AMMTO & IEDO JOINT PEER REVIEW

May 16th-18th, 2023

Washington, D.C.

U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Emerging Decarbonization Technologies

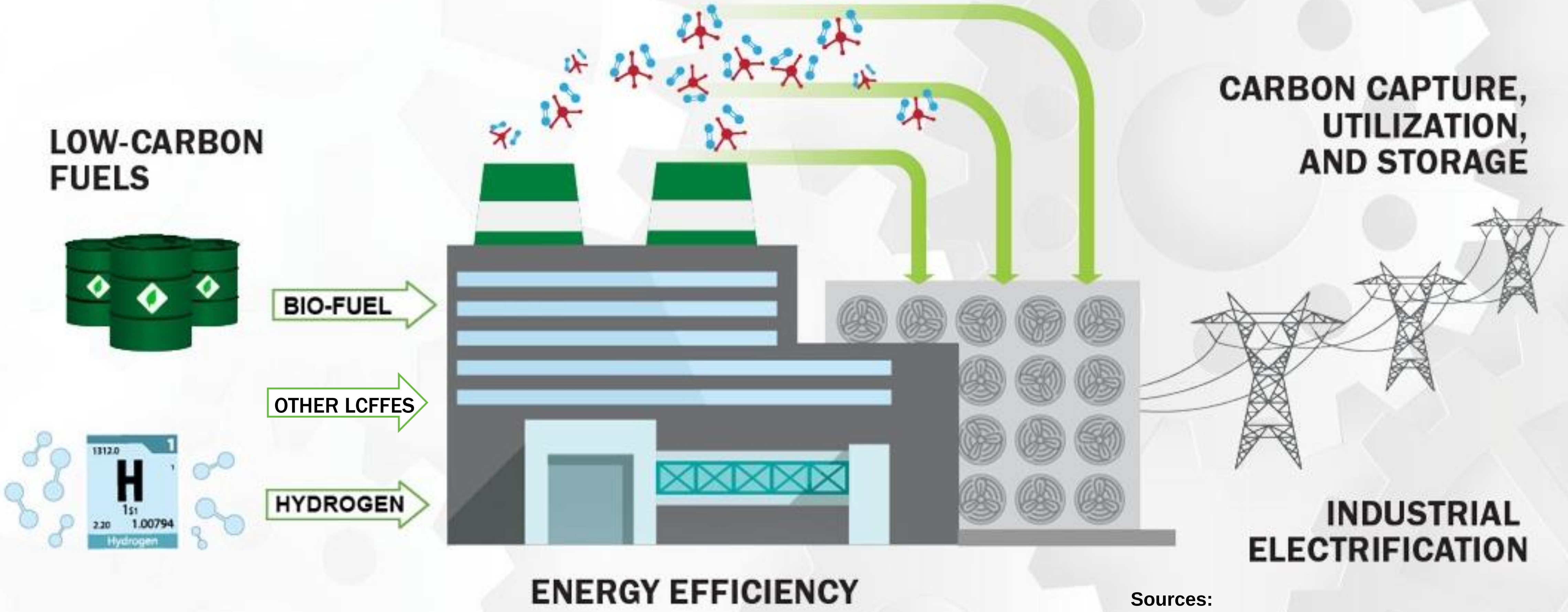
Emmeline Kao, Technology Manager, Cross-Sector Technologies Program

Industrial Efficiency and Decarbonization Office

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

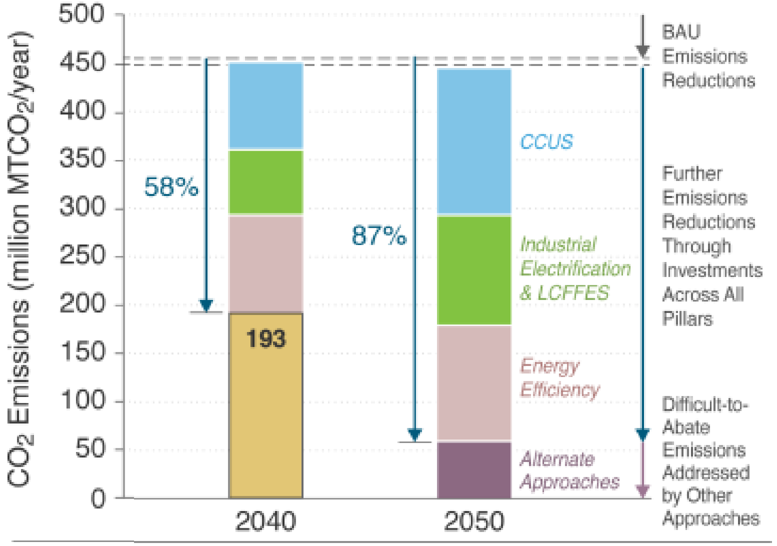
Industrial Decarbonization Roadmap

Four Main Strategies to Decarbonize the Manufacturing Sector

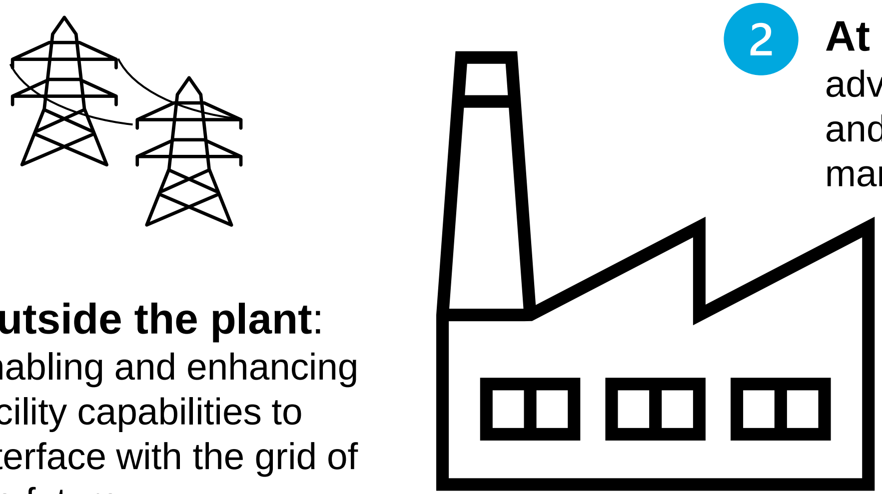


Sources:
(1) DOE Industrial Decarbonization Roadmap, September 2022

Approach to Emerging Efficiency and Decarbonization



Cross-sector decarbonization will require a multi-modal approach ...



2 **At the plant**: advanced facility management and operations such as smart manufacturing

1 **Outside the plant**: enabling and enhancing facility capabilities to interface with the grid of the future

3 **In the plant**: Alternative and novel processes that dramatically reduce GHGs

addressing RD&D opportunities across all pillars of decarbonization

Sources:

(1) DOE Industrial Decarbonization Roadmap, September 2022

Emerging Technologies Background

Advanced thermal management and operational innovation in 4 key technology areas

Industrial Flexibility

Challenges and Barriers

Challenges/Barriers	Emerging Decarbonization Examples
Legacy process equipment not designed for transformative efficiency improvements	• Thermal Management: current heat exchanger materials/designs cannot efficiently transfer heat at low cold approach temperatures. • Smart Manufacturing: legacy equipment is not designed for integration with smart manufacturing systems. • Industrial Flexibility: traditional processes are designed for steady state operation; need to develop novel process design for flexible operation and ramp tolerance. • Alternative Processes: transformative processing equipment may not be easily integrated into current facilities.
Lack of auxiliary equipment to address industrial infrastructure needs	• Industrial Flexibility: Long-duration thermal energy storage technologies need performance improvements and validation for industrial systems • Thermal Management: lack of end-user options for captured waste heat. Multi-pronged approaches are often required for successful heat integration. • Smart Manufacturing: lack of industrial demonstrations of AI/ML for Industry 4.0 energy management.
Industry hesitation towards adopting new technologies	• Technology scale-up and de-risking required to advance the current state-of-the-art. • Product quality concerns • Potentially higher capital costs and longer payback periods

Stakeholder Engagement and Analysis to Develop Objectives and Targets

Goal: invest in next-generation technologies to achieve an efficient and competitive industrial sector with net-zero greenhouse gas emissions by 2050.

pre-2023 — Lab & Industry Input

- ✓ Energy Storage for Manufacturing Workshop
- ✓ Thermal Process Intensification Workshop
- ✓ Energy Storage Grand Challenge Roadmap
- ✓ Technology Assessment on Low-Temperature Waste Heat Recovery in Industry
- ✓ Industrial Decarbonization Roadmap
- ✓ Energy Earthshot Lab Ideation Forum

2023+ — Planned Stakeholder Engagement

- 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

Current Portfolio Highlight

Alternative Process Technologies: a novel processing pathway utilizing CO_2

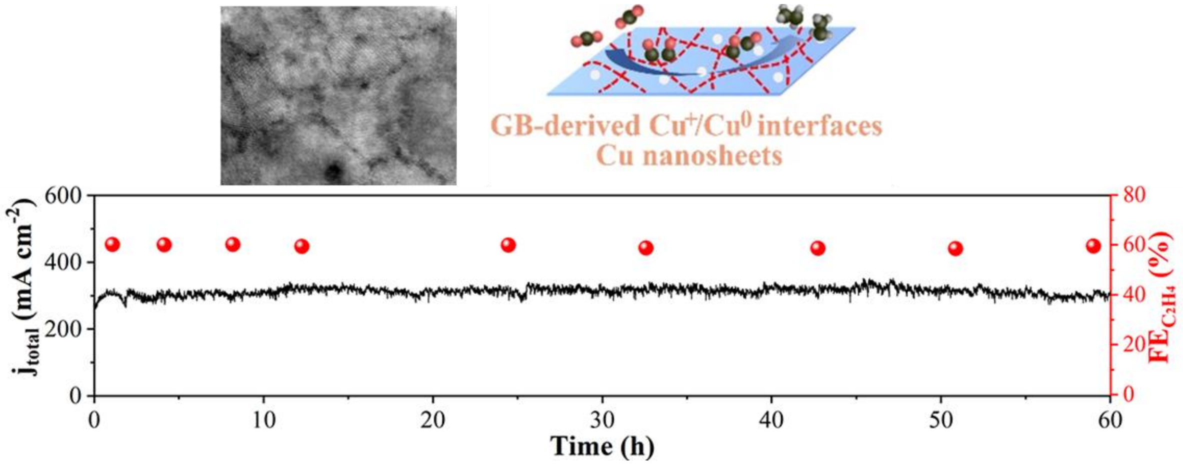
Modular Reactors for Capture and Electroconversion of CO_2

Lead: University of Louisiana at Lafayette; + Giner, Idaho National Lab, University of Cincinnati

Innovation: Develop modular reactors to open a pathway toward formation of C_2H_4 from electro-conversion of CO_2.

Specific Goals:

(1) to select materials for the HE-EMR for the capture of CO_2 with a variety of concentrations in industrial streams,
(2) to incorporate the high-efficiency electrodes into an AEM reactor capable of using renewable electricity,
(3) to employ an auxiliary unit to utilize the heat from the industrial sources and electricity



Emerging Technologies 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.*

Total	# Awards	Funding Mechanism	Topic Area	Description
$9.8M	TBD	FY23 MT FOA (2997)	• Exploratory Cross-Sector R&D: Flexible Industrial Energy Use & Thermal Energy Storage	• Technologies to enable core unit operations with fixed energy input levels to operate flexibly for flexible industrial energy use. • Develop and integrate thermal energy storage systems for providing process heat.
$800K	4	FY22 and FY23 SBIR Phase I	• Enhanced Heat Exchanger Waste Heat Recovery • High Operating Temperature Thermal Storage	• Invest in cost-effective IHP systems integration for industrial process heating. • Focus on high temperature heat exchanger for thermal storage, non-metallic heat exchangers for industrial heat pumps, and thermoelectric heat exchanger systems.
$19M	TBD	FY22 Industrial Efficiency and Decarbonization FOA (2804)	• High Operating Temperature Thermal Energy Storage • High Efficiency Waste Heat to Power	• Novel energy transfers for process heating, including waste heat recovery and reuse of process heat. • Enable technologies to demonstrate high operating temperature storage thermal systems to harvest, store, and utilize waste heat.

Emerging Decarbonization Technologies

Emmeline Kao, Technology Manager,
Industrial Efficiency and Decarbonization Office

End

Illustrative Example: Industrial Flexibility

Opportunity

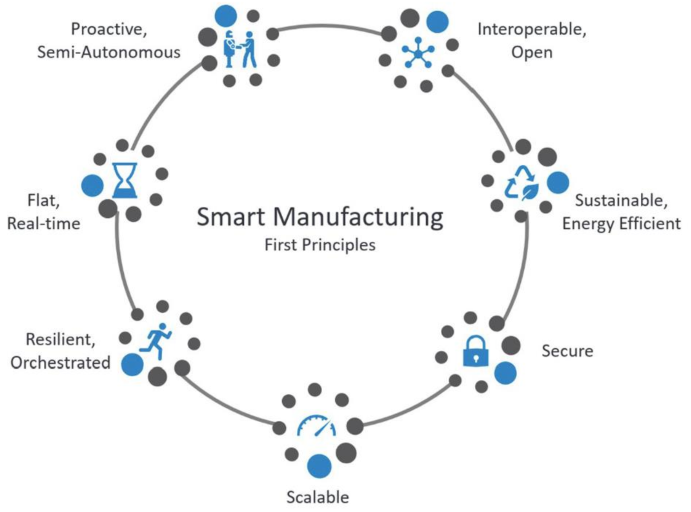
- **Smart manufacturing has potential to:**
  - Reduce average company energy demand by 20%.
  - Realize savings of $15B in annual electricity costs.[1]

R&D Pathways

- Advanced sensing instrumentation, monitoring, controls, and process optimization technologies.
- Comprehensive digitalization, monitoring, and control platforms to analyze production and energy consumption in real-time.[1]
- Improved performance in manufacturing areas such as: speed, agility, innovation, quality, costs, safety, reliability, and energy productivity.[2]
- Use artificial intelligence/machine learning to train predictive models to act as "energy managers" in Industry 4.0 plants

CESMII Project Highlight: Smart Manufacturing of Pulp and Paper: Advanced Machine Learning Enabled Multi-Objective Control for Energy Efficient Operation of Brownstock Washing

- Goal: develop, test, and analyze statistics pattern analysis (SPA) enhanced ML sensor for entrained air content and the corresponding advanced multi- objective model predictive control (MPC) for defoamer dosing, wash water flow, and washed pulp quality of brownstock washing



1 Smart Manufacturing Technologies and Data Analytics for Improving Energy Efficiency in Industrial Energy Systems. Sachin Nimbalkar, et al, 2017.
2 CESSMII Smart Manufacturing. 2022.

Illustrative Example: Industrial Flexibility

Importance to Industrial Decarbonization

- *Catalyzes industrial electrification* by connecting intermittent energy sources (solar, wind) with industrial consumers requiring a consistent power supply.
- High operating temperature storage (HOTS) from waste heat can be utilized in manufacturing to *reduce reliance on traditional fuels for energy*.
- Provides clean and equitable energy access for consumers and communities

Strategy: Invest in energy storage technologies that can enable greater use of clean energy across multiple industrial subsectors.

Objective/Goal[6]	Metric	Target
Round trip efficiency	Energy delivered/energy input	>70%
Thermal capacity	MWh	5-50
Discharge time	hours	10-48

1SBIR & STTR FY2022 Phase 1 Release 2. DOE, 2021.
2Solar Thermochemical Energy Storage. AIChe. 2017.
3Energy StorM workshop report. Sandia National Laboratories, 2022.
4Chemical Energy Storage. PNNL. 2022.
6IEDO/AMMTO FY23 Multitopic FOA. DOE, 2023.

Energy Storage Systems: Challenges and Barriers

Challenges/Barriers[3]

- Cost of electrical energy storage is prohibitive at industrially relevant scales with currently available technologies (traditional batteries)
- Scale-up and technology de-risking
- Long-duration thermal energy storage is currently infeasible due to excessive heat losses.

R&D Needs[1]

Advanced and efficient heat exchanger materials, geometry, and manufacturing.

- High performance thermal insulations to minimize heat loss for long-term storage.
- Storage media with high thermal energy density.
- Corrosion protection for harsh operating conditions, including high-temperature chemical resistance.

Candidate Technologies

- Thermochemical Energy Storage (TCES) – thermal energy used to "drive a reversible endothermic chemical reaction" to be stored as chemical potential energy. Reverse reaction "recombines chemical reactants and releases energy" when needed.[2].
- Chemical Storage– carbon-free energy option where electricity or thermal energy produced is converted into a chemical carrier where the carrier is moved or stored.[3]
  - Adds power into the grid and allows for storage of excess power from the grid for later use.
  - E.g.: Hydrogen can be stored in physical containers or within a chemical compound.[4]

1SBIR & STTR FY2022 Phase 1 Release 2. DOE, 2021.
2Solar Thermochemical Energy Storage. AIChe. 2017.
3Energy StorM workshop report. Sandia National Laboratories, 2022.
4Chemical Energy Storage. PNNL. 2022.
5Thermal Energy Storage Presentation. DOE, 2022

Increased Demand Flexibility: Challenges and Barriers

Challenges/Barriers

- Natural gas is the predominant source of fuel for industrial CHP systems.
- Traditional processes are designed for steady state operation; need to rethink process design for flexible operation and ramp tolerance.[4]
- Capitalize on large amounts of energy across the industrial sector to:
  - Provide ancillary grid services.
  - Enhance facility value.
  - Increase resiliency of industrial sites.

R&D Needs

- Hardware and controls development to integrate with existing facility equipment and grid connectivity.
- Approaches to facilitate automatic interactions between CHP systems and the grid.[2]
- Industrial demand reduction during peak loading hours.
- Integration and control of numerous equipment technologies (e.g., heat exchangers) and energy sources.

Objective/Goal[3]	Metric	Target
Increased energy flexibility	% energy usage vs. baseline	+/- 35%
Reduced downtime	% decrease in plant downtime	50%
Increased productivity	% increase in production per unit time	10%

1 *Flexible Combined Heat and Power (CHP) Systems*, DOE, 2018.
2 Combined Heat and Power Deployment Program. DOE, 2021
3 IEDO/AMMTO FY23 Multitopic FOA. DOE, 2023.
4 Energy StorM workshop report. Sandia National Laboratories, 2022.

Waste Heat Recovery: Challenges and Barriers

Challenges/Barriers

- 60% of waste heat is at or below 225°C, making it difficult to capture.[4]
- Sources of waste heat vary by industrial application, requiring a multi-pronged approach.

Candidate Technologies

- Integration of thermoelectric (TE) technology with heat exchangers.
- High-temperature thermal storage for WHR.
- Cascading waste heat recovery utilization schemes to maximize efficiency.
- Piezoelectrics materials with ability to develop an electric charge under applied mechanical stress.

R&D Needs

- System-level solutions that enable reuse of waste heat for other thermal processing applications.
- Low-cost, tight temperature approach heat exchangers for heat recovery from products.
- Low-cost flue gas heat recovery.
- Waste heat to power (WHP) technologies that convert both high and low temperature waste heat to electricity.

Objective/Goal[4]	Metric	Target
Conversion efficiency (waste heat to electricity)	%	30
Electricity production costs of the WHP system	$/Watt	<1

1 Manufacturing Energy and Carbon Footprints. DOE, 2018
2 SBIR & STTR FY2022 Phase 1 Release 2. DOE, 2022.
3 Industrial Decarbonization Roadmap. DOE, 2022.
4 Industrial Efficiency and Decarb FOA. DOE, 2022

Smart Manufacturing and Advanced Data Analytics: Challenges and Barriers

Challenges/Barriers

- Lack of industry-wide data management systems and standards makes integration within and across facilities difficult.
- Legacy equipment is not designed for integration with smart manufacturing systems.
- High up-front capital cost to implement smart manufacturing systems.
- Data security concerns.

R&D Needs

- Advanced sensing instrumentation, monitoring, controls, and process optimization technologies.
- Comprehensive digitalization, monitoring, and control platforms to analyze production and energy consumption in real-time.[1]
- Improved performance in manufacturing areas such as: speed, agility, innovation, quality, costs, safety, reliability, and energy productivity.[2]

Existing Concepts

- Celanese energy dashboard creation to further engage plant operators, which saved $300k annually from operator adjustments based on real-time data.[1]
- General Mills energy visualization and assigned targets based on production levels, which saved $650k annually, resulting in a 1.6 year payback period.[1]

1Smart Manufacturing Technologies and Data Analytics for Improving Energy Efficiency in Industrial Energy Systems. Sachin Nimbalkar, et al, 2017.
2CESSMII Smart Manufacturing. 2022.