U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

AMMTO & IEDO JOINT PEER REVIEW

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THERMAL PROCESSES AND SYSTEMS

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Industrial Efficiency and Decarbonization Office

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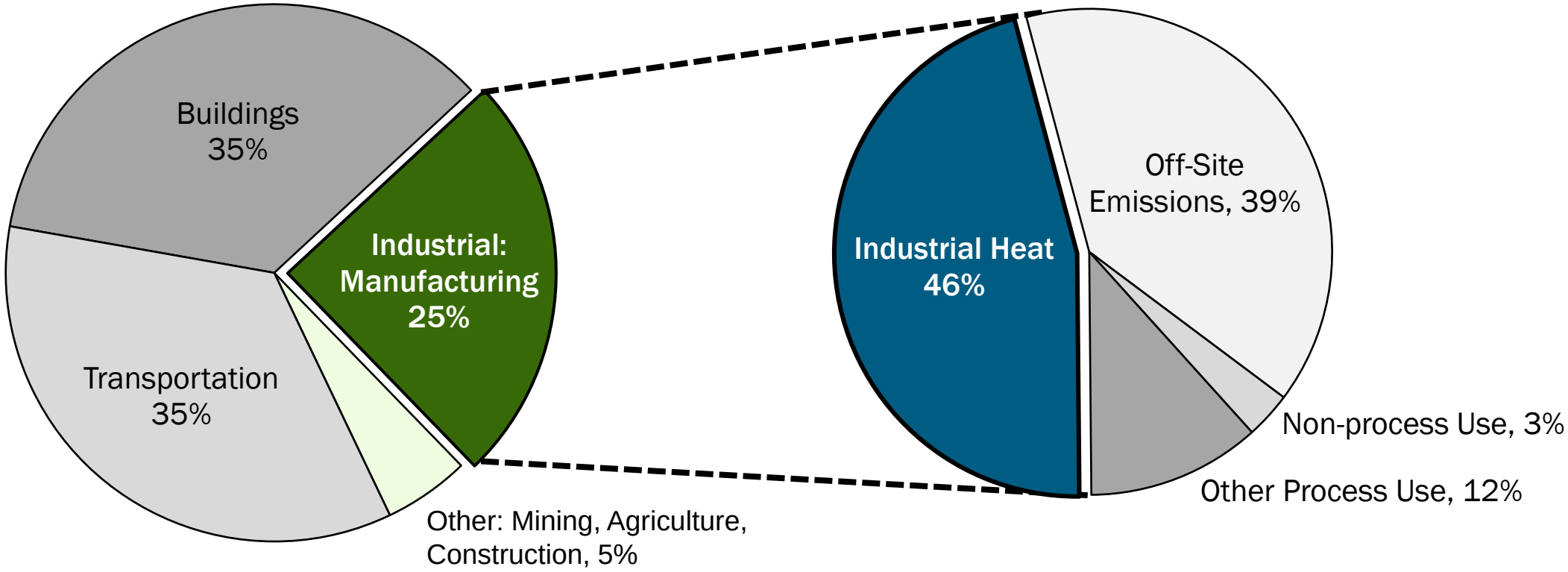
Thermal Processes are Key to Industrial Decarbonization

Industrial Heat Causes 11% of All U.S. Energy-Related Emissions



2020 Energy-Related CO_2 Emissions by U.S. Economic Sector

2020 Estimated Industrial: Manufacturing Energy-Related CO_2 Emissions by Source

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

Cross-Sector Approach is Challenging but Necessary

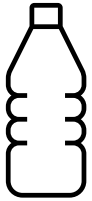
Thermal processes and systems are <u>essential</u> and <u>pervasive</u> in industry, but every major industrial subsector uses heat in <u>different ways</u>…

drying
paper, batteries

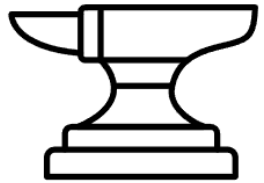
steam
pasteurized food

distillation
high purity chemicals

melting
formed plastics, semiconductors



smelting
iron, copper, aluminum



calcining
cement, lime

Decarbonization of Thermal Processes & Systems at IEDO

Reduce the amount of heat used and the emissions from generating heat to make cleaner products by…

Overcoming Critical Barriers

- Develop diverse technology portfolio to address industry's heterogeneous heat demands
- Meet or exceed operational demands
- Address cost competitiveness
- Quantify non-energy/non-emissions benefits
- Scale-up towards commercialization

Advancing Key Technologies

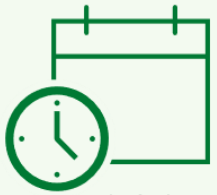
- Electro-technologies & industrial heat pumps
- Innovative low- and no-heat processes & advanced non-thermal separations (e.g., membranes)
- Advanced furnace equipment and process control technologies

Supporting DOE's Industrial Heat Shot

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

Industrial Heat Shot: 3 Pathways to Decarbonize Industrial Heat

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, thermal storage, 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.

Thermal Processes and Systems Portfolio

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

Emerging Efficiency and Other Decarbonization Technologies

Low-carbon Fuels and Feedstocks

Objective and Targets

Objective

Advance cost-effective technologies for process heating that improve the properties of manufactured products, and develop alternative, low thermal budget technologies that reduce the energy and carbon requirements of materials processing.

Targets

1. Develop **electrified process heating technologies** to replace existing fuel-based technologies through **cost competitiveness, reduced emissions, improved flexibility, and greater efficiency.**
2. Develop **low-thermal-budget manufacturing technologies** that **reduce energy intensity** (energy consumed per unit of physical output) by at least 50% compared to typical technology.
3. Develop **advanced process heating unit operations** that provide **improved properties, quality, and/or product value** at cost parity to conventional techniques.

Budget Request & Priorities

- Industrialize electro-technologies to replace fossil-based process heating within 10 years.
- Develop next-generation component and system technologies for decarbonized process heating applications in multiple sectors.
- Develop non-thermal replacements for heat-intensive processes.
- Advancements in heat pumps, transformative processes, and industrial refrigeration/cooling.

Activity (dollars in millions)	FY23	FY24 Request
Thermal Processes and Systems	38.50	*71.245*

Execution

- FY22 Institute 7 FOA
- FY22 Industrial Efficiency and Decarbonization FOA
- FY23 IEDO Multi-Topic FOA

Technology Priority
Electric and hybrid heating systems to replace fuel burning heaters.
High-temperature industrial heat pumps which can efficiently transfer heat from waste-heat streams to useful process heating applications up to 200°C.
Transformative low thermal budget processes, which achieve similar end products to current processes while utilizing significantly less thermal energy.
Membrane separation technologies that utilize physical and electrical methods instead of thermal energy for use in multiple sectors.

Key FY 2023 Investments

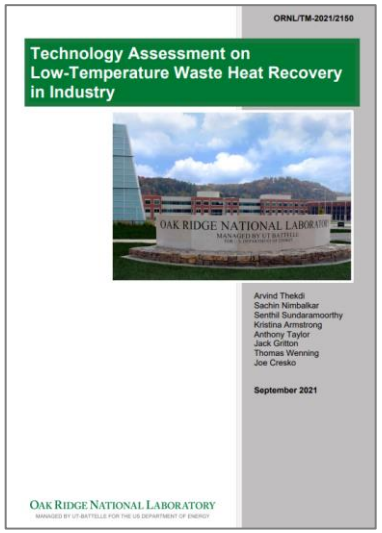
- **Institute 7 (Electrification of Process Heating)** – Selection spring 2023.
- **Electrification of thermal processing equipment** used across industry via resistive, hybrid, and advanced electrotechnologies.
- **Low-thermal budget energy equipment** to enable transformative processes that uses significantly less energy.
- **Design and integration of industrial heat pumps** and AI-based approaches for system design and optimization.

Program Planning Input from Stakeholder Engagement & Analysis

Thermal Process Intensification (TPI)

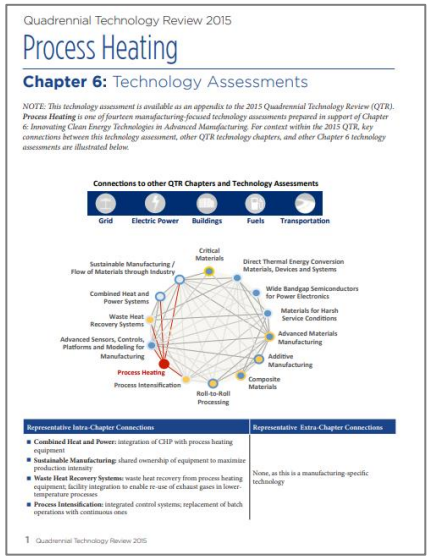
Input from subject-matter experts on transformative technologies and strategies to substantially improve the performance of thermal processing systems in the industrial sector.

- Workshop in late 2020
- Report published in May 2022



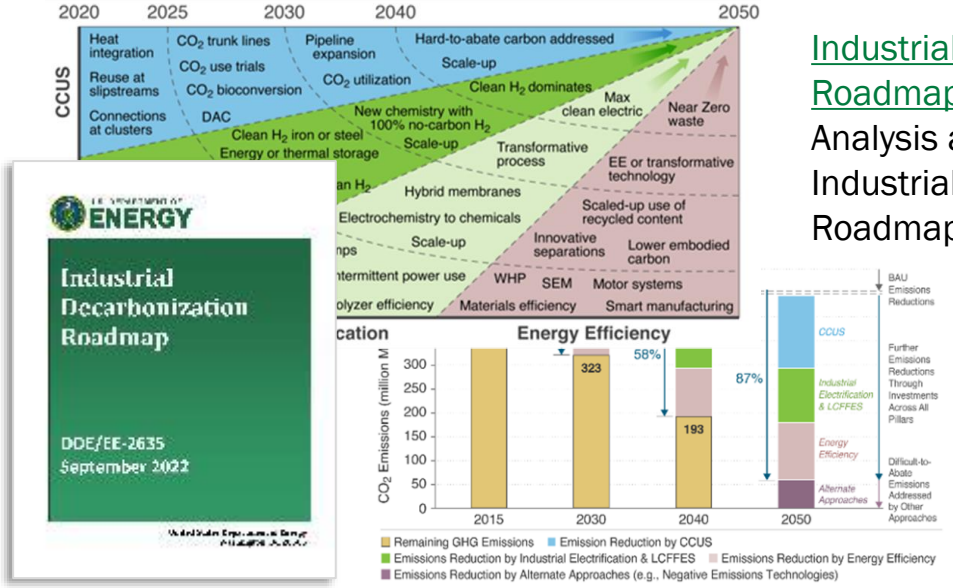
Technology Assessment of Low-Temperature Waste Heat in Industry 2021

Characterization of waste heat streams, emerging technologies, and research opportunities.



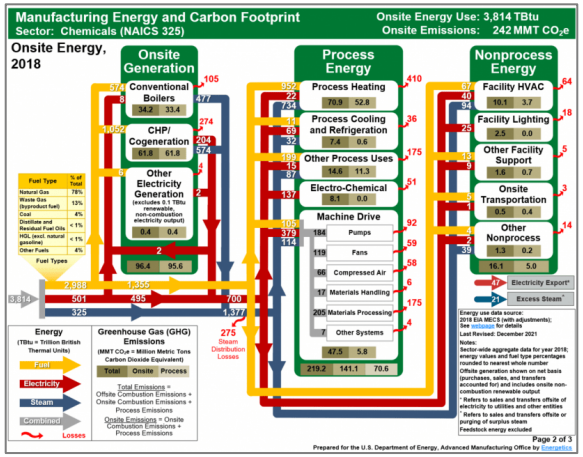
DOE Quadrennial Technology Review 2015

Assessment on process heating



Industrial Decarbonization Roadmap

Analysis associated with Industrial Decarbonization Roadmap



Manufacturing Energy and Carbon Footprints

The flow of energy supply, demand, and losses as well as greenhouse gas (GHG) emissions for end uses in 15 U.S. manufacturing industries and manufacturing-wide.

Thermal Processes & Systems Portfolio

FY19
- **AMO Multi-Topic FOA.** Topic 2: Lower Thermal Budget Processes for Industrial Efficiency & Productivity
  - Subtopic 2.1: *Advances in Industrial and Process Drying* (6 awards; ~$11.7M)
    - Area of Interest 1 – *Novel Drying Systems in Manufacturing*
    - Area of Interest 2 – *Drying Modeling, Sensing, and Control Strategies*
  - Subtopic 2.2: *Thermal Process Intensification* (2 awards; ~$9.4M)
    - Area of Interest 1 – *R&D of Electromagnetic Sources for Manufacturing*
    - Area of Interest 2 – *Electromagnetic Energy for Advanced Manufacturing Applications*

FY20
- **AMO Multi-Topic FOA.** Topic 1: Efficiency Improvements in Advanced Manufacturing Processes
  - Subtopic 1.2: *Enhanced Efficiency of Drying Processes* (3 awards; ~$7.7M)

FY21
- **AMO Multi-Topic FOA.** Topic Area 1: Manufacturing Process Innovation
  - Topic Area 1a: *Efficiency Improvements to Drying Processes* (3 awards; ~$6.2M)

FY22
- **Clean Energy Manufacturing Innovation Institute for Electrification of Process Heating (Institute 7)**
  - FOA released June 2022; Selection announcement planned for May 2023
- **Industrial Efficiency and Decarbonization FOA.** Topic Area 6: Cross-sector Decarbonization Technologies
  - Area of Interest 3 – *Industrial Heat Pumps*

FY23
- **IEDO Multi-Topic FOA.** Topic Area 1: Decarbonizing Industrial Heat
  - Area of Interest 1 – *Electrification of Industrial Heat*
  - Area of Interest 2 – *Innovative Low- and No-Heat Processes*
  - Area of Interest 3 – *Industrial Heat Pumps*

Current Portfolio: Two Example Projects

Novel Energy-Efficient Drying Technologies for Food, Pulp and Paper, and other Energy Intensive Manufacturing Industries (FY19 AMO Multi-Topic FOA)

Lead: Worcester Polytechnic Institute; + University of Illinois, ORNL, CARD

Innovation: Scaling high-performing drying technologies with integration of advanced sensors and AI for optimal process control

Project Tasks:

- Three drying technologies pursued: dielectrophoresis drying; acoustic/ultrasonic drying; and impinging (slot jet reattachment) nozzle
- Smart dryer testbed commissioned in October 2022

Impact: Reduce manufacturing drying energy consumption by 25-35%, cut material waste, and improve product quality

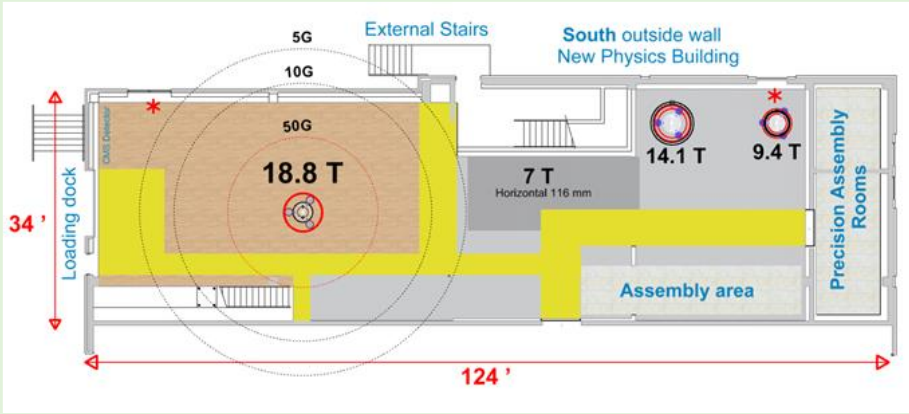
Industrial Thermomagnetic Processing (FY19 AMO Multi-Topic FOA)

Lead: University of Florida; + VA Tech, U. of Illinois Urbana, Dante Solutions, ORNL and Industry participation

Innovation: Development of High Energy Density Thermomagnetic Processing Technology for Intensification of Industrial Heat-treatment and Increased Material Performance

Project Tasks:

- No-Field and Field Assisted Experimental Evaluation
- Computational Model Suite Development and Validation
- Commercial System Development



Impact: Projected 90% reduction of CO_2e over conventional steel mfg.

New Partners: John Deere; Eck Industries; Tenneco; Ajax-TOCCO. Testing on candidate parts.

Future Portfolio: Institute on Electrification of Process Heating

Institute Vision: An Industrial Sector that uses **electrified heating processes** to **reduce emissions** and become more flexible, efficient, and competitive.

Institute Mission: Decarbonize industry by developing and scaling electrotechnologies that replace fossil-based process heating within 10 years.

Institute Targets:

- **Cost effective:** Cost parity to fossil-based process heating replacements
- **Efficient:** Reduce total thermal requirements and emissions for processes
- **Scalable:** Pilot-scale demos of electrotechnologies in novel processes
- **Enable co-benefits:** Improve productivity, product quality, process flexibility, and/or efficiency and yield
- **Verifiable:** Develop and share tools and methodologies that enable evaluation of life cycle benefits and integration with existing processes

Key Activity Areas:

1. Collaborative Research, Development, and Demonstration of Electrified Heating Technologies
2. Process Modeling and Optimization Tools
3. Technology, Market, and Impact Analysis

Activity	Date
FOA Released	June 2022
Full Applications Due	October 2022
Selection Announcement	Spring 2023

Thermal Processes & Systems

Cross-Sector Technologies
Industrial Efficiency & Decarbonization Office

Keith Jamison, Technology Manager

Questions?

Future Priorities

- Stakeholder engagement through Industrial Heat Shot Summit
- Advance technologies to achieve IEDO and Industrial Heat Shot goals

Recent Achievements

- Completion of CEMI Institute #7 FOA and selection process
- Completion of Industrial Efficiency & Decarbonization FOA (selections forthcoming)

Backup Slides

Industrial Drying: FY23 Portfolio

FY19 Awards	Technology Approach	Application Focus	Status
Worchester Polytechnic Institute 3 yr project ($3,460k)	Multiple: dielectrophoresis drying; acoustic/ultrasonic drying; impinging (slot jet reattachment) nozzle; smart sensors; AI, ML and controls	Food and paper: products include sliced apples, vegetables, chips, cookies, & paper (linerboard, uncoated fine paper, & pulp)	In Budget Period 3. Project presentation in Food and Beverage Products session.
Molecule Works 3 yr project ($3,818k)	Membrane (water vapor membrane separation)	Ethanol/water separation	Later stages of Budget Period 2. Poster in CST poster session.
Palo Alto Research Center (PARC) 3 yr project ($3,000k)	Spray drying (using filament extension atomization technology)	Dairy products	Transitioning between Budget Period 2 and 3. Project presentation in Thermal Processes and Systems session.
Iowa State 2 yr project ($500k)	Laser drying	Microelectronics (wafers)	Ending August 2023.
Raytheon 2 yr project ($500k)	Electric-field de-wetting (applied to dielectric surface)	Removal of surface liquids (heat exchangers, heat pumps, dehumidifiers, etc.)	Ended January 2023.
Forest Concepts, LLC 2 yr project ($400k)	Radio frequency (pre-heating)	High moisture biomass feedstocks (wood chips, corn stover)	Ended January 2023.

Industrial Drying: FY23 Portfolio (Continued)

FY20 Awards	Technology Approach	Application Focus	Status
Saint-Gobain 3 yr project ($2,283k)	Microwave or radio frequency energy (for calcination)	Gypsum drying	In Budget Period 2. Poster in CST poster session.
U. of Minnesota 3 yr project ($2,364k)	Radio frequency and ultrasonic energy along with conventional processes	Pulp and paper production (and other biomaterial applications)	Transitioning between Budget Period 1 and 2. Project presentation in Forest Products session.
Georgia Tech 3 yr project ($3,000k)	Multi-phase forming (uses foam instead of water as working fluid)	Fiber-based material (paper, tissue, fiber composites)	Later stages of Budget Period 1. Poster in EEII poster session.

FY21 Awards	Technology Approach	Application Focus	Status
Purdue University 3 yr project ($1,894k)	Membrane-based drying that combines a vapor-selective membrane with a refrigeration cycle	Various	In Budget period 1. Poster in CST poster session.
U. of Texas at Dallas 3 yr project ($2,253k)	Thermo-responsive polymeric materials that can effectively absorb and desorb water from porous materials	Paper drying	In Budget period 1. Poster in CST poster session.
Texas A&M ES 3 yr project ($2,206k)	Intelligent desiccant-assisted heat pump drying system	Wood drying	In Budget period 1. Poster in CST poster session.

Process Heating: FY23 Portfolio

Industrial Thermomagnetic Processing

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Project Tasks:

- No-Field and Field Assisted Experimental Evaluation
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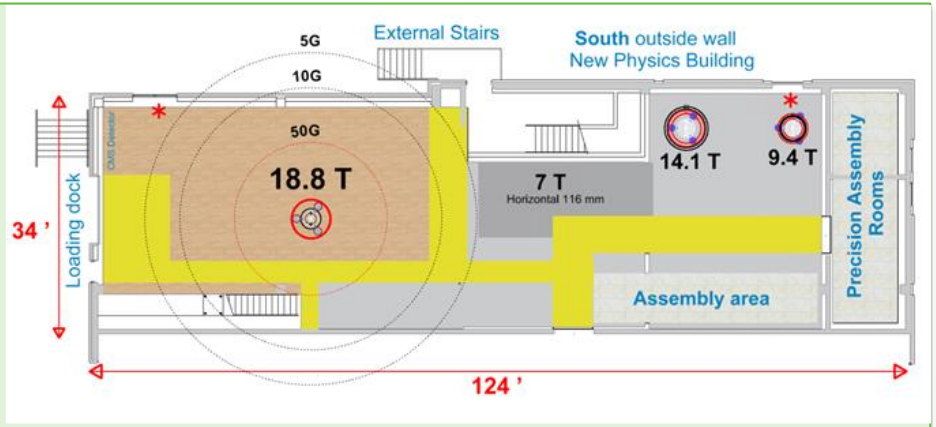


Impact: Projected ~90% reduction of CO2e over conventional steel mfg.

New Partners: John Deere; Eck Industries; Tenneco; Ajax-TOCCO. Testing on candidate parts.

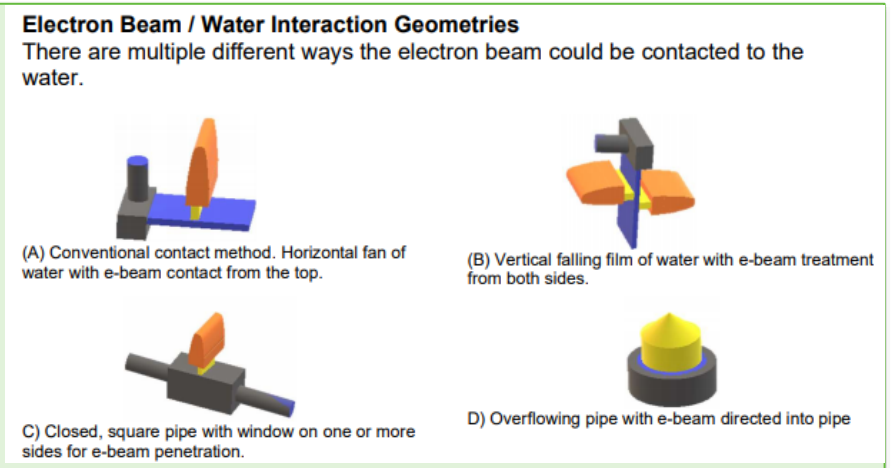
Degradation of Poly- and Perfluoroalkyl Substances (PFASs) in Water via High Power, Energy-Efficient Electron Beam Accelerator

Lead: 3M; + Fermi

Innovation: Use of electron beam (e-beam) for breakdown of a sub-set of the larger family of per- and polyfluoroalkyl substances (PFAS) in an energy efficient and economical manner when compared to conventional water treatment technologies such as granular activated carbon (GAC).

Project Tasks:

- Health/Environmental Assessment and Report of Previous Studies
- Optimal E-beam dose and additive concentration
- Process Flow Specification



Goal: translate results to understand suitability and scale of commercial EB systems for water treatment