U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
INDUSTRIAL EFFICIENCY & DECARBONIZATION OFFICE

Decarbonizing America's Industrial Sector

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IPER
January 30, 2024

Building a Net-zero, Clean Energy Future

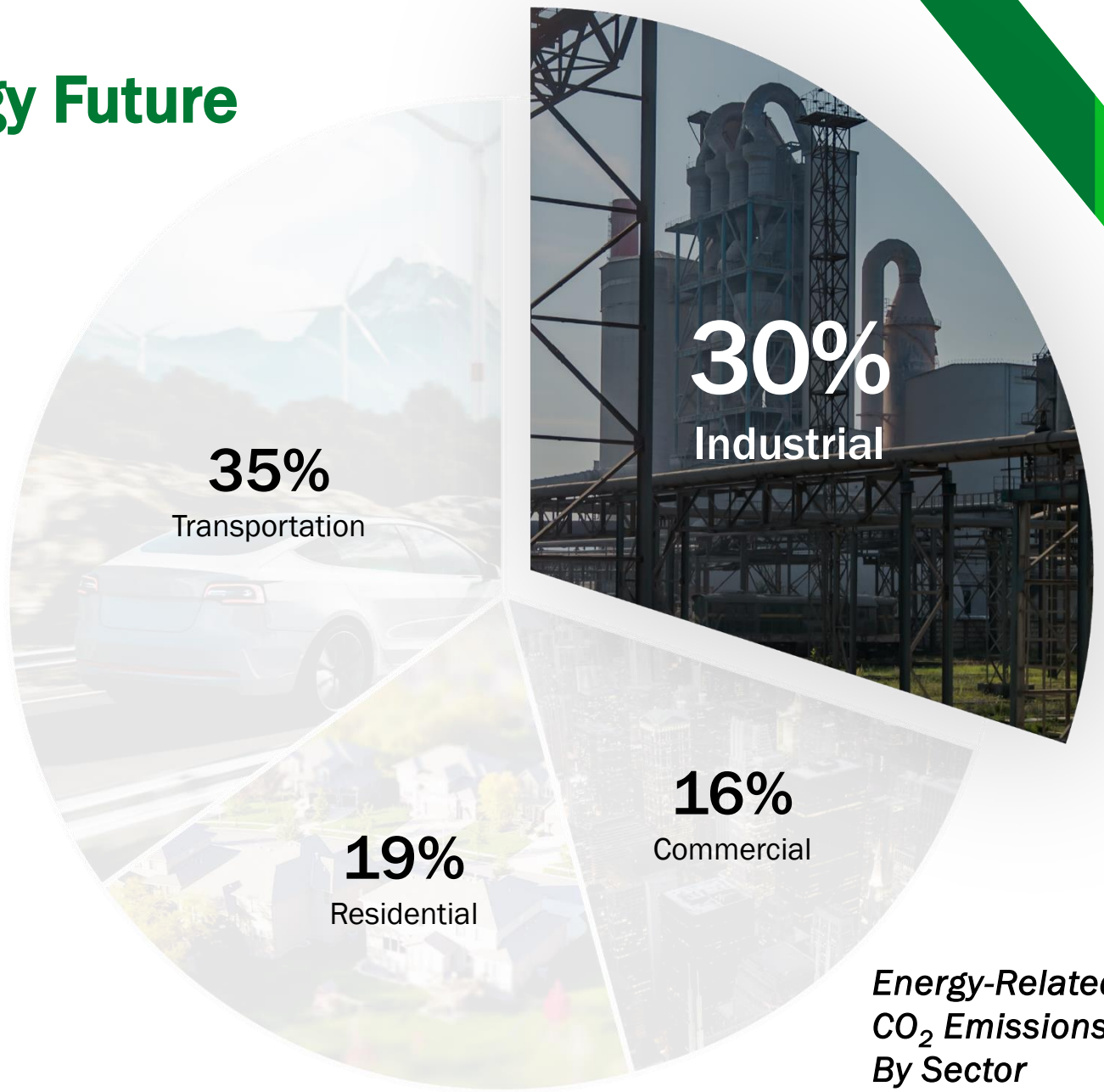
The U.S. industrial sector (manufacturing, agriculture, mining, and construction) accounts for:

33% of the nation's primary energy use

30% of CO_2 emissions

Anticipated industrial sector energy demand growth of 30% by 2050 may result in a:

17% CO_2 emissions increase*



Energy-Related CO_2 Emissions By Sector

*EIA, *Annual Energy Outlook 2021 with Projections to 2050*.

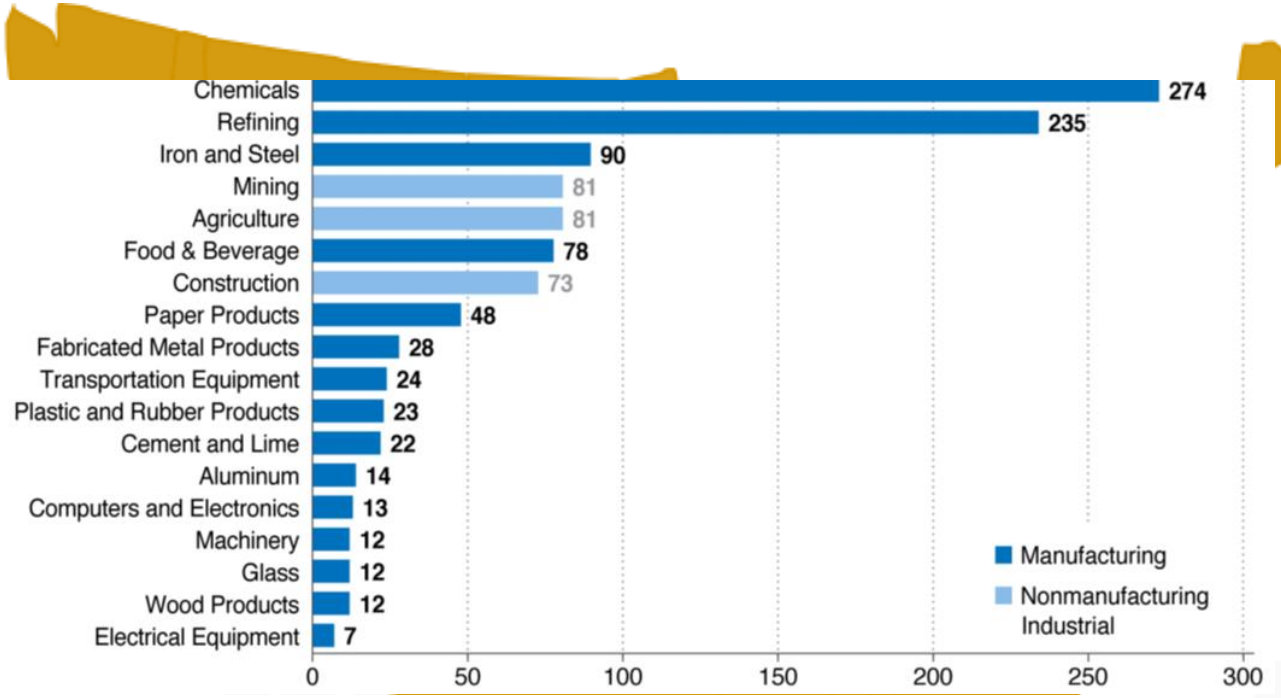
Decarbonizing Industry is an Opportunity for America's Economy

U.S. manufacturing subsector…

CONTRIBUTES
$2.79 trillion to the U.S. Economy

GENERATES
12% of U.S. GDP

SUPPORTS
11.2 million jobs



While working to **DECREASE** CO_2 emissions

We need to work across all the industrial subsectors to decrease overall emissions

U.S. Census Bureau Annual Survey of Manufactures & U.S. Bureau of Economic Analysis data for 2021

New Technologies Required to Meet Net-Zero Goals

RD&D Helps Solve Economic, Technical, & Sustainability Barriers

Risk to Industry's Bottom Line

Investment scale → In the range of

$0.7 – $1.1T

just for 8 industrial sector of focus in the IRA :

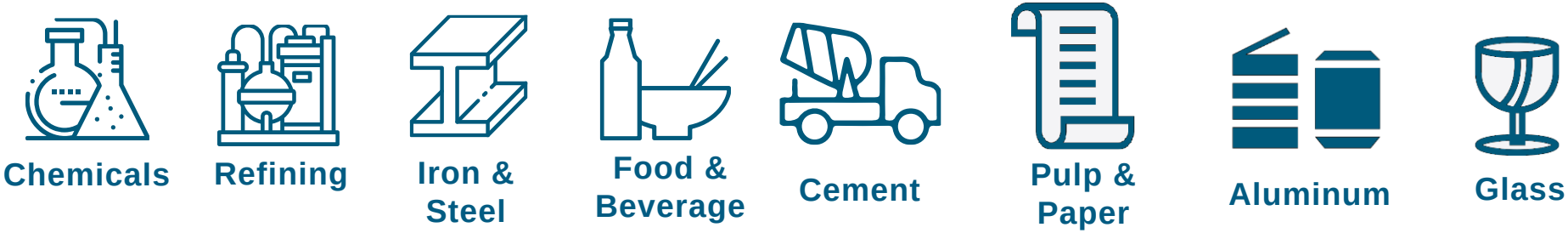
Source: DOE Pathways to Commercial Liftoff; Industrial Decarbonization

Estimated that

60% of heavy industry emission reductions

by 2050 will come from technologies that are not currently market ready
(IEA, 2022)

Targeted investments in **RD&D** are required for U.S. industry to overcome these barriers



Industrial Efficiency and Decarbonization Office (IEDO)

Vision: An efficient and competitive industrial sector with net-zero greenhouse gas emissions by 2050.

Mission: IEDO leads development and accelerates adoption of new and emerging technologies that are sustainable, increase efficiency, and eliminate industrial GHG emissions

$266.5
Million FY23 Budget

ENERGY- AND EMISSIONS-INTENSIVE INDUSTRIES

CROSS-SECTOR TECHNOLOGIES

TECHNICAL ASSISTANCE AND WORKFORCE DEVELOPMENT

IEDO RD&D Programs

Energy- & Emission-Intensive Industries (EEII)

IRON & STEEL
1,469 TBtu
100 MMT CO_2e

CHEMICALS
(including production of low-carbon fuels)
4,842 Tbtu
332 MMT CO_2e

FOOD & BEVERAGE
1,935 TBtu
96 MMT CO_2e

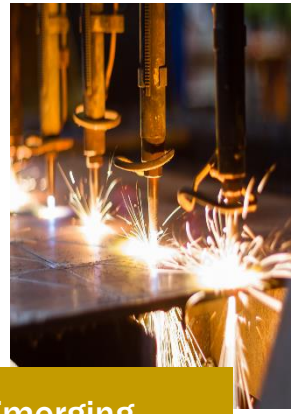
FOREST PRODUCTS
2,883 TBtu
80 MMT CO_2e

CEMENT & CONCRETE
367 TBtu
66 MMT CO_2e

Cross-Sector Technologies

Thermal Processes & Systems

Low-Carbon Fuels, Feedstocks, & Energy Sources



Emerging Efficiency

Water & Wastewater Treatment

IEDO's RD&D Approach to Industrial Decarbonization

Cross-Sector

- Process Electrification
  - Electrified Processes for Industry without Carbon (**EPIXC**) Institute EPIXC ($70M/5yrs)
- Low-carbon Industrial Thermal Systems
  - **Industrial Heat Shot**
  - Heat pumps, low carbon fuels, induction heating, etc
  - Cogeneration of Heat & Power
  - Drying, separations, waste heat recovery
- Water-Energy Nexus
  - **National Alliance for Water Innovation (NAWI)**
- Carbon Capture Tech & Integration

Energy- and Emissions-Intensive Industries

- Chemicals & Fuels
  - Bulk Chemicals, value chains, separations, catalysts, intensification, alternative feeds
  - **Clean Fuels & Products Shot**
  - **RAPID Inst ($40M/5 yrs)**
- Iron & Steel
  - Alt iron processes, recycling, ore beneficiation
- Cement & Concrete
  - Alt binders & process, SCMs, CO2 mineralization
- Food & Beverage
  - Energy recovery, alt processing, waste reduction. efficiency, electrification, separations, packaging
- Pulp & Paper, Wood Products
  - Alt pulp chemistry, waste recovery, alt fibers, alt water removal, drying , waste valorization, stranded CO2

Arizona State University to Lead New DOE Institute Focused on Electrifying Process Heat

- The Electrified Processes for Industry without Carbon (**EPIXC**) Institute is DOE's 7th Clean Energy Manufacturing Innovation Institute.
- EPIXC will:
  - Allocate up to **$70M** in federal funding over the next 5 years to fund RD&D projects to electrify process heating.
  - Mobilize a multisector coalition of private companies, National Labs, universities, labor unions, and community partners to create an innovation ecosystem.
  - Bridge the gap between research and commercialization to move novel electrification processes out of the lab and into the market.

EPIX
ELECTRIFIED PROCESSES FOR INDUSTRY WITHOUT CARBON

ASU Arizona State University

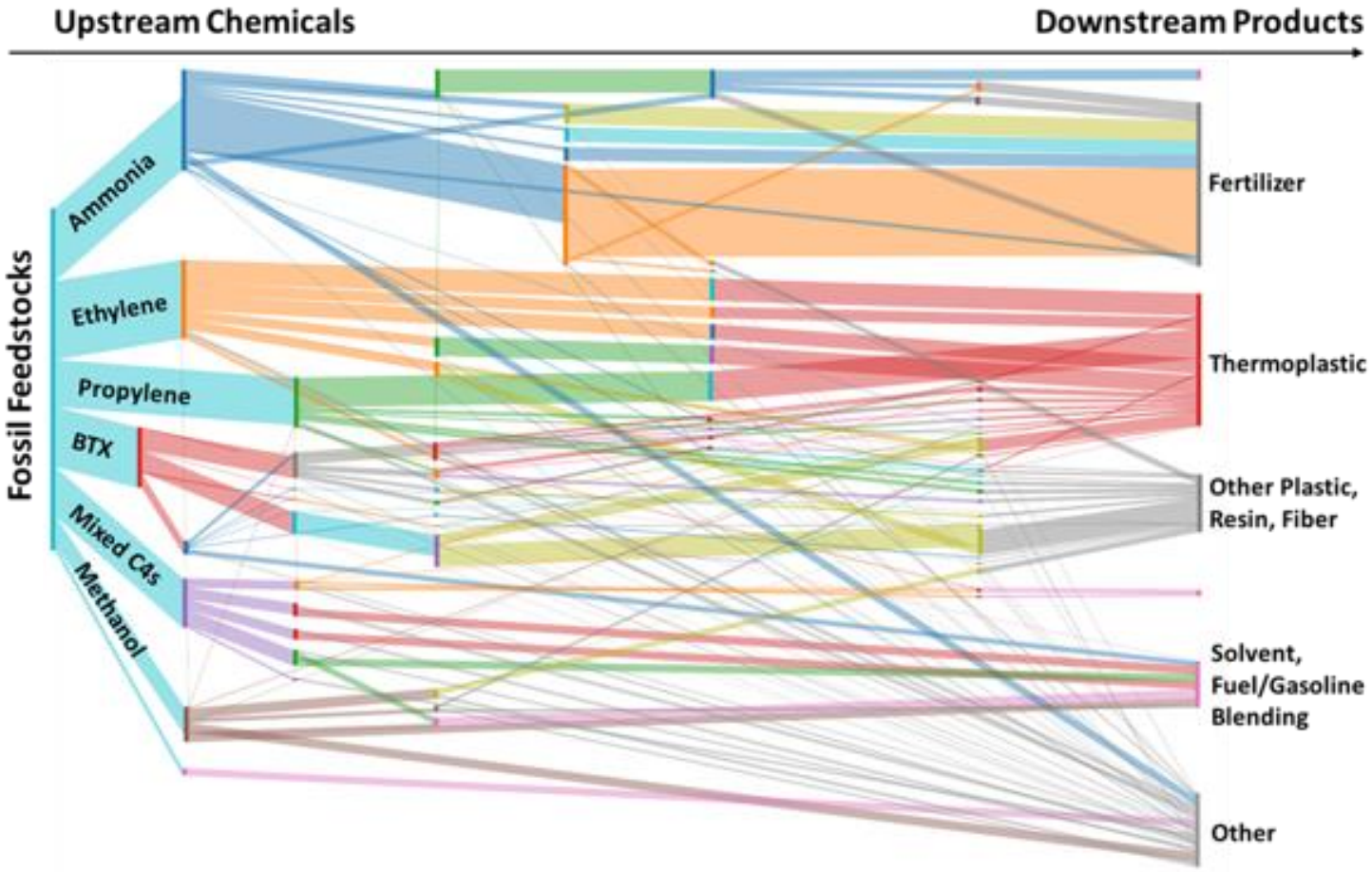
National Alliance for Water Innovation

- Energy-water desalination hub led by Lawrence Berkeley National Laboratory
- Focused on early-stage research on desalination and water-treatment technologies to secure affordable and energy efficient water supplies from nontraditional water sources
- Goal: 75% reduction in cost and energy of desalination

NAWI

Chemicals and Fuels Priorities

70,000 Products
70 > 0.5MT/yr CO2
~70% of Emissions from top 6



Chemicals and Fuels Priorities

Crosscutting

- Low-carbon fuels
- Low-carbon & electrified process heating
- Waste heat recovery
- Carbon capture integration

Sector-Specific

- Sustainable feedstocks (especially carbon)
- Electrochemical reactors
- High-efficiency thermal reactors
- Advanced separations
- Material reuse

Project Awarded to E2H2Nano – Novel Ammonia Synthesis

Background:

- Ammonia global production capacity: ~235 million metric tons in 2019
  - ~2% of the world's energy consumption
  - ~1% of global CO_2 emission
  - Produced using energy-intensive Haber-Bosch process

Innovation:

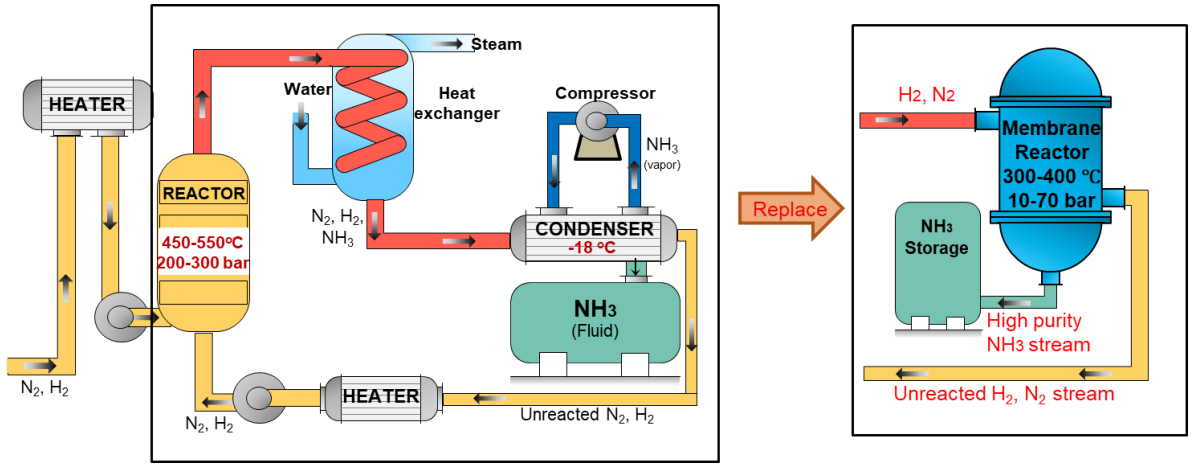
- Compact catalytic membrane reactor incorporating
  - **High activity, low-cost catalyst**
  - lower process temperatures and pressures
  - **Revolutionary membrane reactor** improves efficiency and eliminates need for cryogenic separations

Project Impact:

Energy & Emissions: Reduce >80% energy consumption	**Cost & Competitiveness:** Reduce > 80% operating cost
Technical & Scientific: >50 % N_2 conversion in single-pass	**Other Impacts:** Compact, simplified modular design

End of Project Goal:

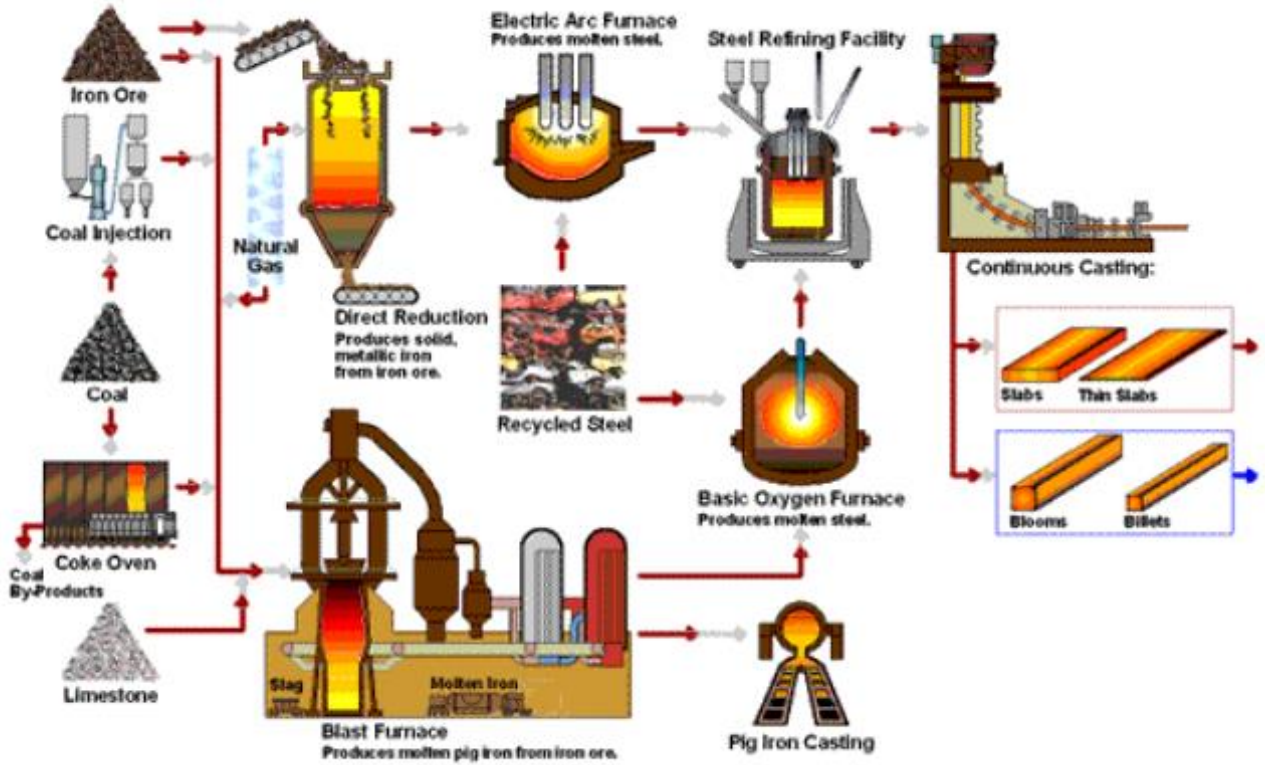
- 0.2 kg/day prototype system



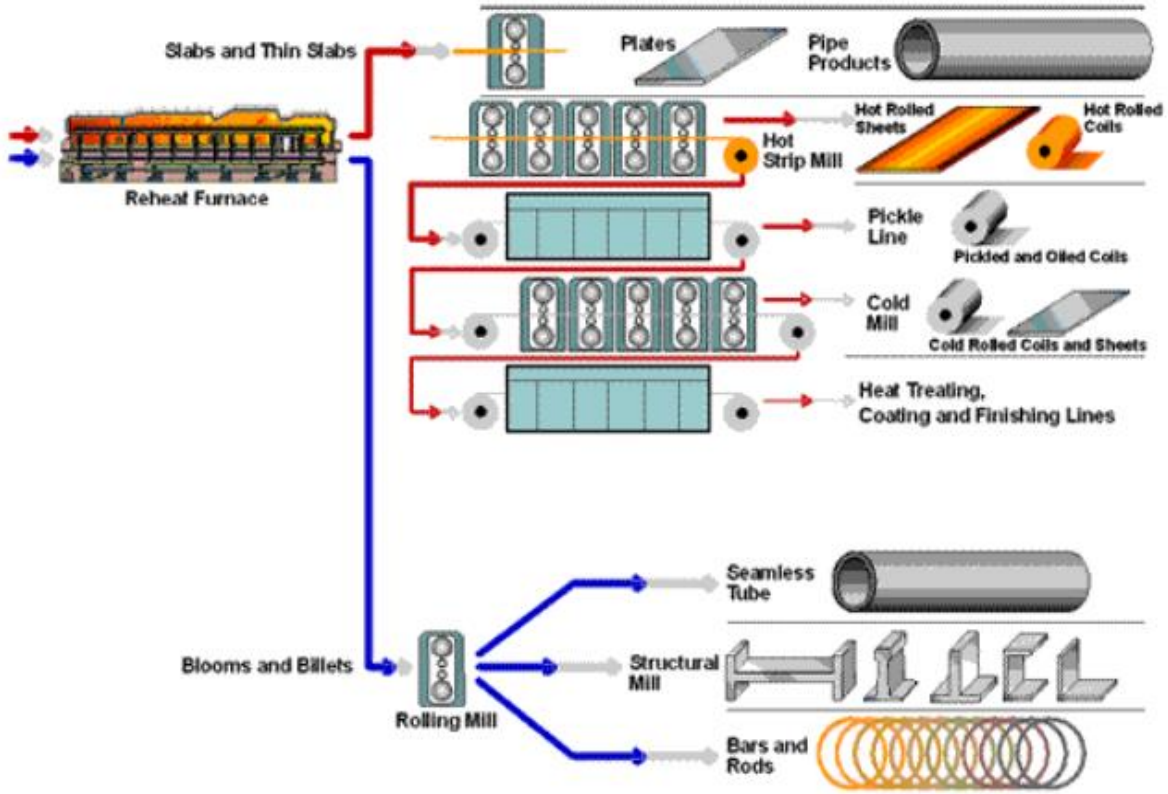
Commercial Process: Haber-Bosch	**Proposed Technology:** Compact membrane reactor
Operating conditions: 450-550 °C, 200-300 bar	Mild operating conditions: 300-400 °C, 10-70 bar
N_2 conversion: ~15% single pass, large quantity of unreacted gas recycling and reheating	High N_2 conversion: >50% single pass
Cryogenic condensation: (-18 – -24 °C) for NH_3 recovery	Cryogenic condensation: eliminated
High cost and energy consumption	Low cost and energy efficient

Iron and Steel Priorities

Iron & Steel Production



Final Steel Shaping & Treating



Iron and Steel Priorities

Crosscutting

- Low-carbon fuels and electrification for process heating, reheats
- Waste heat recovery

Sector-Specific

- Alternative iron production
  - Electrolytic (molten, aqueous)
- Alternative reductants
  - H_2, NH_3, Biomass
- Carbon Capture
- Increased recycling (tramp element contamination)

Iron & Steel Decarbonization Projects

Alternative Iron Production: Molten Sulfide Electrolysis (FY23)

$5.6M award to Massachusetts Institute of Technology.

- Groundbreaking electrochemical ironmaking using molten sulfide slag.
- Game changer technology, potential to remove copper from molten iron.

Metallic iron (bottom) reduced electrolytically from a molten sulfide slag (top)

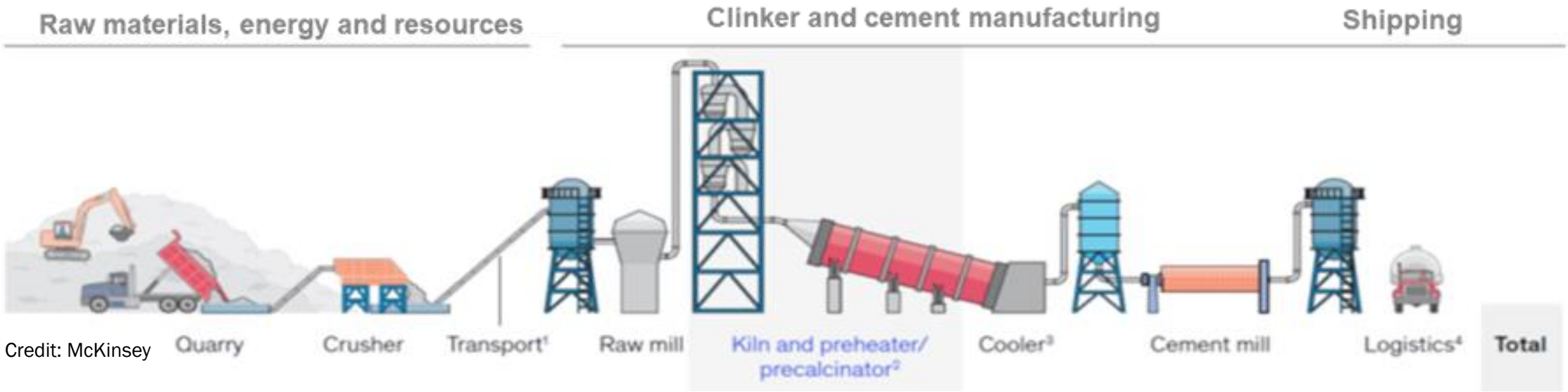
Decarbonizing EAF Steelmaking using CO_2 sourced graphite electrodes (FY23)

3 graphite electrodes being lowered into an AC electric arc furnace to strike an arc and make steel.

$8.9M award to Seerstone Development.

- Development of alternative material to fossil fuel derived needle coke for electrodes.
- Project includes electrode fabrication and production scale test of CO2 sourced electrodes.

Cement and Concrete Priorities



Credit: McKinsey

Cement and Concrete Priorities

Crosscutting

- Carbon capture from limestone decarbonation
- Electrification & low-carbon fuels
- Waste heat recovery

Sector-Specific

- Alternative binders and process routes to OPC
- Clinker substitutes
- CO_2 mineralization
- Alternative building materials

Cement & Concrete Decarbonization Project

Advanced Electrolytic Cement production W/ alternative calcium sources (FY23)

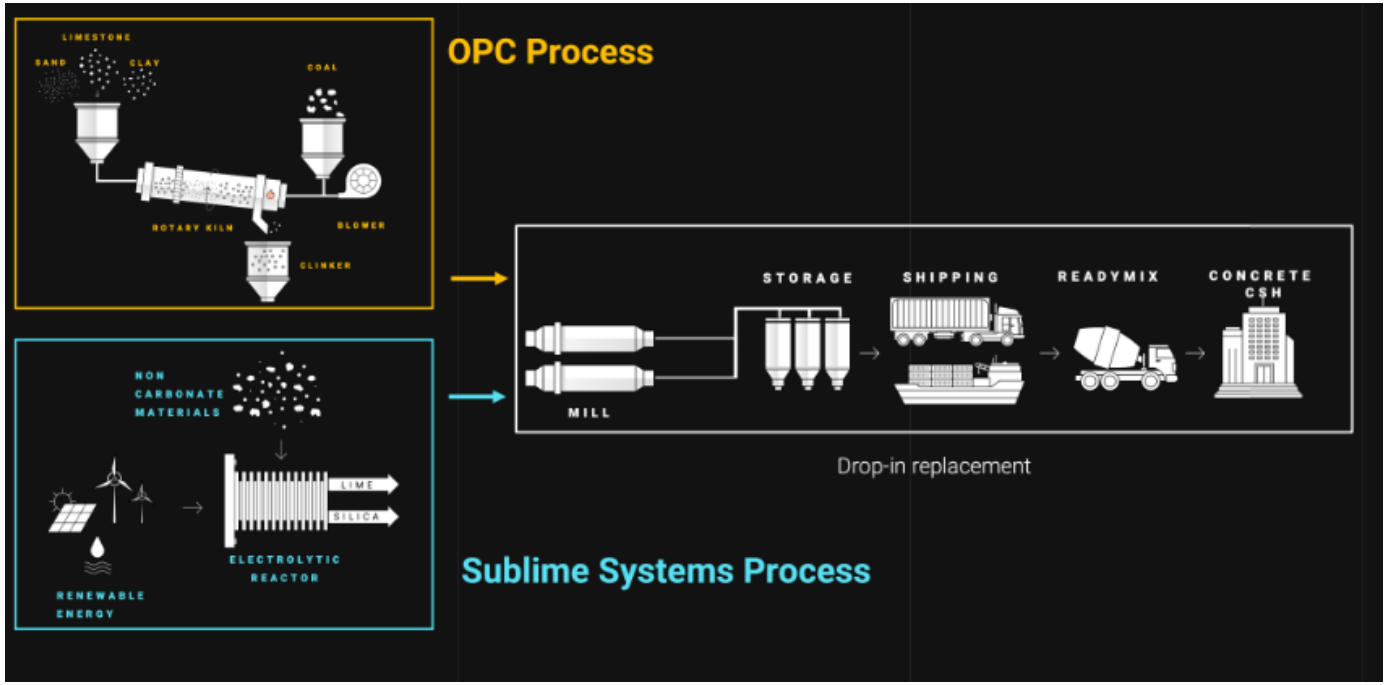
$6.7M Federal Awarded to Sublime Systems

Innovation:

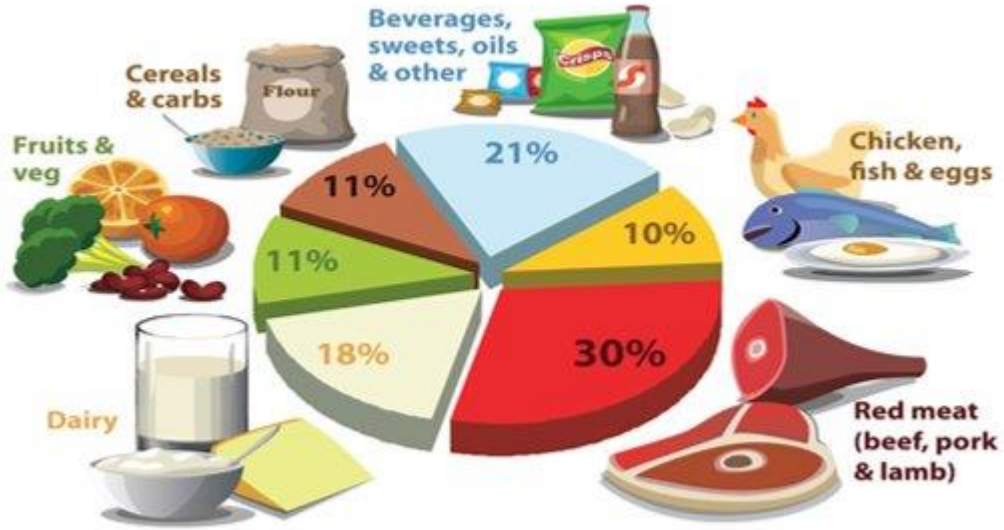
- Scale up and Integration of a novel electrolyzer to produce hydraulic cement binder and SCMs
- Use of industrial waste as feedstock for cement production (non-carbonates)
- Low temperature, aqueous process (no kiln)
- Fully electrified process (electrolysis)

Project Impact:

- Reduced energy demand
- Reduced CapEx & OpEx
- Increase in feedstock availability (no limestone)
- Reduced CO2 emissions (~90% vs OPC clinker)



Food and Beverage Priorities



Beer Brewing processing

Food and Beverage Priorities

Crosscutting

- Low-carbon fuels or electrification for steam boilers
- Low-temperature waste heat recovery from process exhausts
- Smart/flexible manufacturing processes
- Drying and dewatering innovations
- Wastewater recovery and reuse

Sector-Specific

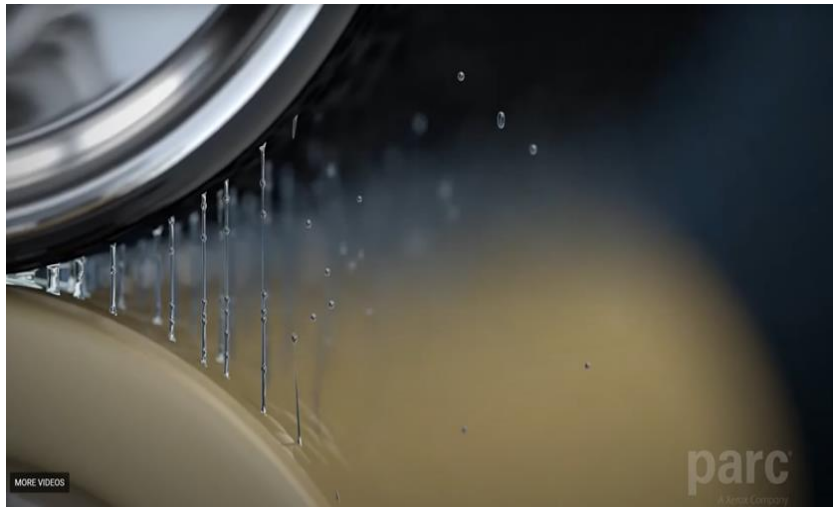
- Alternative protein products
- Food loss reduction & waste management
- Innovative cooling, refrigeration, and freezing solutions
- Drying, cooking, dewatering, and processing innovations

Filament Extension Atomization for High Solids Loading in Energy Efficient Spray Drying Systems

Palo Alto Research Center 2019, 2022

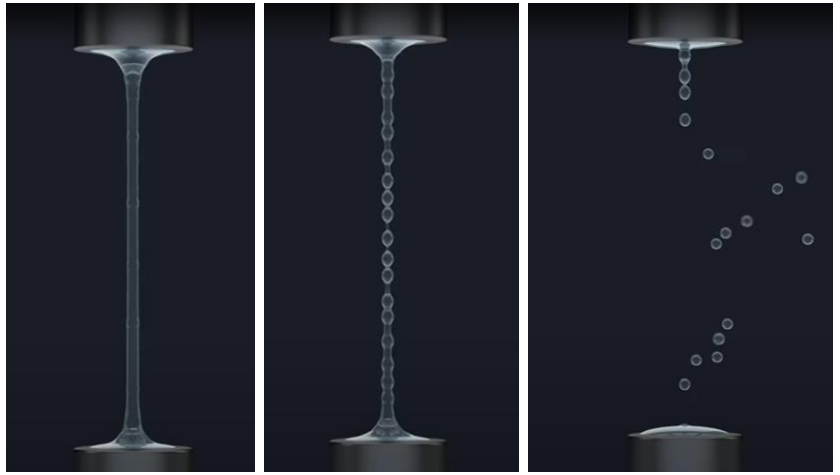
SUMMARY

- Scale & demonstration industrial spray drying of high concentration whey protein feedstocks to produce high quality whey powder with lower energy input
- **Filament Extension Atomization (FEA)** tech → enable high solids spray drying
- Decrease dairy spray drying process energy use by 40%



GOALS

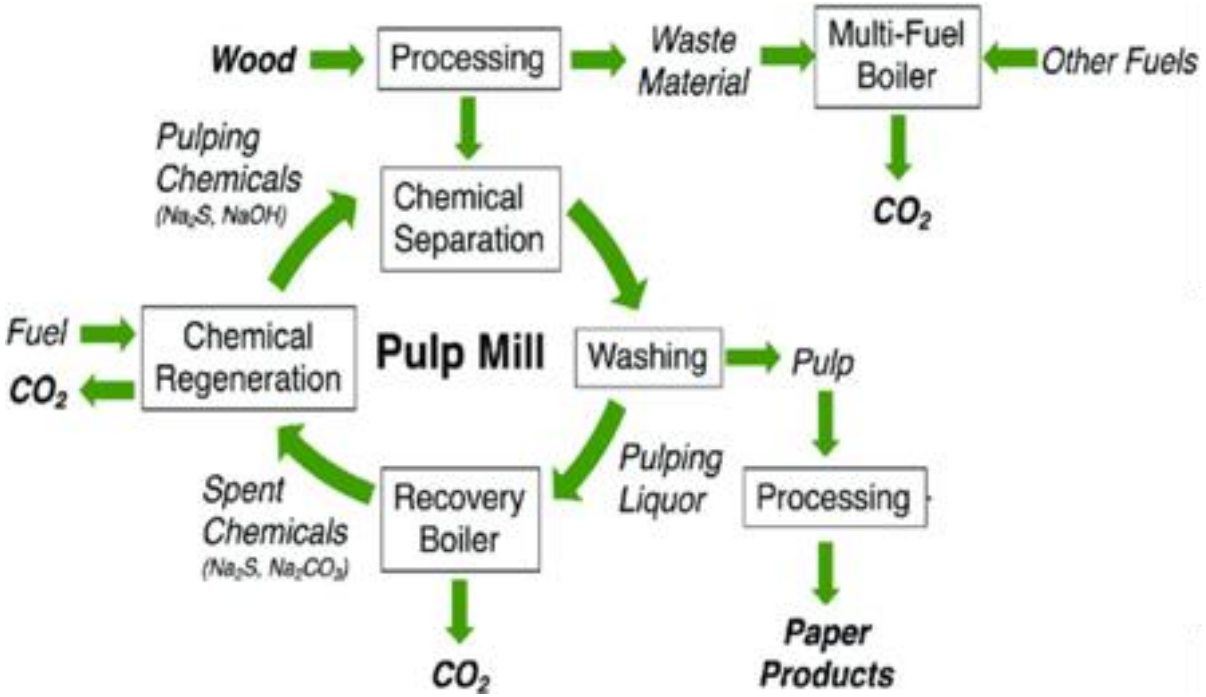
- **Scale up** process to (7.5L/min)
- Demonstrate in a dairy processing plant environment
- Maintain high product quality standards



IMPACT

- **Reduce spray drying energy consumption** and production costs by up to 40%
- **Increase of solids loading** from 50% (state of art) to >70% (FEA-enabled) to achieve 40% energy savings at the spray dryer-level and 15% at system-level
- **Additional energy savings** from decreased size variability (minimize over-drying)

Forest Products Priorities

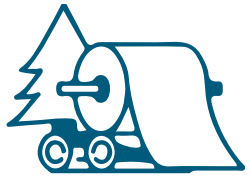


Forest Products Priorities

Crosscutting

- Carbon capture integration with boilers
- Low-carbon fuels for lime kilns
- Low-carbon fuels or electrification for steam boilers
- Drying and dewatering innovations

Sector-Specific



- Increase biomass utilization
- Energy efficient separations for concentrating liquor
- Increase fiber yield of pulping
- Increasing solids content in paper forming

Funding Opportunity: FY24 EEII FOA

$83M for Applied RD&D to Decarbonize Heavy Industry

Date	Milestone
Jan 25	FOA Issue Date
Mar 19	Concept Papers Due
Jun 11,	Full Application Due
Oct '24	Award Announcements

Topic 1: Chemicals & Fuels

1. Sustainable feedstocks → chem/fuel
2. Non-hydrocarbon products
3. Value chain approach

Topic 2: Iron and Steel

1. Alternative ironmaking (non-H_2 DRI)
2. Ore beneficiation
3. Recycling (tramp metal solutions)
4. Steelmaking with low-carbon iron

Topic 3: Food and Beverage

1. Food packaging
2. Commercial food services
3. Energy recovery/redistribution
4. Post-Harvesting activities

Topic 4: Cement, Asphalt, Glass

1. Binders & SCMS → Concrete
2. Novel lime/OPC processing
3. Asphalt
4. Glass

Topic 5: Forest Products

1. Dewatering & drying
2. Fiber prep, pulping, chemical recovery

Topic 6: Industrial Pre-FEEDs

1. H_2 feedstock integration **(HFTO)**
2. Carbon Capture, heavy industry **(FECM)**
3. Process integration **(IEDO, FECM, HFTO)**

www.energy.gov/eere/iedo/iedo-fy24-energy-and-emissions-intensive-industries-foa

IEDO Technical Assistance & Workforce Development

Public /private partnerships to help manufacturers and industrial organizations set and achieve long-term energy intensity reduction goals

Education and training for the current and future manufacturing workforce

No-cost tools and resources for manufacturers to reduce GHG emissions and improve energy efficiency and competitiveness

End-user support, stakeholder engagement, and technical services for the industrial sector

TA WORK PRODUCTS INCLUDE:

- ENERGY ASSESSMENTS
- PEER-TO-PEER NETWORKING
- TOOLS & TRAINING
- TECHNOLOGY SCREEINING
- PROJECT PROFILES

Key Takeaways

1. Targeted RD&D is essential to deliver technology that is:
   - Efficient
   - Sustainable (CO2 and…)
   - Economical
2. Silver bullet vs silver buckshot
   - No single approach to decarbonizing industry—a broad, multipath approach is required.
3. Both broad and tailored solutions needed
   - Transformative sector specific solutions
   - Integrated cross-sector solutions (thermal, fuels, water…)

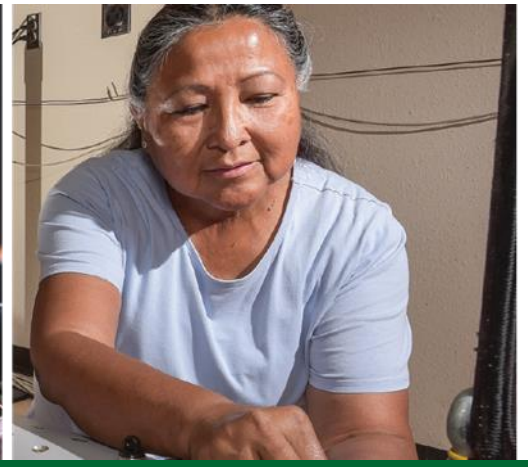
www.energy.gov/eere/iedo/iedo-fy24-energy-and-emissions-intensive-industries-foa

IEDO Announcements

1. **IEDO is Hiring!**
   - Cross-Sector Technology Manager, Iron & Steel, Cement & Concrete.

   Email: IEDOJobs@ee.doe.gov

   www.energy.gov/eere/iedo/iedo-careers
2. Industrial Decarbonization Pathways Strategy Initiative
   - Led by IEDO (follow on to the Roadmap); broad DOE initiative
   - Workshop planned (seeking participation and engagement)
3. Open Funding Opportunity (EEII FY24 FOA)
4. FY23 Selections Announced (CST & EEII Projects)

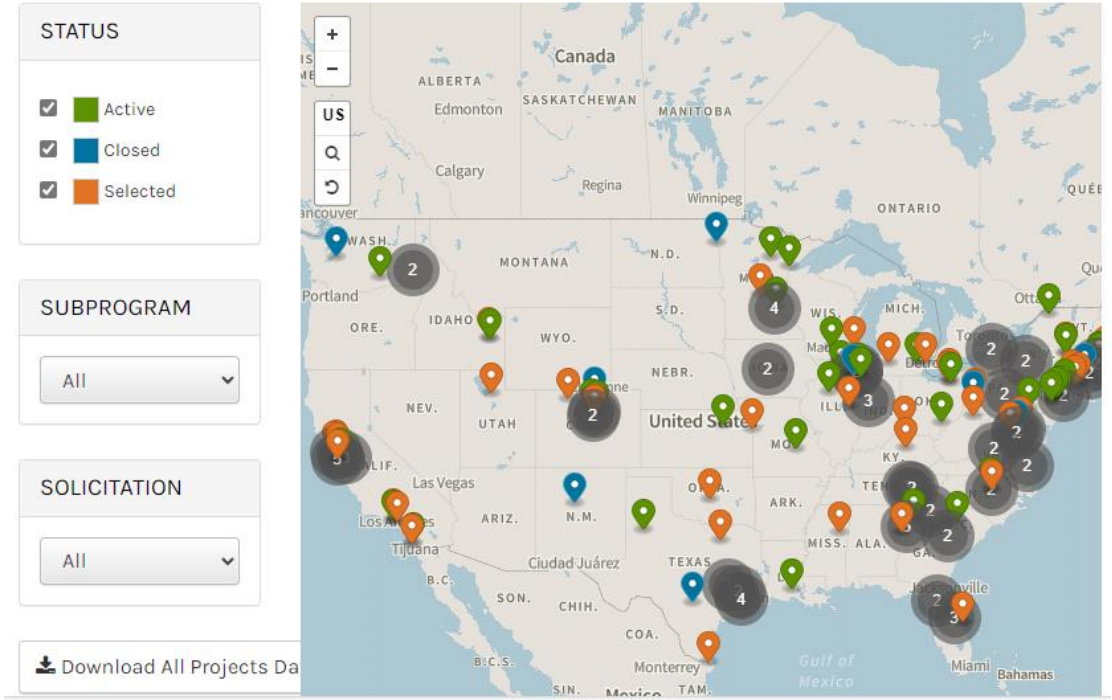
Thank You!

Subscribe to our newsletter "**The Production Line**" to get the latest information on:

- Announcements
- Funding opportunities
- Events
- Tool and resources
- And more!

www.energy.gov/eere/iedo/subscribe-iedo-newsletter

IEDO Project Database



www.energy.gov/eere/iedo/iedo-project-database

EXTRA SLIDES

Diversity, Equity, Inclusion, and Accessibility (DEIA) Focus

We seek to create a workforce that reflects the diversity of Americans and ensures that all Americans benefit from a decarbonized industrial sector.

Increasing **Diversity** in Partnerships, Applicant FOA pool, and FOA Reviewers

Using **Inclusive** Language to welcome broader participation in funding opportunities

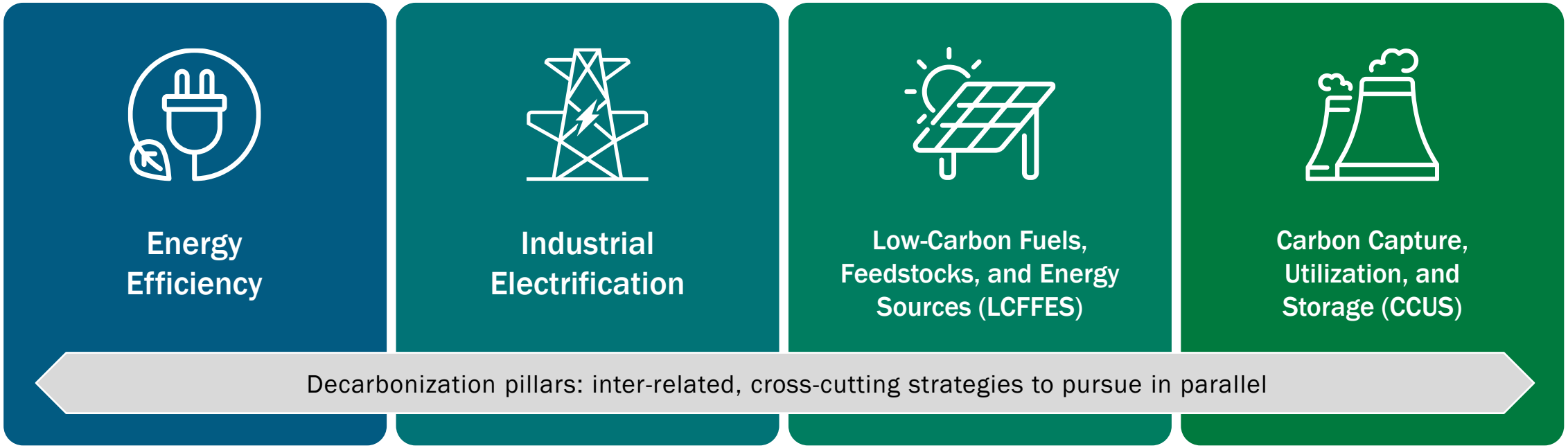
Identifying **Equity**-related barriers that impact communities

Expanding **Accessibility** for Disadvantaged Communities (DACs), including through community-based stakeholder engagement

IEDO is committed to empowering diverse communities and amplifying best practices for DEIA internally and externally.

DOE Industrial Decarbonization Roadmap

Industrial Decarbonization Pillars




Iron & Steel


Chemicals


Food & Beverage


Petroleum Refining


Cement

www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Industrial Efficiency and Decarbonization Office (IEDO)

Energy- and Emissions-Intensive Industries

FY23 = $131M

Dr. Paul Majsztrik

Cross-sector Technologies

FY23 = $90.5M

Isaac Chan

Technical Assistance and Workforce Development

FY23 = $45M

Anne Hampson

$266.5
Million FY23 Budget

Dr. Avi Shultz
Director

Anne Hampson
Acting Deputy Director

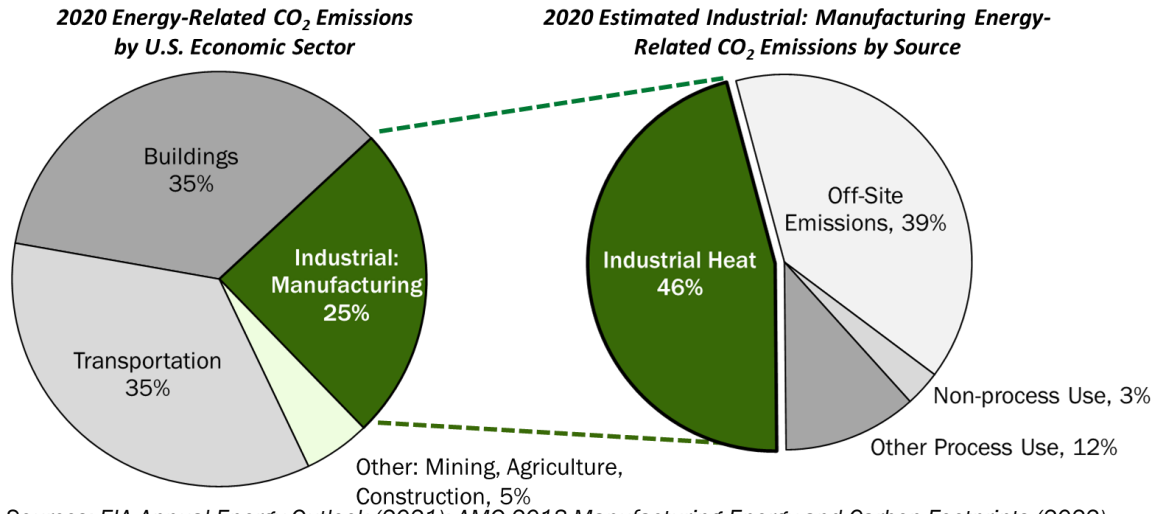
Joe Cresko
Chief Engineer

Lauren Hall
Operations Supervisor

Ava Coy
Program Manager
Technical Project Officers

Mattie Gainer
Strategic Communications Lead

11% of U.S. Energy-Related Emissions are from Industrial Thermal Systems



Sources: EIA Annual Energy Outlook (2021); AMO 2018 Manufacturing Energy and Carbon Footprints (2022)

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

Develop cost competitive industrial heat decarbonization technologies with at least 85% lower greenhouse gas emissions by 2035

>85% Lower Emissions

2035

Goal: Reduce the amount of heat and/or emissions from heat to make cleaner products

Generate Heat from Clean Electricity

Reduce Emissions:
electrify equipment & use clean electricity, improve energy efficiency

Examples:
heat pumps, microwave heating, resistive heating, etc.

Integrate Clean Heat from Alternative Sources

Reduce Emissions:
switch to low-emissions heat sources and increase thermal storage

Examples:
solar thermal, nuclear, geothermal, hydrogen, some sustainable fuels, etc.

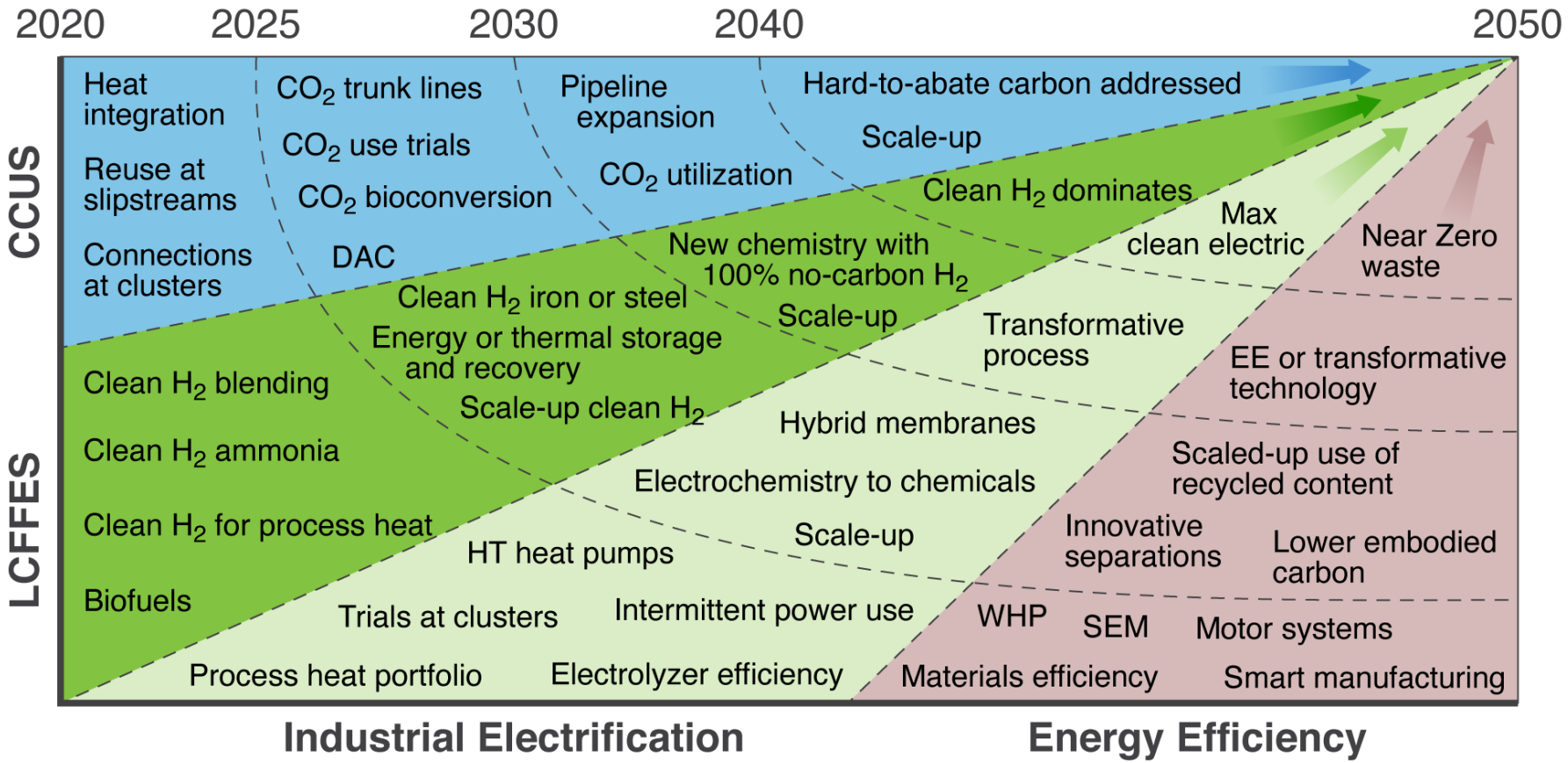
Innovative Low- or No-Heat Process Technologies

Reduce Emissions:
new chemistry and emerging approaches to reduce heat demand

Examples:
advanced separations, electrolysis, ultraviolet curing, biobased manufacturing, etc.

Enabling technologies and systems: e.g. energy storage, materials, modeling, data analytics, etc.

Landscape of Needed RD&D Investment



Landscape of major RD&D investment opportunities for industrial decarbonization between now and 2050.

LCFFES = Low Cost Fuels, Feedstocks, and Energy Sources; **CCUS** = Carbon Capture Utilization and Storage

Source: [Industrial Decarbonization Roadmap]

Rapid Advancement in Process Intensification Deployment (RAPID)

- A **5-year, $40 million** investment to drive RD&D of advanced process technologies to enable **more resilient, lower cost, and reduced energy and carbon footprint manufacturing** in the process industries.
- Includes the production of chemicals and fuels, which account for **more than a third** of all U.S. industrial emissions and energy consumption.
- RAPID's work will align with the **Clean Fuels & Products Shot**.

ENERGY earthshots
U.S. DEPARTMENT OF ENERGY

Clean Fuels & Products Shot

>85% net reduction vs. fossil-based sources

2035

2050 Resource Supply

1,050 MMT biomass and waste

450 MMT CO_2

...can be converted into...

2050 Projected Hydrocarbon Demand

>400 MMT* fuels and chemicals

*This Shot assumes that 50% of marine, rail, off-road, hydrocarbon chemicals and 100% of aviation demand will be met by hydrocarbon fuels in 2050.