U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

INDUSTRIAL EFFICIENCY & DECARBONIZATION OFFICE

IEDO Cross-Sector Technologies (CST) Subprogram Overview

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Why A Cross-Sector Approach Is Needed

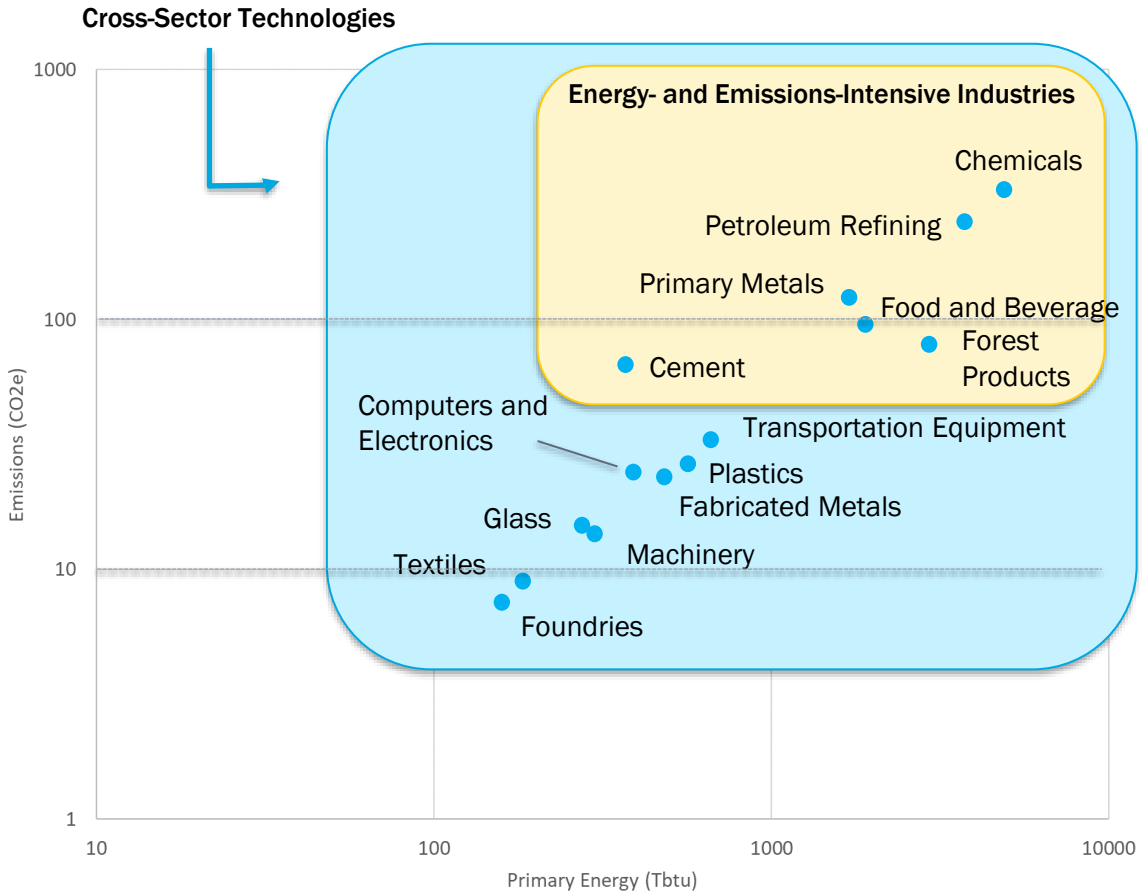
Diversity of products, processes, energy inputs, and complex supply chains make the industrial sector "difficult-to-decarbonize."

But common end-uses underpin the diversity of processes and products found within the industrial sector. For example:

- Process heat (>90% supplied by fossil fuel combustion)
- Auxiliary energy systems, waste heat recovery and utilization, CHP
- Production and process control
- Water use and wastewater treatment

Enormous challenge to address diverse technological needs and sources of GHG emissions across the industrial sector.

IEDO RD&D Landscape



Manufacturing Energy and Carbon Footprints, DOE AMO, 2022.

Cross-Sector Technologies in IEDO

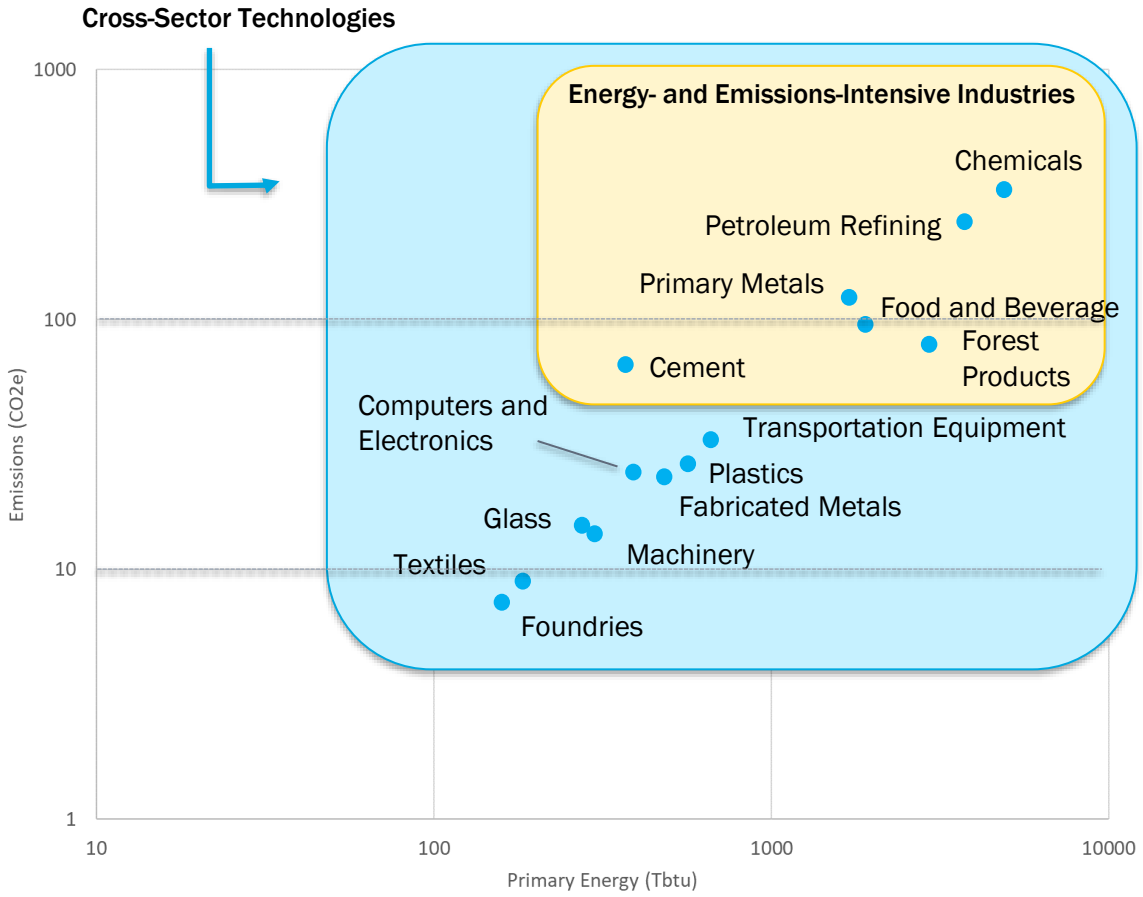
Accelerates the readiness of energy- and emissions-reducing components, systems, and operational technologies, across a broad range of industries.

Key program themes:

- Industrialize low carbon processing equipment and enabling component technologies that can be integrated with existing facilities and processes.
- Advance energy systems and auxiliary control and component technologies, e.g., waste heat recovery, CHP, sensors and controls, smart manufacturing, thermal energy storage.
- Develop next-generation production and processing technologies, e.g., low thermal budget processes.
- Reduce energy and emissions from water and wastewater treatment.

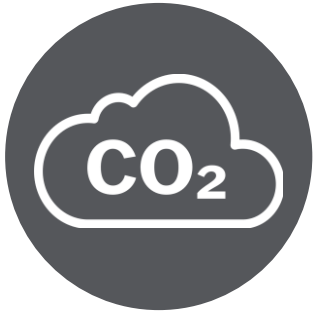
Enabling technologies developed under CST (mid-TRL) can be further advanced under EEII for specific applications.

IEDO RD&D Landscape



Manufacturing Energy and Carbon Footprints, DOE AMO, 2022.

CST Priorities Support the Industrial Heat Shot



85% Reduction

2035

Industrial Heat Shot Pathway	CST Technology Priorities
Generate Heat from Clean Electricity	Electrotechnologies, industrial heat pumps, and hybrid systems to electrify industrial heat
Integrate Clean Heat from Alternative Sources	Combustion of low-carbon fuels and integration of renewable thermal energy sources
Innovative Low- or No-Heat Process Technologies	Low thermal budget processes, advanced separations, non-thermal drying
Enabling Technologies and Systems	Thermal energy storage, industrial load flexibility, sensors and controls

CST Approach to Energy and Environmental Justice

Prioritize Cross-Sector RD&D Areas with EEJ Impact

- Develop alternatives to on-site combustion of fossil fuels to address disproportionate exposure to particulate matter and other criteria pollutants from industrial sources
- Develop technologies to increase access to safe drinking water in disadvantaged communities

Address EEJ Concerns for Cross-Sector Industrial Decarbonization Technologies

- *Hydrogen Combustion:* Develop component technologies to mitigate NOx generation and require Safety Plan for H_2 projects
- *Workforce Development:* Build a more diverse and skilled workforce to electrify process heating through EPICX

Leverage Community Benefits Plan to Select RD&D Projects that Advance DEIA, Energy Equity, and Workforce Development

- Incorporate CBP milestones into project workplans
- CBP criterion accounts for 15% of Full Application score

Engage with EEJ Communities and Stakeholders

- Explore non-GHG impact factors in Industrial Heat Shot Summit and other workshops to understand how transformation of industrial heat can support EEJ

CST Program Areas

Thermal Processes and Systems

Portfolio Objective: Advance innovative and cost-effective technologies for process heating with applications in multiple sectors.

Current Portfolio
RD&D: 24 projects worth over $65M.
Institute: EPIXC, $70M over 5 years.

Technology Development Priorities

- Electro-technologies and hybrid heating systems.
- High temperature industrial heat pumps.
- Innovative low- and no-heat processes, e.g., electromagnetic heating.
- Advanced furnace equipment and process control technologies.

Challenges Addressed

- Diversity of industrial processes with different operational and thermal demands.
- Cost competitiveness of emerging technologies.
- Quantification of non-energy/non-emissions benefits.
- Scale-up towards industry-readiness.

Targets

1. Replace existing fuel-based technologies that are cost competitive, reduce emissions, improve flexibility, and more efficient.
2. Reduce energy intensity by at least 50% compared to typical technology.
3. Improve properties, quality, and/or product value at cost parity to conventional techniques.

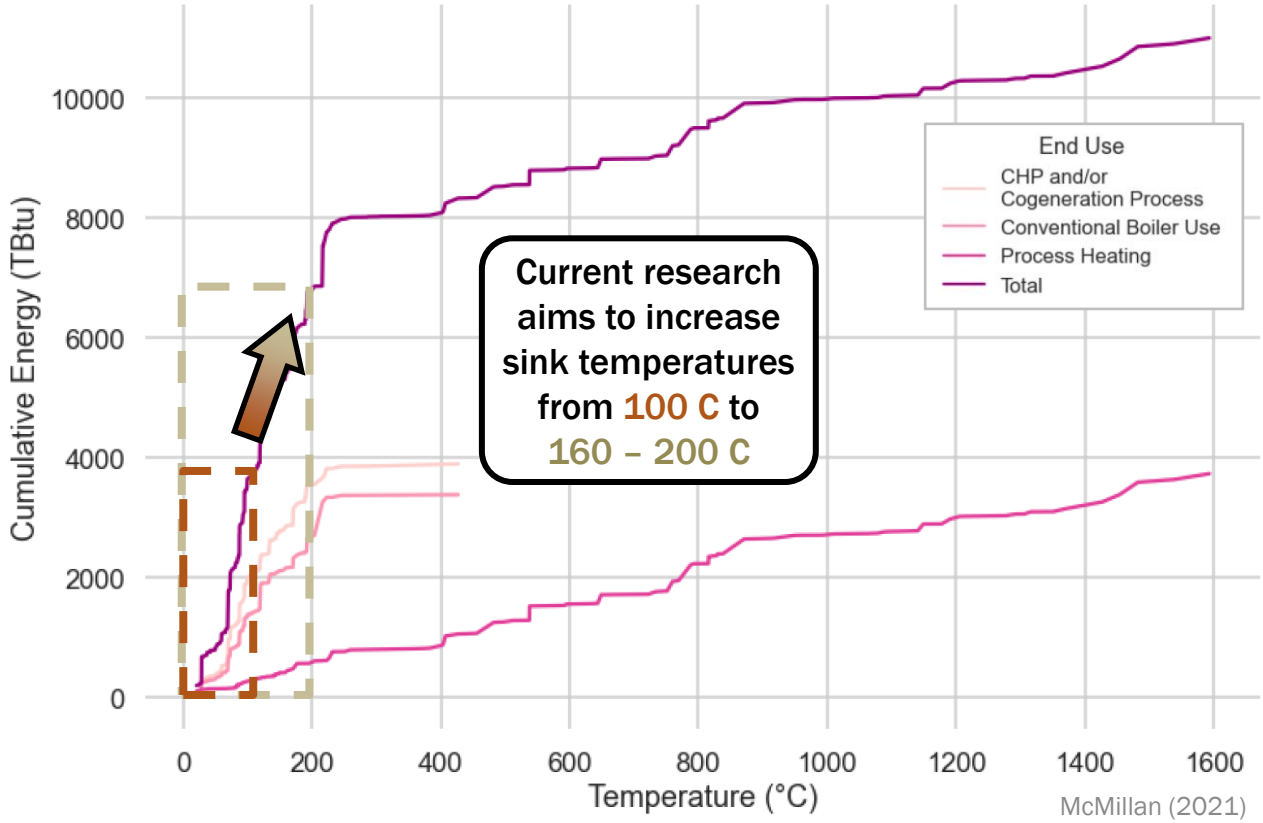
Priority Area: Industrial Heat Pumps

Opportunities

- Expand economic application space by increasing COP through new components (e.g., oil-free compressors), alternate cycles (e.g., multi-stage), and optimal use of waste heat streams
- Testing and application of synthetic (e.g., HFOs, HCFOs), hydrocarbon (e.g., butane, pentane), and natural (e.g., CO2, water) refrigerants
- Developing tools and modular/mass-producible technology options (e.g., steam generating heat pumps) to simplify integration

Additional Challenges:

- Increasing sink temperature & lift range
- Scale-up to industrial scale
- Temperature-resistant components
- Heat-activated heat pumps



McMillan (2021)

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

Portfolio Objective: Enable the adoption and/or use of low-carbon fuels, feedstocks, and energy sources to reduce combustion-associated GHG emissions for industrial processes.

Current Portfolio
RD&D: 18 projects worth over $48M.

Technology Development Priorities

- Low-carbon fuel combustion equipment and systems.
- Approaches to mitigate adverse impacts of low-carbon fuel combustion.
- Renewable thermal energy technologies.
- Clean hydrogen for industrial applications, including for process heat and material feedstocks.
- Flexible combined heat and power (CHP) systems.

Challenges Addressed

- Lack of process equipment to address alternative fuel specific phenomena.
- Lack of auxiliary equipment of address industrial infrastructure needs.
- Industry hesitation towards adoption new energy sources.
- Inadequate supply chain for materials and fuels.

Targets

1. Reduce emissions by 85% for clean fuels and energy sources.
2. Validate process parameters and heating profiles as comparable with incumbent.
3. Non-GHG emissions reductions comparable to incumbent.

Priority Area: Hydrogen Combustion

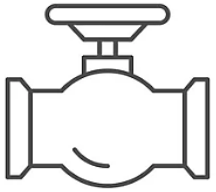
Opportunity:

- Global low-carbon H_2 demand is expected to increase 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

Emerging Efficiency & Decarbonization Technologies

Portfolio Objective: Explore innovative, next generation energy efficiency and decarbonization technology concepts to enable transformational decarbonization impact and improve industrial production system efficiencies, process yield, and recovery of thermal energy.

Current Portfolio
RD&D: 4 projects worth $16.3M.

Technology Development Priorities

- Technologies to enable advanced heat management and increased flexibility in energy use, e.g., ultra-efficient industrial heat exchangers, thermal energy storage, sensors and controls.
- Low-thermal budget operations that reduce or eliminate thermal demand, e.g., membranes and electrochemical pathways.
- Modeling, digitalization, and software to enable industrial grid interactivity and support electrification with clean electricity.

Challenges Addressed

- Legacy process equipment not designed for transformative efficiency improvements.
- Lack of auxiliary equipment to address industrial infrastructure needs, including those around industrial flexibility and thermal management.
- Industry hesitation towards adopting new technologies.

Targets

1. Develop and demonstrate next-generation technologies, including component technologies and data-driven approaches, that maximize efficiency and minimize waste.
2. Reduce emissions by 85% for next-generation processes.

Priority Area: Thermal Energy Storage

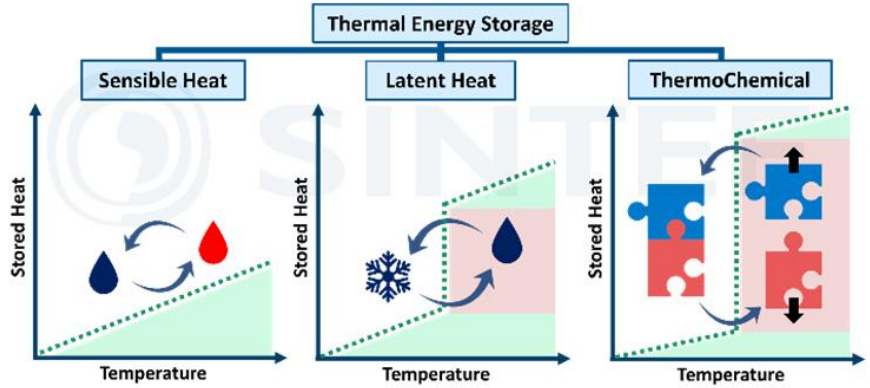
Opportunity: Provide economical process heat, enable renewables penetration, and improve resiliency.

Advantages

- Lower cost than electrical storage
- Potential link to thermal-electric systems
- Strong advantage if used directly as heat

Key Technical Challenges

- Lower efficiency when converting to power (need higher temperatures to drive efficiency)
- High temperature systems have issues with cost and corrosion
- Increasing energy density and reducing losses
- Process integration challenges
- Investments for smaller manufacturing facilities are disadvantaged due to economy of scale using current technology



SINTEFblog. "Thermochemical Energy Storage: The next generation thermal batteries?" (2022) *(link)*

Energy Storage Metrics

Round trip efficiency
Exergetic efficiency
Thermal Cycles
Thermal Capacity, MWh
Payback, yrs
Discharge Time, hr
Energy Density
Cost $/kWhr

Water and Wastewater Treatment

Portfolio Objective: Reduce GHG emissions (CO_2, CH_4, NO_2) and recover resources from municipal wastewater treatment processes and systems and develop approaches to treat non-traditional sources of water to meet future water needs.

Technology Development Priorities

- Decarbonization technologies for wet organic waste treatment and handling from municipal, agricultural, and industrial sources.
- Decarbonization of WRRF unit processes without increasing total WRRF operating costs.
- Reducing overall emissions from WRRF facilities with integrated unit processes, higher levels of technological readiness, and larger scales.

Challenges Addressed

- Energy efficiency and adoption of alternative energy sources for water and wastewater treatment facilities
- Measurement and characterization of direct emissions from WRRFs on a life cycle basis.
- Enable non-traditional water sources for end-use.

Targets

1. Reduce GHG emissions from Water Resource Recovery Facility (WRRF) unit processes by at least 50% and plant-wide emissions by a minimum of 25% without increasing overall costs.
2. Achieve pipe parity – enabling non-traditional water sources for end-use.

CST Investment Highlights

Recent Investments

$76.5M *in FY22-FY23 FOAs to advance industrial electrification, industrial heat pumps, hydrogen combustion systems, thermal energy storage, and other cross-sector technologies.*

$70M *over 5 years to new manufacturing institute: Electrified Processes for Industry without Carbon (EPIXC).*

FY24 Cross-Sector Technologies FOA

$38M *to accelerate the innovative, cross-sector technologies required to decarbonize industry. Solicitation is currently open.*

Topic Areas

1. Electrification of Industrial Heat
    - Electrotechnologies
    - Industrial Heat Pumps
2. Efficient Energy Use in Industrial Systems
    - Advanced Membrane Separations
    - Industrial Heat Exchangers
3. Decarbonizing Organic Wastewater and Wet Waste Treatment