	• Research, development, validation, and demonstration to accelerate the commercial readiness of hydrogen-fueled process heating technology and low-carbon-input, flexible CHP.
$16.3M	7	FY19 MT FOA FY20 MT FOA	Demonstration and Validation in district energy systems	• RD&D to advance DE systems, including integration of CHP, renewables, and/or energy storage into DE systems for improving grid services and resiliency.
$23.9M	12	FY18 Flexible CHP FOA FY18 lab call FY19 MT FOA	CHP components and systems development	• Connection of flexible CHP systems with the electricity grid for improved stability, and renewable generation capabilities. • Development of advanced CHP systems to instill resiliency and modernize energy generation and delivery. • R&D activities for increasing the CHP electricity generation efficiency while maintaining overall CHP system efficiency.

Current Portfolio Highlights

Flexible Natural Gas/Hydrogen CHP System Development & Demonstration

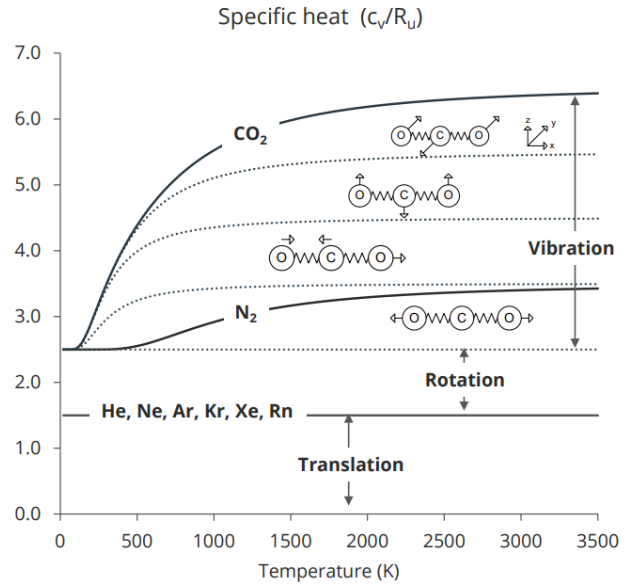
Lead: Caterpillar Inc.; + DESP, NREL, McKinstry, Linde, Ziegler Power Systems

Innovation: Develop and demonstrate a hydrogen/natural gas flex-fuel CHP genset capable of running on 100% natural gas, 100% hydrogen, or up to 25% hydrogen+natural gas blends. Will demonstrate in in District Energy St. Paul, Minnesota

Ultra-Efficient CHP with High Power/Heat Ratio Using a Novel Argon Power Cycle

Lead: Noble Thermodynamic Systems, Inc.; + Membrane Technology Research, UC Berkeley, Susteon, Trimeric

Innovation: Develop and demonstrate an Argon Power Cycle with 100% CO_2 capture, ≥ 70% overall CHP system efficiency, and a power to heat ratio above 1.5.



Portfolio Assessment

Current Portfolio

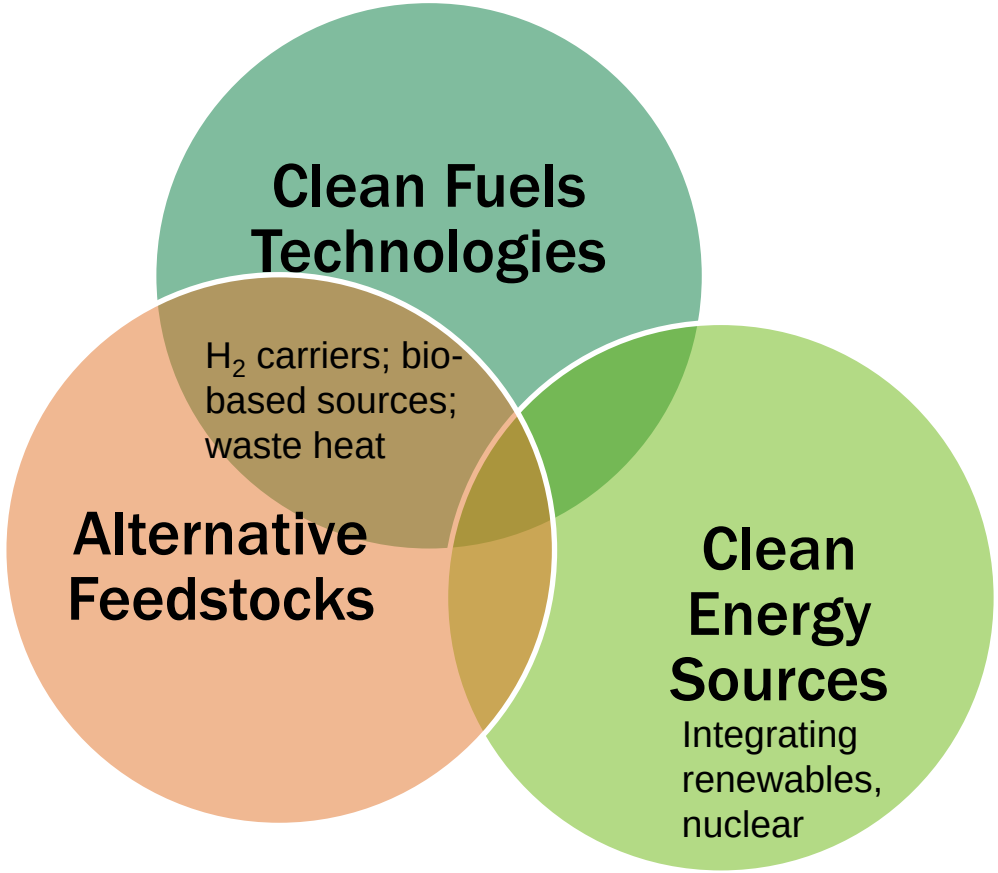
- **CHP**: CHP efficiency improvements, flexible CHP, high power-to-heat ratio CHP, demonstrations
- **District Energy**: waste heat recovery, validation and verification of renewably powered DE systems

Future Projects

Build upon IEDO's historical program in CHP and DE:

- Waste heat capture (FY22 Decarb FOA)
- Low-carbon fuels utilization (FY23 IEDO Multi-Topic FOA)
- Low-carbon input CHP for industrial sites (FY23 IEDO Multi-Topic FOA)

FY22 and 23 projects



Questions?

Low Carbon Fuels, Feedstocks, and Energy Sources

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U.S. DEPARTMENT OF ENERGY

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Backup

IEDO Strategy: Why Hydrogen?

- 10 million metric tons (MMT) of hydrogen are produced annually in the U.S. (90 MMT globally)
- Global low-carbon H_2 demand is expected to increases to 200 MMT by 2030
- Critical molecule with applications as transportation fuel, energy storage medium, and industrial fuel and feedstock
- Physical properties make hydrogen a promising candidate as a low-carbon process heating combustion fuel

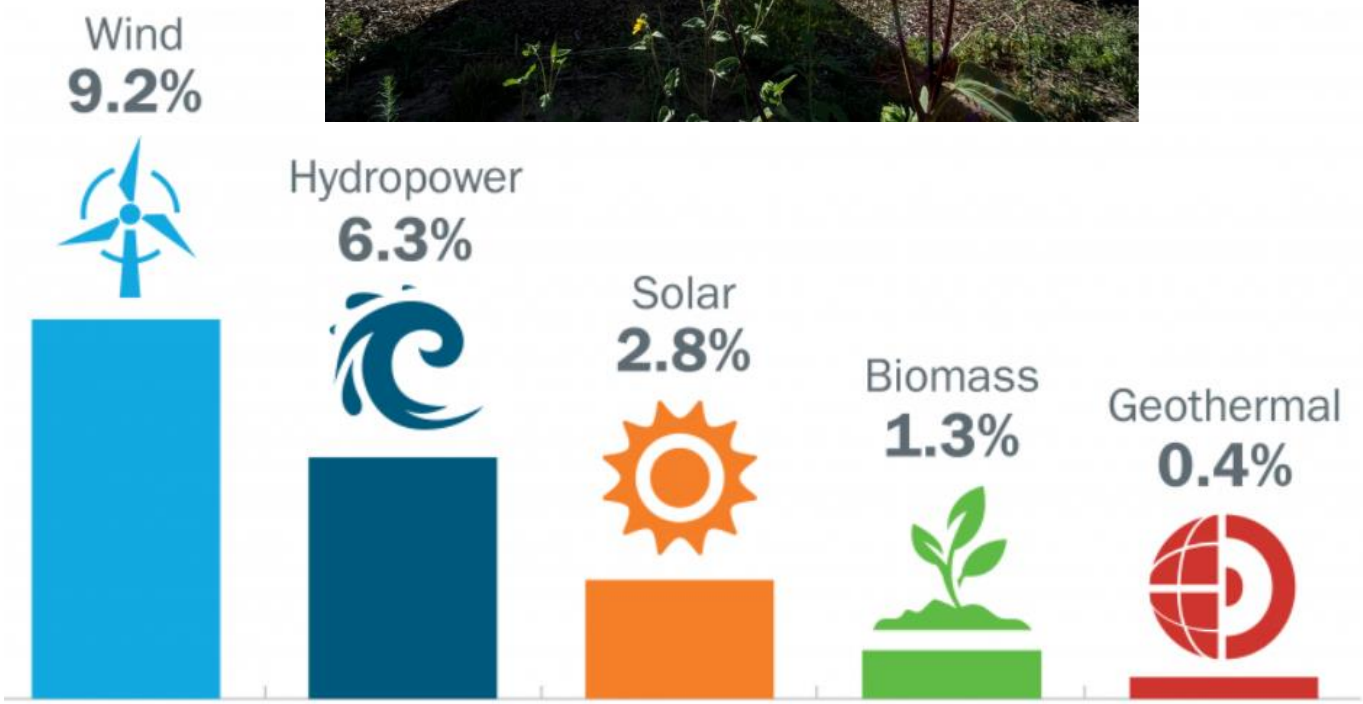
Fuel	Molecular weight (g/mol)	Heating Value by mass (Btu/lb)	Heating value by volume (Btu/ft^3)	Flame Speed (cm/sec)	Flame Temperature (°F)	Flammability limits
Hydrogen	2	51,623	266	300	4000	4% and 75%
Methane	16	21,518	881	30	3565	7% and 20%

- Clean combustion in oxygen generates only water vapor and excess O_2
- High flame temperature enables decarbonization of hard-to-electrify industrial process heating applications:
  - Calcination processes in the cement, chemicals, aluminum, and pulp & paper industries
  - Melting and forming processing in the glass industry
  - Reactive thermal processes in the iron & steel and nonferrous industries

DOE Industrial Decarbonization Roadmap. https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf
H2Tech Market Data 2023
Decarbonization Options for Process Heating White Paper, Arvind Thekdi, 2022

IEDO Strategy: Why Renewable Energy Sources?

- **20% of all U.S. electricity is generated from renewables.**
- **Other renewable sources of heat include the following:**
  - Concentrating Solar-Thermal Energy
  - Geothermal Energy
  - Hydropower
  - Wind Energy
- **Benefits include:**
  - Enhanced reliability, security, and resilience of the power grid
  - Reduced carbon emissions and air pollution
  - Increased U.S. energy independence
  - Increased affordability given cost-competitiveness with traditional energy sources
  - Expanded clean energy access for non-grid-connected communities
- **Focus: Integration of thermal energy from renewable sources for industrial process uses.**



Sources: Renewable Energy. Office of Energy Efficiency & Renewable Energy

Renewables: Challenges and Barriers

Challenges for wider deployment of renewable energy technologies include:

- *Access to Components and Raw Materials*: more widespread access to key components and materials, including expanded manufacturing capacity, is needed to ensure a continued transition from non-renewable sources[1]
- *Capital costs*: significant upfront expense required for deploying technologies with longer paybacks[1]
- *Transmission*: additional power lines and infrastructure needed to deliver electricity from point of generation to the user[2]
- *Energy Storage Needs*: a fluctuating supply often requires storage methods to meet a varying demand.[3]

Sources:

- (1) Jumpstart the Renewable Transition. United Nations. 2021
- (2) Barriers to Renewable Energy Technologies. UCS. 2017
- (3) Breaking barriers in deployment of renewable energy. National Library of Medicine. January 2019

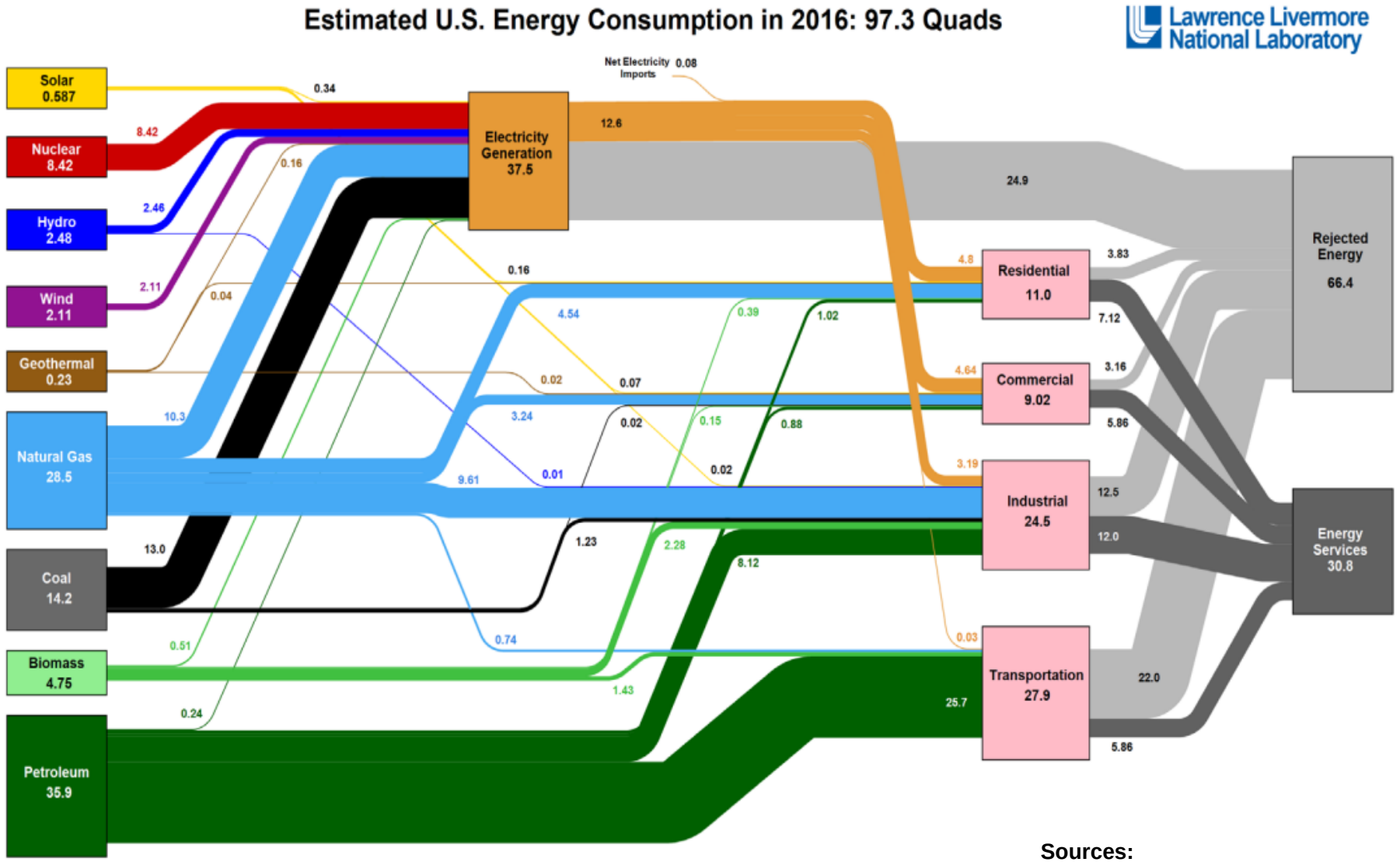
IEDO Strategy: Why Nuclear?

- **Nuclear power: use of sustained nuclear fission to generate heat and electricity**
  - Currently contributes nearly 20% of U.S. electricity generated[1]
- **The benefits of nuclear power as an energy source are that it is:[2]**
  - Concentrated
  - High quality
  - Dispatchable
  - Carbon-free
- **Strategy: invest in RD&D focused on integration methods of the heat generated into industrial processes to offset fossil fuel sources[2]**
  - Greatest thermodynamic efficiencies obtained via direct application of thermal energies produced from nuclear reactors
  - Estimated 16.5% of the domestic industrial heat market could be supplied with nuclear energy

Sources:

- (1) Nuclear. DOE.
- (2) DOE Industrial Decarbonization Roadmap, September 2022

Nuclear and Overall Energy Consumption



Sources:

- (1) The Future of Nuclear Energy. MIT Study. 2018

LCFFES Investment Areas from DOE Offices

DOE/Federal Office	Description	Relevant Sector
BETO	Alternative feedstocks for chemicals and material production: low-carbon fuels and energy through focus on alternative feedstocks (e.g., biomass, waste, CO_2)	Chemicals/refining
FECM	Natural gas-based hydrogen production with CCUS, hydrogen from sustainable biomass, municipal waste, and waste coal	Electricity production and chemicals/refining
HFTO	Clean hydrogen production for transportation fuel, storage, select chemicals production (e.g., ammonia), and iron & steel production	Transportation, chemicals, iron & steel
SETO	Concentrating solar thermal for industrial decarbonization: steel, cement, ammonia, fuels, and other chemicals and fuels	Chemicals/refining, cement, iron and steel
NE/HFTO	Hydrogen production from nuclear power for electricity production and feedstock for chemicals/fuels	Electricity production and chemicals/refining

- Other technology offices have LCFFES activities (hydrogen and other) with similar scopes that may offer opportunities to collaborate with IEDO.