U.S. Department of ENERGY | Office of Energy Efficiency & Renewable Energy

Industrial Efficiency & Decarbonization Office

IEDO 2024 Accomplishments

Dr. Avi Shultz, IEDO Director

MEETING RECORDING ANNOUNCEMENT

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U.S. Department of ENERGY | Office of Energy Efficiency & Renewable Energy

THE U.S. INDUSTRIAL SECTOR

AMERICA'S ECONOMIC ENGINE

CONTRIBUTES
$4.8 trillion to the U.S. economy annually [1]

CREATES
21.6 million jobs [2]

BOLSTERS
U.S. competitiveness in global markets

1. *Interactive Access to Industry Economic Accounts Data*, Bureau of Economic Analysis (2023).
2. *Goods-Producing Industries*, Bureau of Labor Statistics (2023).

INDUSTRIAL EFFICIENCY AND DECARBONIZATION OFFICE

Investing in innovation to position the U.S. to lead in emerging global markets and to increase the competitiveness of the U.S. industrial sector.

Accelerating the development of technologies that expand and secure supply chains for American-made industrial products and commodities such as steel, chemicals, cement, and glass.

Collaborating with a wide range of partners to ensure that the health and prosperity of American communities and workers grows alongside the industrial sector.

GROWING DEMAND FOR DECARBONIZED PRODUCTS

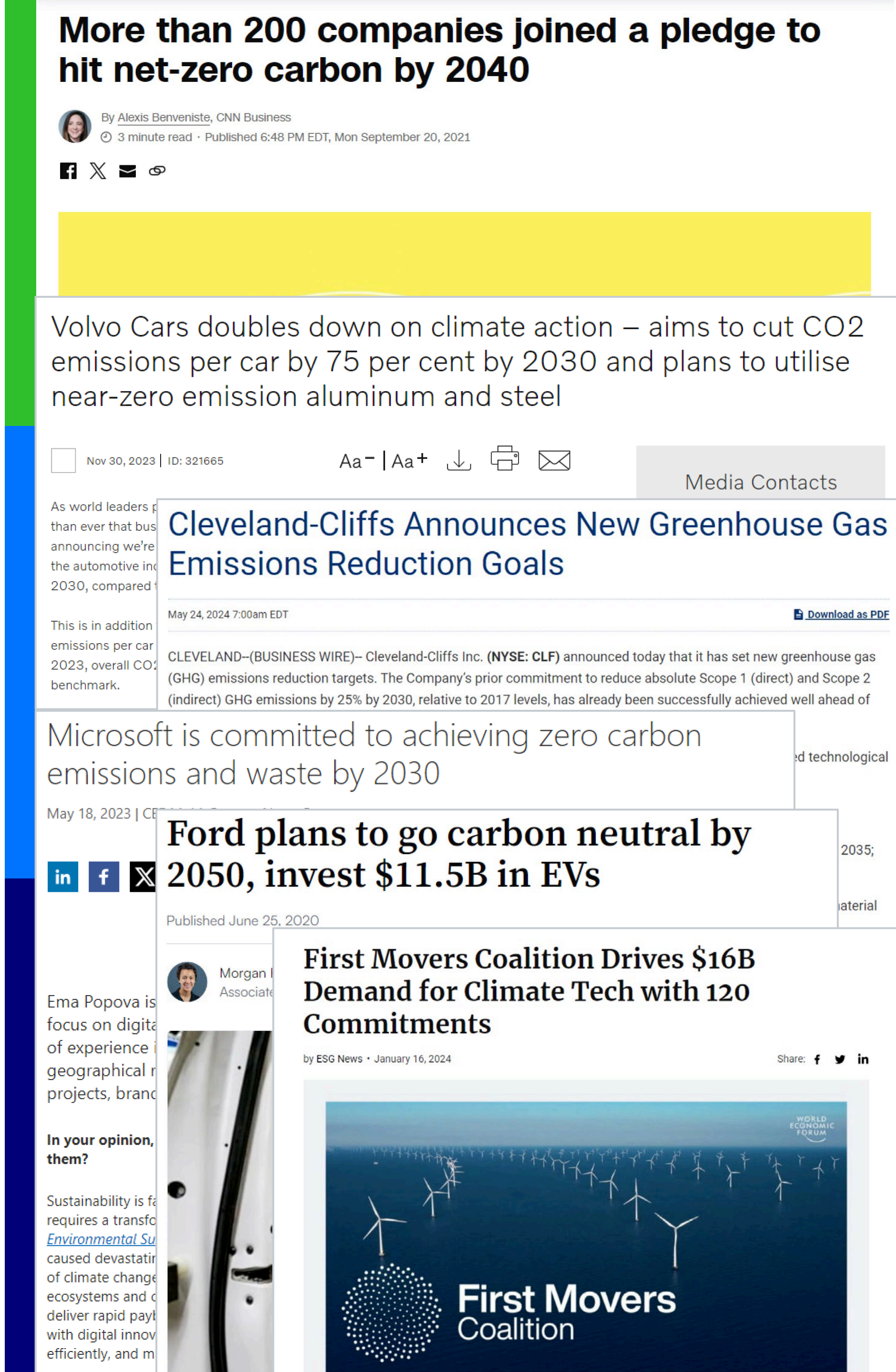
PRIVATE SECTOR LEADERSHIP

Commitment to purchase ≥ 10% low-carbon steel and aluminum by 2030

100+ global corporations including Ford Motor, General Motors, and Volvo Group

Commitment to reduce portfolio-wide scope 1 and 2 emissions by ≥ 50% within 10 years

250+ partners ranging from manufacturers and data centers to healthcare systems and universities



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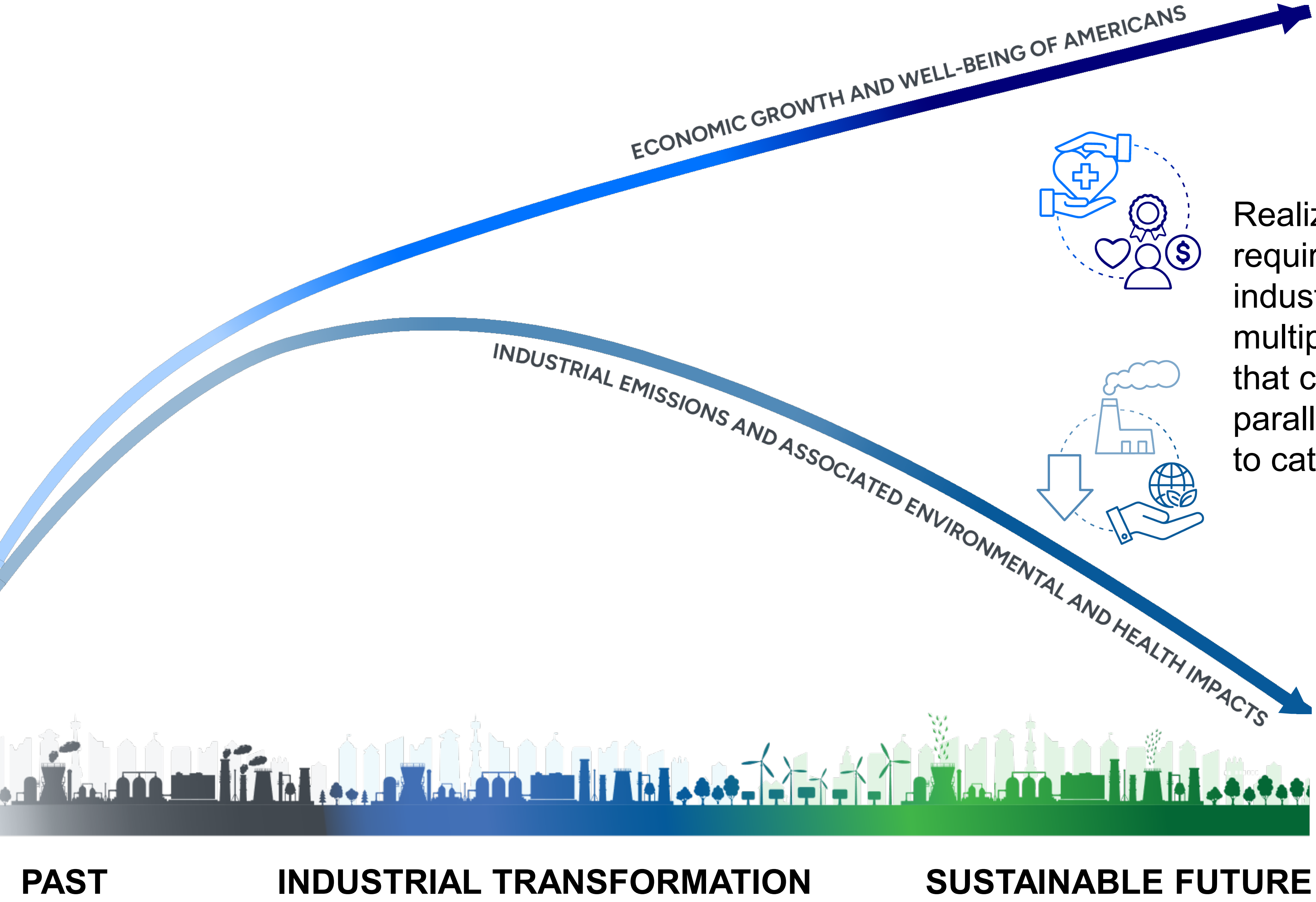

Realizing this vision will require re-imagining the industrial sector, identifying multiple technology pathways that can be pursued in parallel, and ambitious action to catalyze innovation.

LEADERSHIP TEAM

INDUSTRIAL EFFICIENCY AND DECARBONIZATION OFFICE

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Director

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Deputy Director

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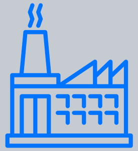
Operations Supervisor

Ava Coy
Program Manager
Technical Project Officers

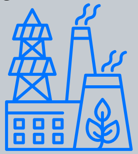
Mattie Gainer
Engagement & Outreach Lead

Paul Majsztrik
Energy- and Emissions-Intensive Industries Program Manager



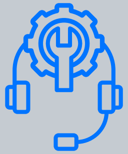
FY24
$113M

Samuel Bockenhauer
Cross-sector Technologies Program Manager



FY24
$81M

Anne Hampson
Technical Assistance and Workforce Development Program Manager



FY24
$43M

$237 Million FY24 Budget

R&D INVESTMENTS IN TRANSFORMATIONAL INDUSTRIAL TECHNOLOGIES

+ $350 MILLION

INVESTMENTS IN ENERGY-INTENSIVE INDUSTRIES

Accelerating innovation tailored for energy-intensive industries.

	Topic Area	Number of Awards	Federal Funding
1	Chemicals and fuels	11	$32M
2	Iron and steel	14	$29.7M
3	Food and beverage products	10	$18M
4	Buildings and Infrastructure	11	$19.9M
5	Forest products	8	$18.8M
6	Industrial Pre-FEED Studies	12	$17.5M
	Total	**66**	**+$136M**

A COMPACT, MODULAR MEMBRANE REACTOR FOR >10 KG/DAY, HIGH-EFFICIENCY AMMONIA (NH3) SYNTHESIS AT MODERATE TEMPERATURES AND PRESSURES

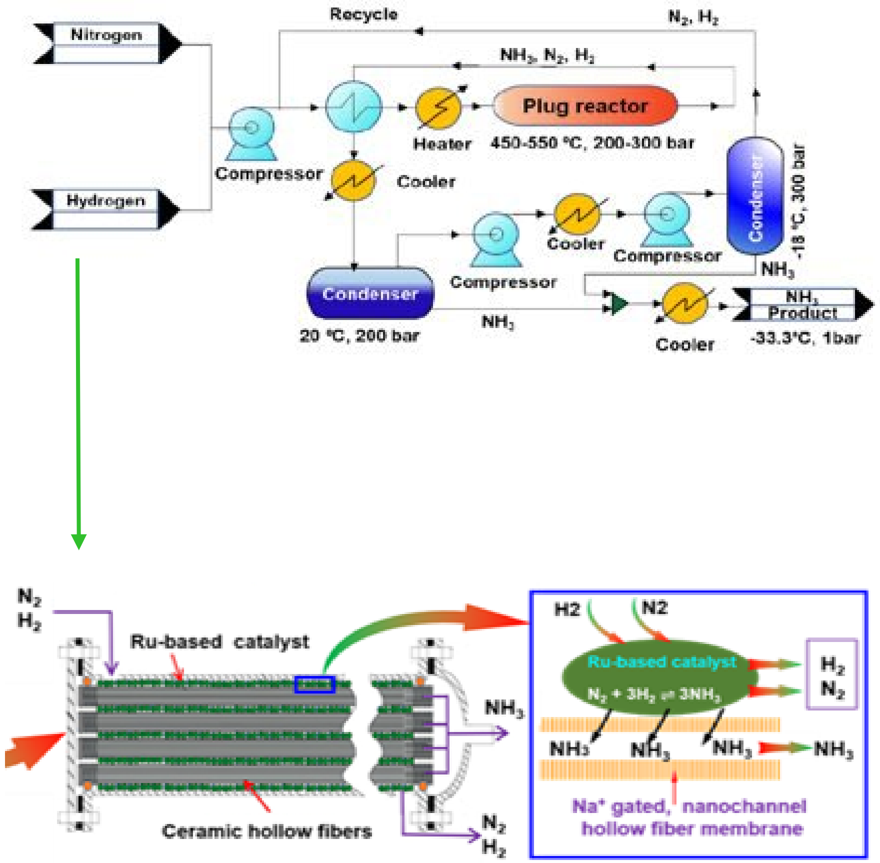
City/State: Buffalo, NY

Federal Funding: $3,000,000

Project Lead: E2H2NANO, LLC

Partners: Johnson Matthey (JM), University at Buffalo, University of South Carolina

Description: Scale up the membrane, catalysts, and membrane reactor itself to produce ammonia from N2 and H2 with improved performance compared to conventional Haber-Bosch (HB). Continuing from a past AMO/IEDO project demonstrating 0.2 kg/day this project plans to achieve 10 kg/day continuous production.



TRANSFORMATIVE TACONITE BENEFICIATION FLOWSHEET OF THE FUTURE

City/State: Duluth, MN

Federal Funding: $3,100,000

Project Lead: University of Minnesota - Duluth

Partners: National Renewable Energy Laboratory, U.S. Steel

Description: Develop a transformational new beneficiation flowsheet for upgrading Minnesotan taconite ores to ‘direct reduction’ (DR) grade. This integrated approach will leverage state of the art separation technologies including High Pressure Grinding Rolls, Vertical Stirred Mills, Hydrofloat, and Jameson Floatation technologies to reduce the energy intensity, yield loss and intensive grinding required to produce DR grade iron ore products

INVESTMENTS IN CROSS-SECTOR TECHNOLOGIES

Accelerating innovation for technologies that have wide applicability across the diverse industrial sector.

	Topic Area	Number of Awards	Federal Funding
1	Electrification of Industrial Heat	5	$12,553,347
2	Efficient Energy Use in Industrial Systems	6	$13,737,783
3	Decarbonizing Organic Wastewater and Wet Waste Treatment	5	$12,224,930
	Total	**16**	**+$38M**

HEATING, BAKING, DRYING WITH LASER TECHNOLOGY FOR FOOD AND PULP AND PAPER INDUSTRY SECTORS

CARD
CENTER FOR ADVANCED RESEARCH IN DRYING

City/State: Worcester, MA

Federal Funding: $2,750,000

Project Lead: Worcester Polytechnic Institute

Partners: University of Illinois at Urbana-Champaign; RAPID Manufacturing Institute; Reading Bakery Systems; Electric Power Research Institute; Alliance for Pulp and Paper Technology Innovation; IPG Photonics

Description: Develop and demonstrate heating process electrification utilizing laser technology and integrate laser technology with other heating and drying technologies including ultrasound and infrared.

AQUEOUS-PHASE ROLL-TO-ROLL CONTINUOUS MANUFACTURING OF ROBUST AND TUNABLE GRAPHENE OXIDE MEMBRANES FOR FRACTIONATION OF COMPLEX FEEDSTOCKS

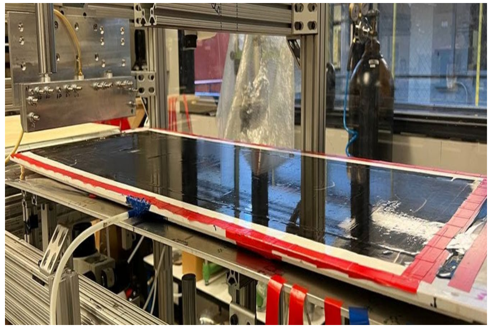
City/State: Atlanta, GA

Federal Funding: $2,126,875

Project Lead: Georgia Tech Research Corporation

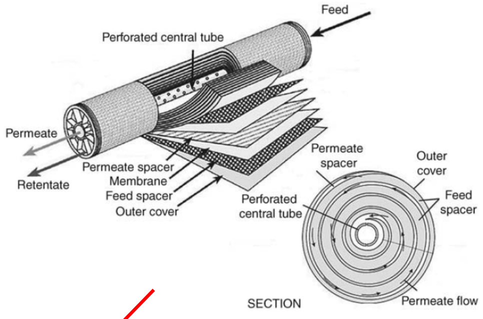
Partners: Mott Corporation

Description: 1) develop and scale-up a continuous roll-to-roll (R2R) fabrication process for the robust and tunable reduced graphene oxide (rGO) and rGO-X nanofiltration membrane technology, and 2) assemble spiral wound elements and operate a continuous pilot skid to optimize separation characteristics.

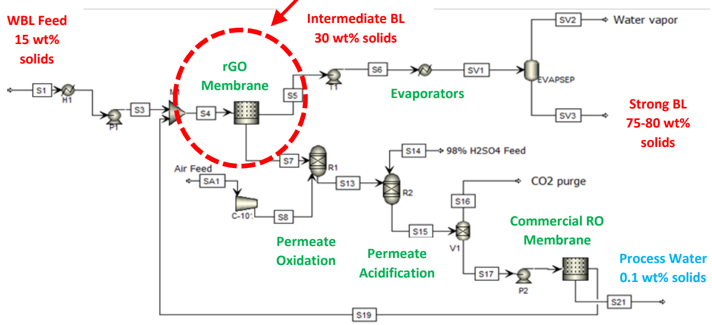


RGO membrane continuous fabrication

Spiral wound element assembly



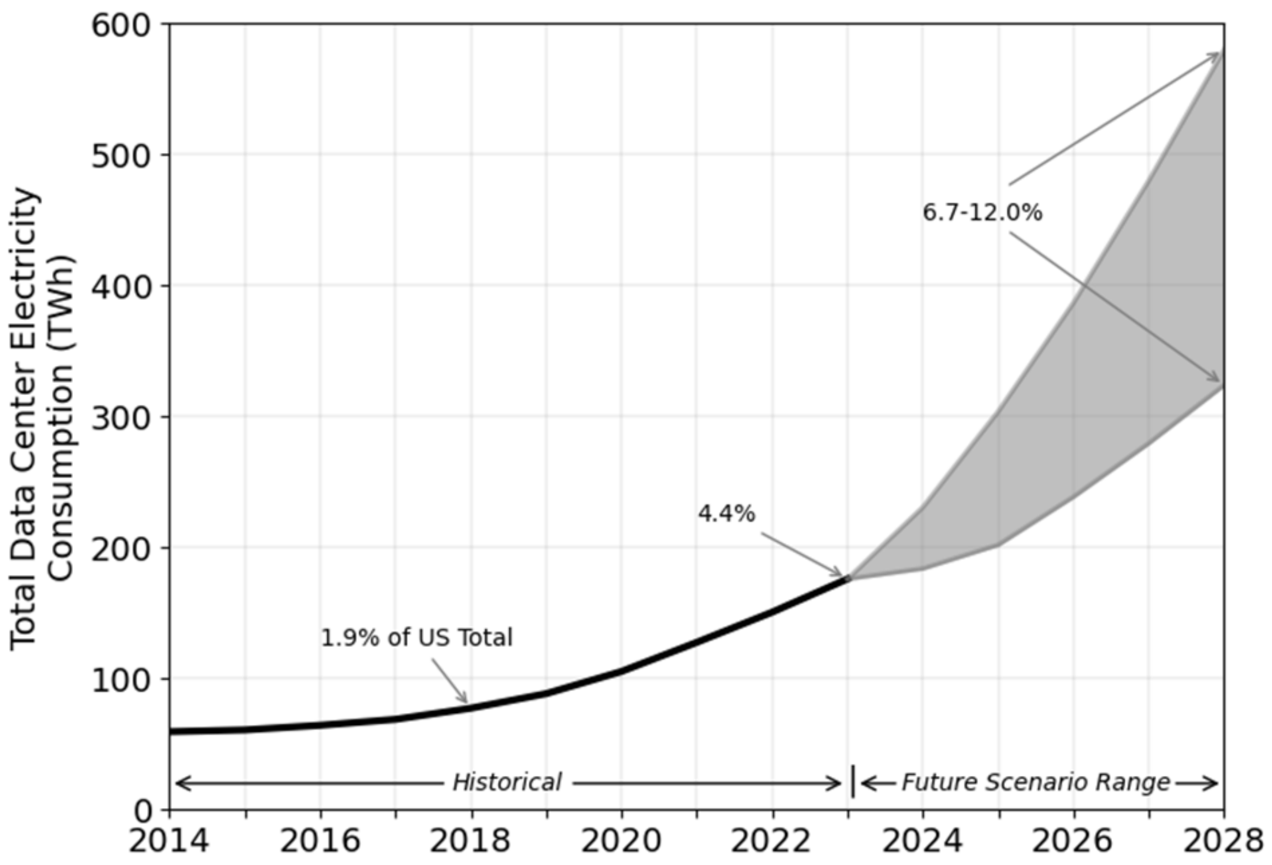
Detailed module evaluation and optimization in real BL



Novel process design and TEA/LCA

SOLUTIONS TO ENABLE NATIONWIDE ELECTRICITY GROWTH

2024 REPORT ON U.S. DATA CENTER ENERGY USE



ELECTRICITY USE ESTIMATES:

- Data centers consumed about 4.4% of total U.S. electricity in 2023
- Data center energy consumption is expected to consume approximately 6.7 to 12% of total U.S. electricity by 2028

DATA CENTER ELECTRICITY USE OVER TIME:

- **2014**: 58 TWh
- **2023**: 176 TWh
- **2028** estimate: 325 to 580 TWh

ONSITE ENERGY PROGRAM

Provides technical assistance, market analysis, and best practices to help industrial facilities, data centers, and other large energy users increase the adoption of onsite energy technologies.

Onsite Energy
Technical Assistance Partnerships
U.S. DEPARTMENT OF ENERGY

- Battery Storage
- Combined Heat and Power
- District Energy
- Fuel Cells
- Geothermal
- Industrial Heat Pumps
- Renewable Fuels
- Solar PV
- Solar Thermal
- Thermal Storage
- Waste Heat to Power
- Wind

INDUSTRIAL ENERGY STORAGE SYSTEM PRIZE

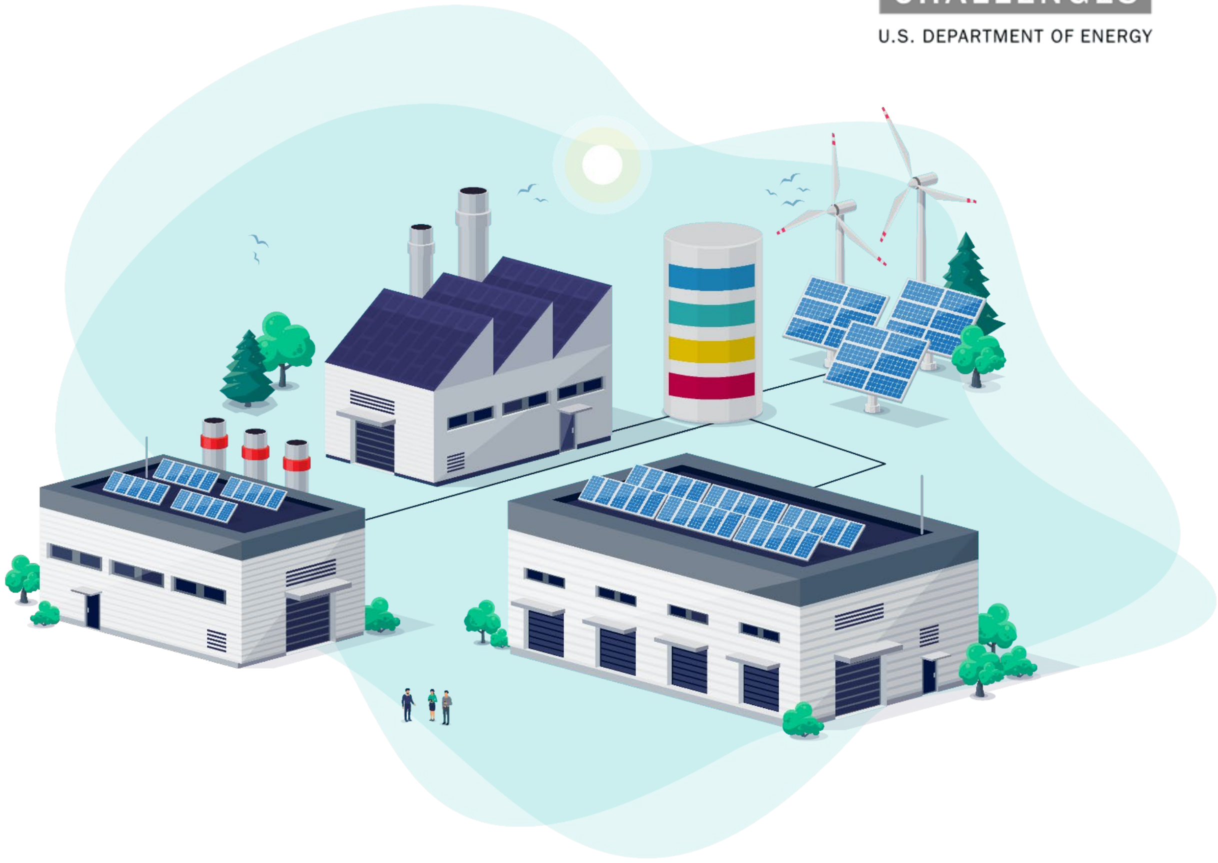
AMERICAN MADE CHALLENGES
U.S. DEPARTMENT OF ENERGY

Prize to accelerate market adoption for cost-effective energy storage technologies for industrial applications and data centers.

IEDO is seeking innovative ideas using thermal energy storage in the following categories

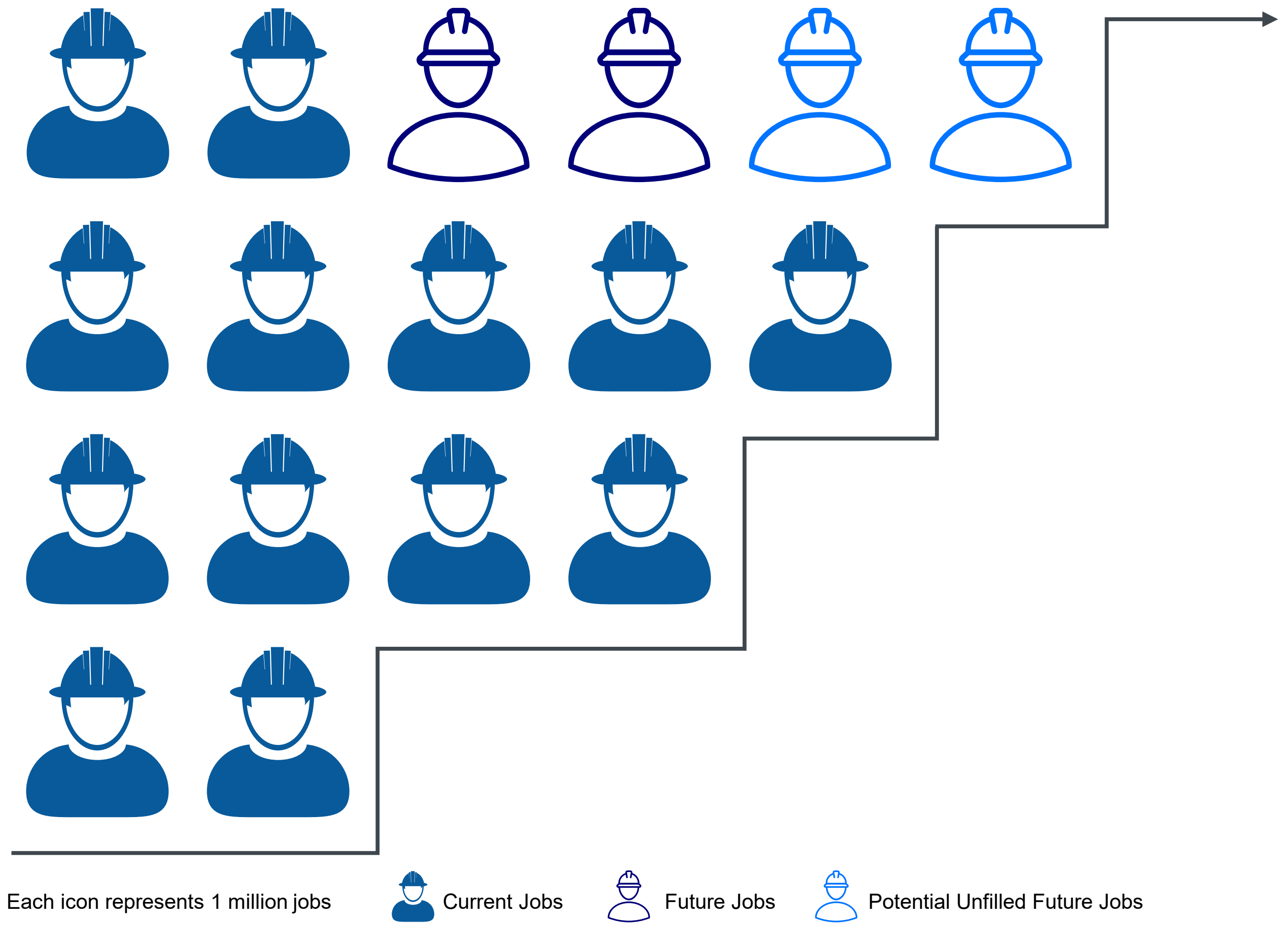
1. Industrial cooling energy storage
2. High temperature industrial energy storage
3. Industrial thermal storage for hybrid cooling, heating, and power

Industrial Energy Storage Systems Prize | HeroX



TECHNICAL ASSISTANCE AND TRAINING TO PREPARE AMERICA'S WORKFORCE FOR THE FUTURE

GROWING THE INDUSTRIAL WORKFORCE OF THE FUTURE



- **4 million new manufacturing jobs** will need to be filled by 2030.
- **Half are at risk of going unfilled** due to increasing specialization and new skillsets needed.
- **Tailored technical assistance and workforce development** can help grow the readiness of the workforce.

Employment by Major Industrial Subsector. Bureau of Labor Statistics (2023).
2.1 Million Manufacturing Jobs Could Go Unfilled by 2030. National Association of Manufacturers (2021).

ISEED WORKFORCE INITIATIVE

- $3 million in funding for new Industrial Sustainability, Energy Efficiency, and Decarbonization (ISEED) Collaborative to help **grow the readiness of the workforce** needed for a competitive U.S. industrial sector of the future.
- ISEED will provide assistance to partners across the manufacturing sector to develop and disseminate instructional **curricula and training programs focused on industrial innovation and competitiveness**.

TRANSFORMATIVE PATHWAYS FOR U.S. INDUSTRY:
UNLOCKING AMERICAN INNOVATION

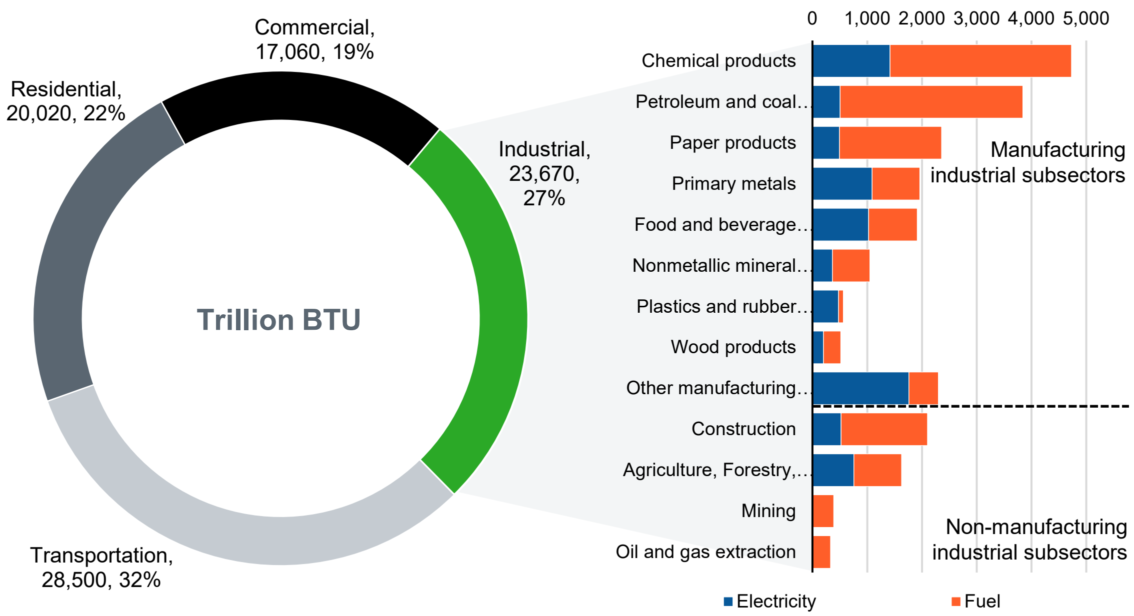
- Identify **cost-effective and industry-specific pathways** to achieve a globally competitive industrial sector of the future
- Address **technological, economical, societal, and environmental & health impacts**
- Present **tailored pathways, metrics, and targets** for overcoming barriers

U.S. INDUSTRIAL SECTOR: ENERGY AND EMISSIONS

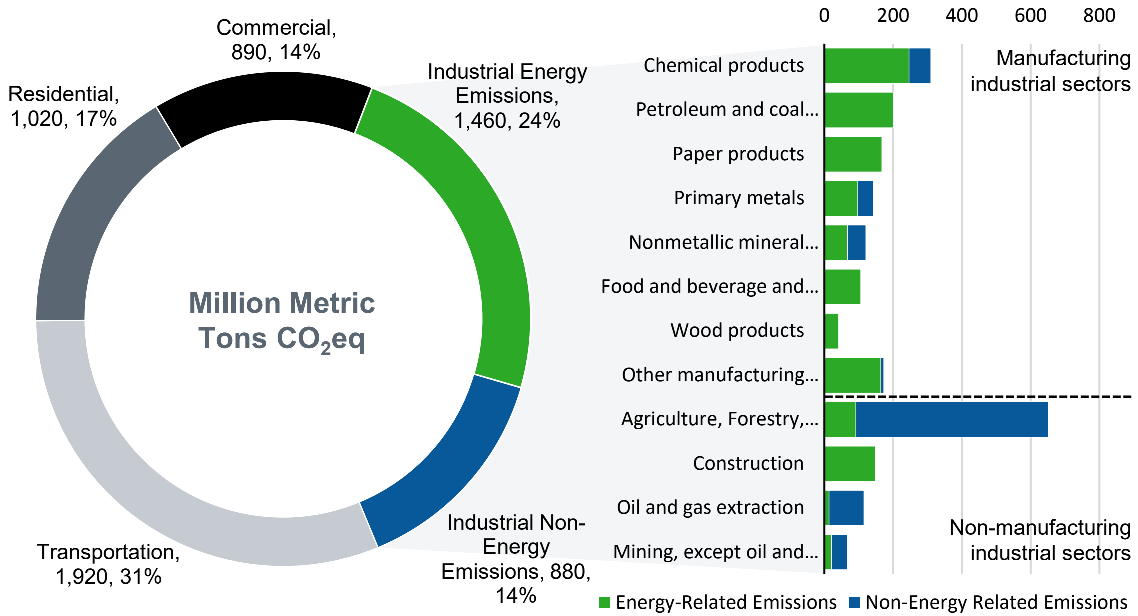
ACCOUNTS FOR **27%** of total primary energy consumption

ACCOUNTS FOR **38%** of total CO_2eq emissions

U.S. PRIMARY ENERGY CONSUMPTION, 2018



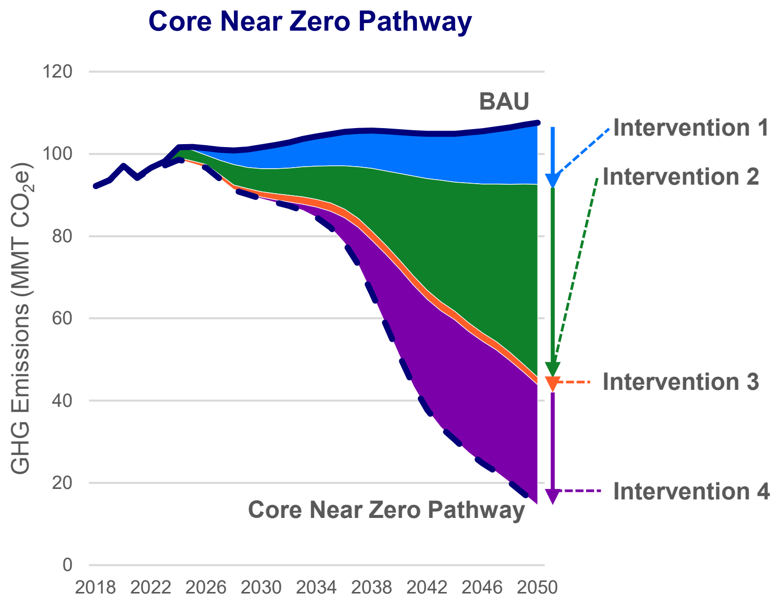
U.S. GREENHOUSE GAS EMISSIONS, 2018



APPROACH FOR INDUSTRIAL PATHWAYS STUDY

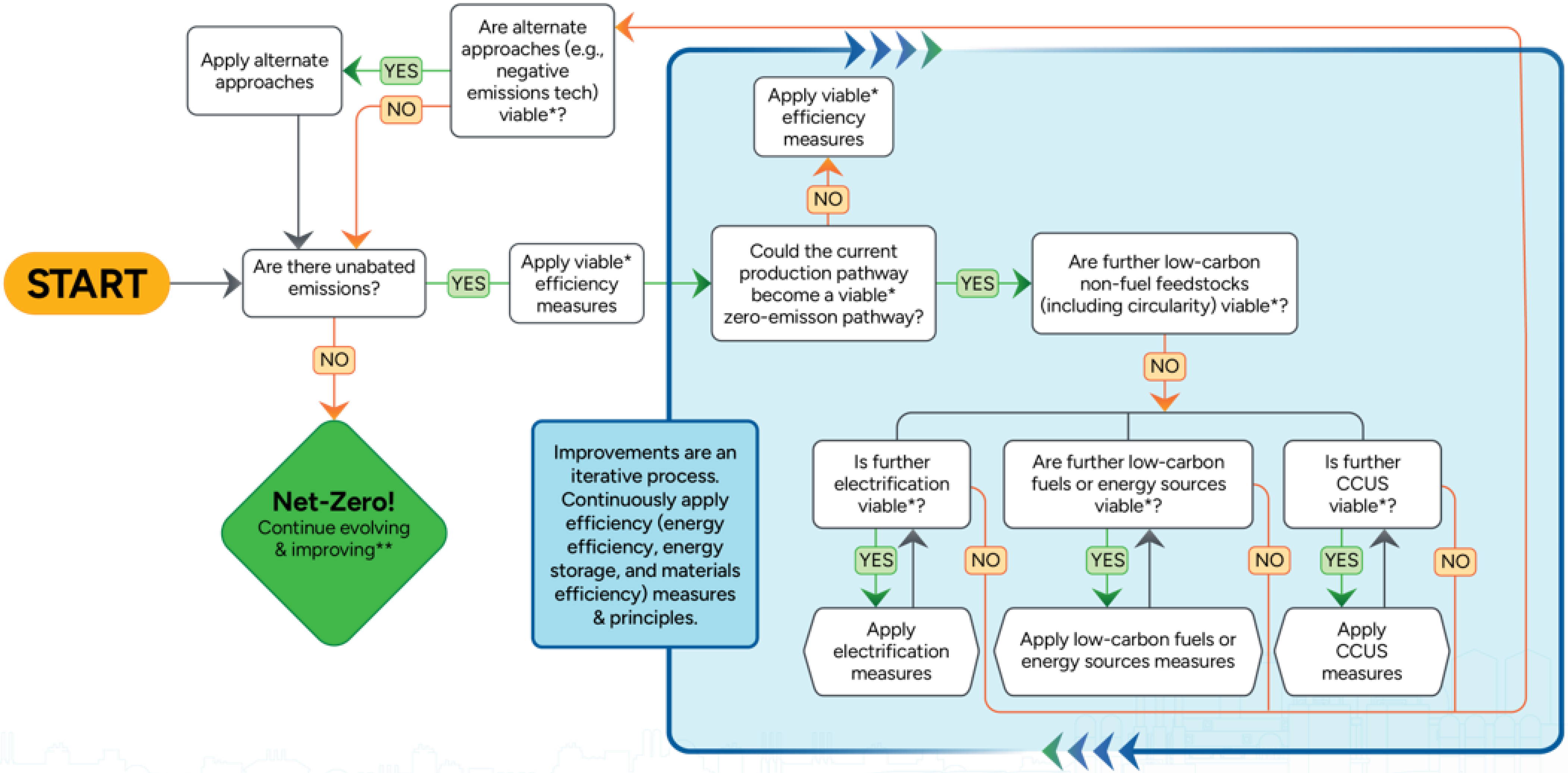
ELUCIDATE PATHWAYS TO DECARBONIZE U.S. INDUSTRY BY 2050

- Expand and extend Industrial Decarb Roadmap approach
- Engage broader cross-section of stakeholders and issues
- Assess barriers
- Decision trees ←→ Model frameworks
- Increase resolution of analysis to chart pathways options



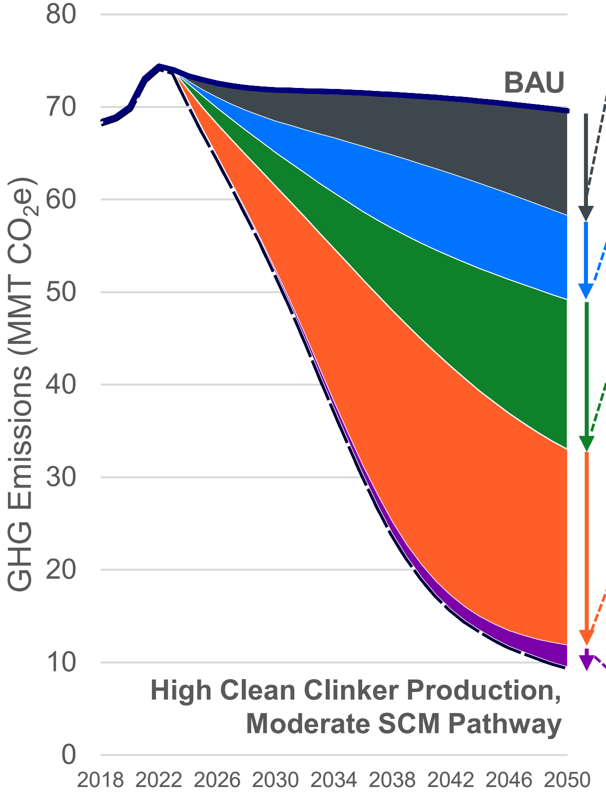
Representative chart highlighting a near zero pathway and the decarbonization potential of different interventions, 2018-2050.

INDUSTRIAL DECARBONIZATION
Decision Tree



CEMENT AND CONCRETE

High Clean Clinker Production, Moderate SCM Pathway



Moderate Increase in SCM Use
Clinker-to-cement ratio drops to 0.6, about 0.3 kg LC3/kg cement, and LC3 CI reduces by 50% by 2050

Clean Clinker Production – Aggressive Adoption

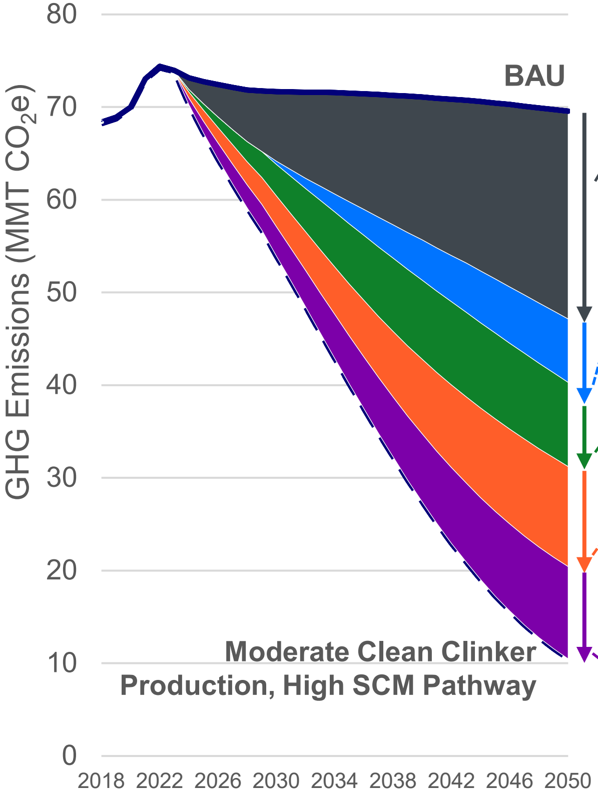
Fuel Switching
Coal & petcoke phased out, natural gas = 78% and biomass = 13% of thermal input by 2050

High Turnover with Limited CCS
Incumbent clinker technologies = 20% market share by 2050, shift to dry kilns with CCS (mostly conventional, some fuel-based indirect heating), only half the CO_2 is captured and stored, minimal calciner/kiln electrification

Aggressive Turnover with Unlimited CCS
Incumbent clinker technologies phased out , dry kilns with CCS = 60%, and calciner/kiln electrification = 40% of market share by 2050, 95% of the CO_2 is captured and stored

Electric Grid Decarbonization
Net zero GHG grid by 2050

Moderate Clean Clinker Production, High SCM Pathway



High SCM Use
Clinker-to-cement ratio drops to 0.4, about 0.5 kg LC3/kg cement, and LC3 CI reduces by 50% by 2050

Near Zero SCMs
LC3 CI reduces by 90% by 2050 through CCS and electrification

Clean Clinker Production

Fuel Switching
Coal & petcoke phased out, natural gas = 78% and biomass = 13% of thermal input by 2050

High Turnover with Limited CCS
Incumbent clinker technologies = 20% market share by 2050, shift to dry kilns with CCS (mostly conventional, some fuel-based indirect heating), only half the CO_2 is captured and stored, minimal calciner/kiln electrification

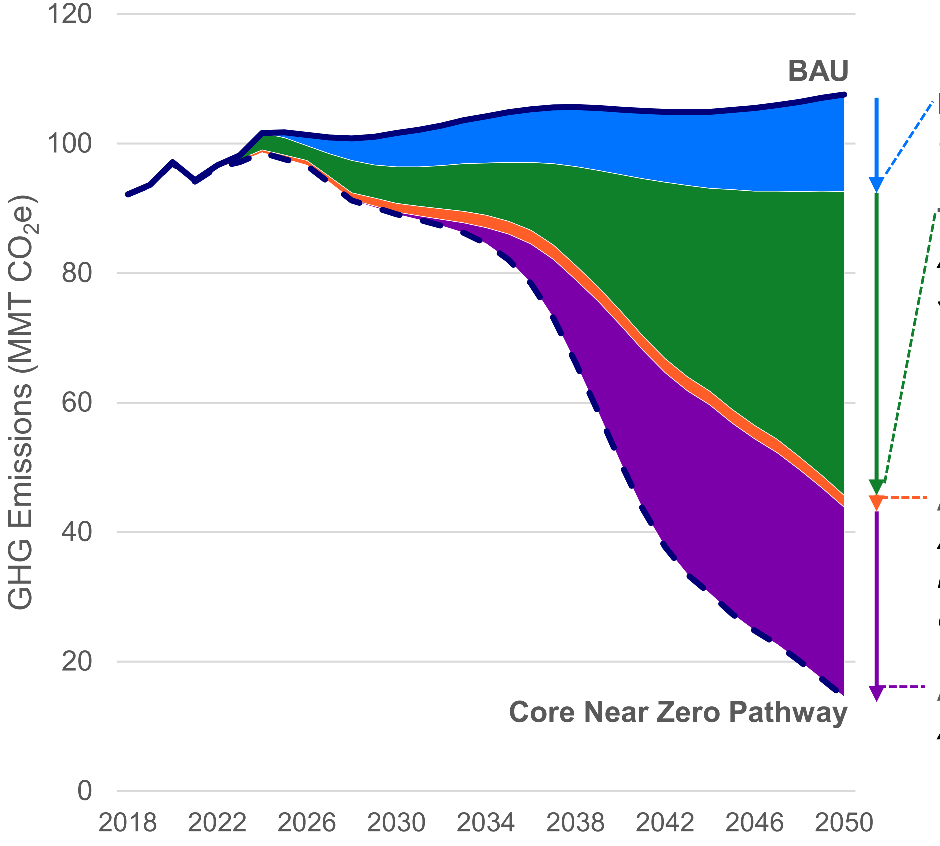
Unlimited CCS
95% of CO_2 is captured and stored

Acronyms/abbreviations: BAU (business as usual), CCS (carbon capture and storage), CI (carbon intensity), CO_2 (carbon dioxide), CO_2e (carbon dioxide-equivalent), GHG (greenhouse gas), kg (kilogram), LC3 (limestone calcined clay cement), MMT (million metric ton), SCM (supplementary cementitious material)

CHEMICALS

Core Near Zero Pathway

(Excludes Ethanol and Rest of Chemicals)*



Demand Reduction

Chemical demand decreases due to increased recycling & greater material efficiency

Technology Transition

Adoption of BAT, electric heating tech., & low-carbon routes (incl. electrified & bio-based); simultaneous grid decarbonization to zero by 2050

Autonomous Improvements & Fuel Switching

Automatic tech. improvements ranging from 0.03% to 0.5% per annum; While the fuel mixes in technology transition overlap with fuel switching, this refers specifically to the increased use of biofuels

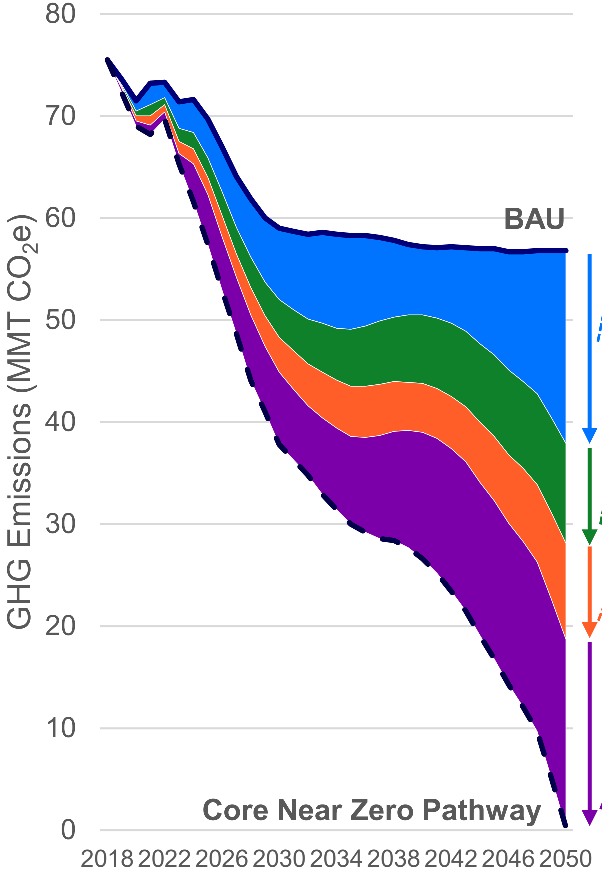
Alternative Clean Production Routes

Approaches can include CCS and/or emerging chemical production processes that reduce GHG emissions compared with incumbent approaches

Acronyms/abbreviations: BAT (best available technology), BAU (business as usual), CCS (carbon capture and storage), CO_2e (carbon dioxide-equivalent), GHG (greenhouse gas), MMT (million metric ton)

FOOD AND BEVERAGE

Core Near Zero Pathway



Fuel intensity reductions with high electrification:

Steam

***74% - SGHPs** (**91-94%** adoption); 19% - boilers EE; 6% - electric boilers (6-8% adoption)*

Hot Air

***76% - SGHPs** (**81-98%** adoption); 14% - dryers/ovens EE; 12% - advanced electroheating technologies (11-17% adoption)*

Hot Water

***74% - HWHPs** (**91-94%** adoption); 19% - boilers EE; 12% - advanced electroheating technologies (11-17% adoption)*

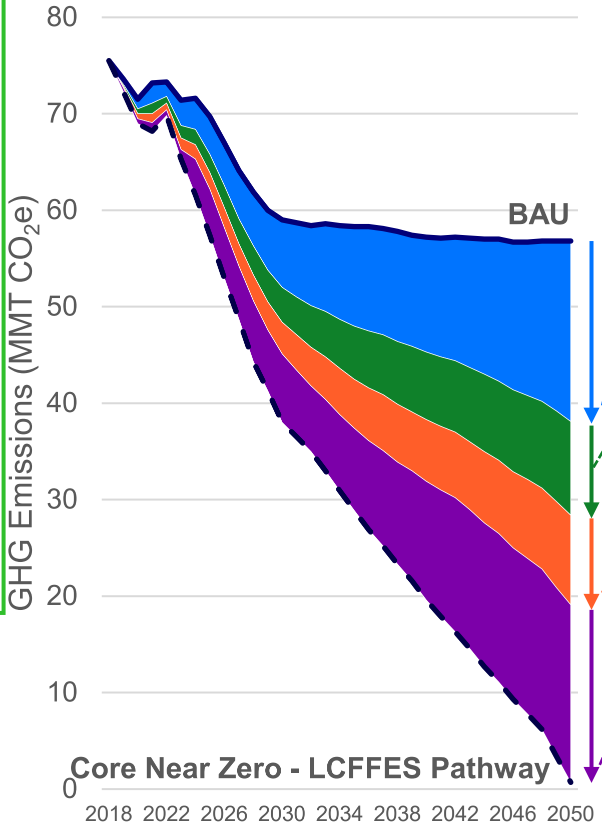
Other End Uses

Facility HVAC: boilers EE; HWHPs (94% adoption)

Machine drive: fans, motors, etc. EE;

Process cooling & refrigeration: chillers EE; process integration

Core Near Zero - LCFFES Pathway



Fuel intensity reductions with increased onsite use of low-carbon fuels and moderate levels of electrification:

Steam

***42% -SGHPs** (53% adoption); **37% - LCFFES**; 18% -boilers EE*

Hot Air

***45% -SGHPs** (**53%** adoption); **41% - LCFFES**; 13% -dryers/ovens EE*

Hot Water

***41% - HWHPs** (**52%** adoption); **37% - LCFFES** ; 18% - boilers EE*

Other End Uses

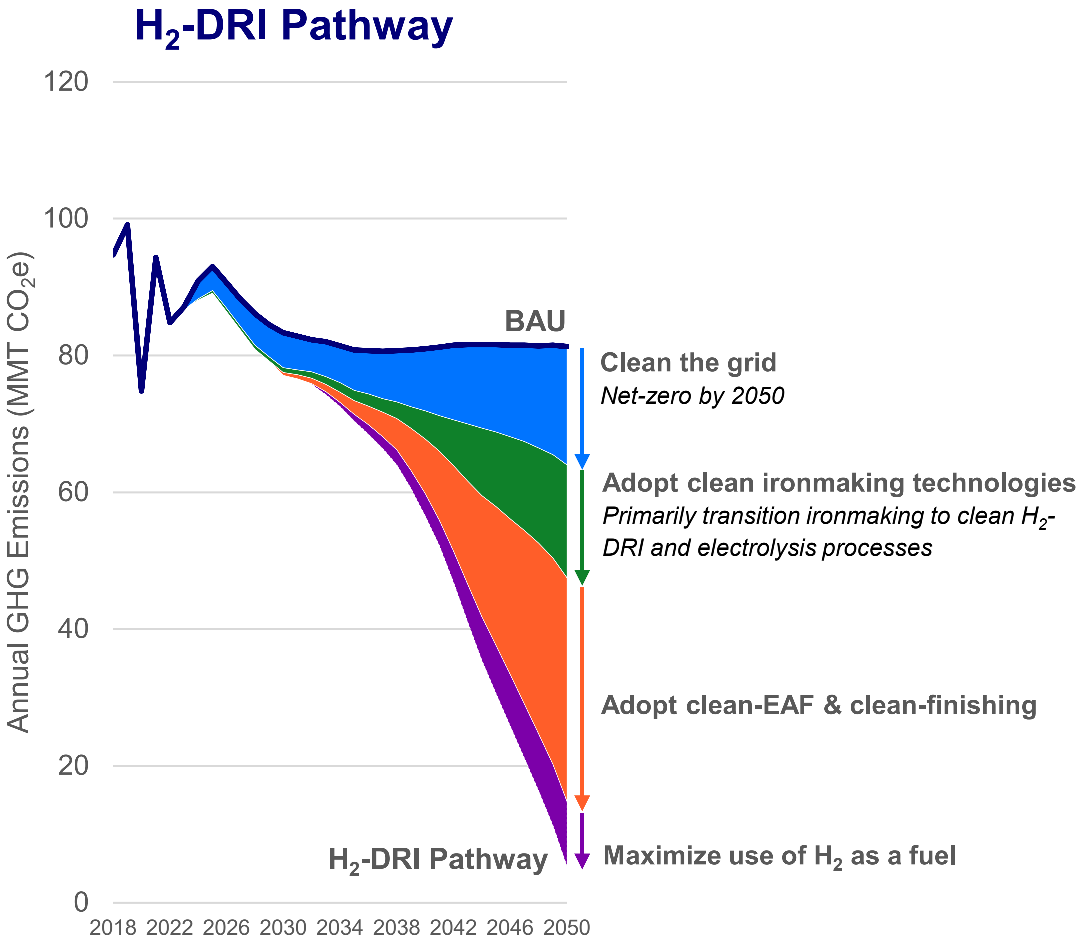
Facility HVAC: boilers EE; HWHPs (52% adoption)

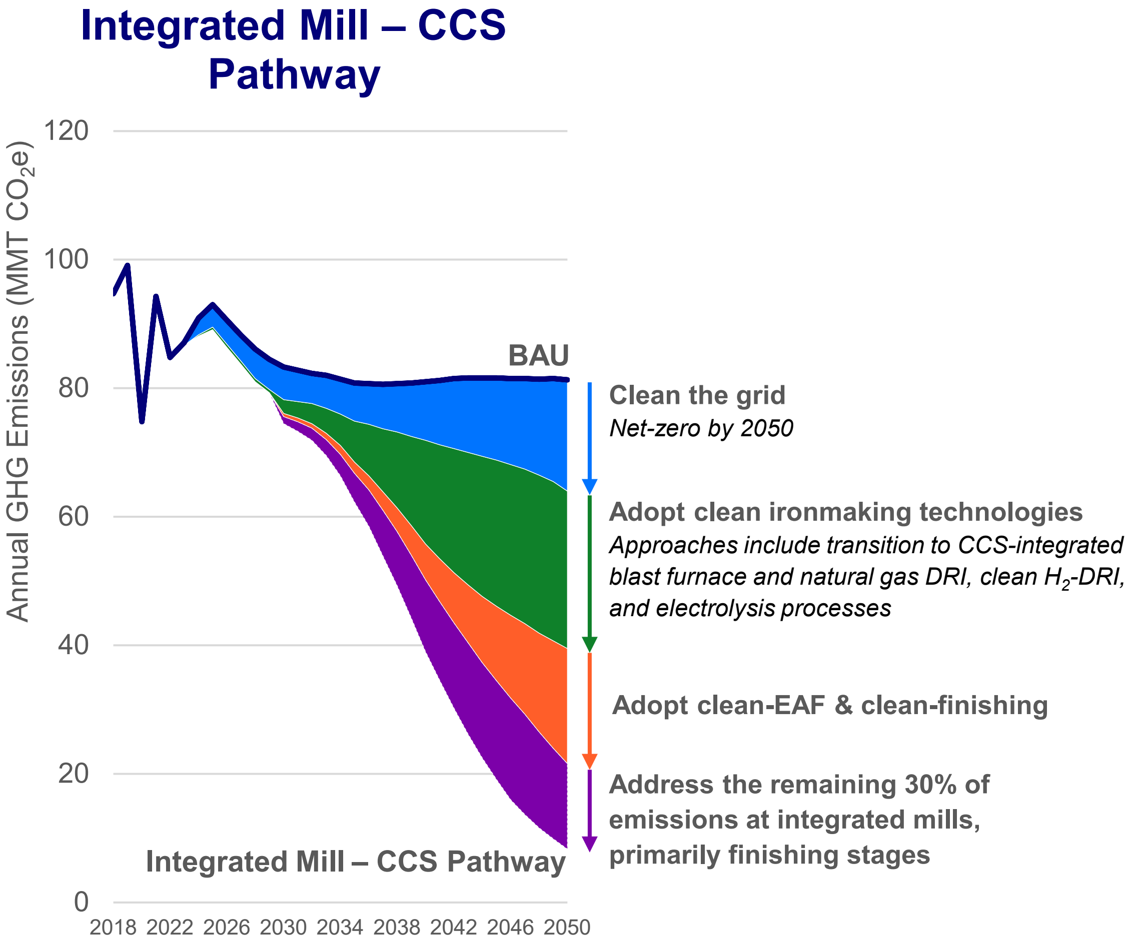
Machine drive: fans, motors, etc. EE;

Process cooling & refrigeration: chillers EE; process integration

Acronyms/abbreviations: BAU (business as usual), CO_2e (carbon dioxide-equivalent), EE (energy efficiency), GHG (greenhouse gas), HVAC (heating, ventilation, and air conditioning), HWHP (hot water heat pump), LCFFES (low-carbon fuels, feedstocks, and energy sources), MMT (million metric ton), SGHP (steam-generating heat pump)

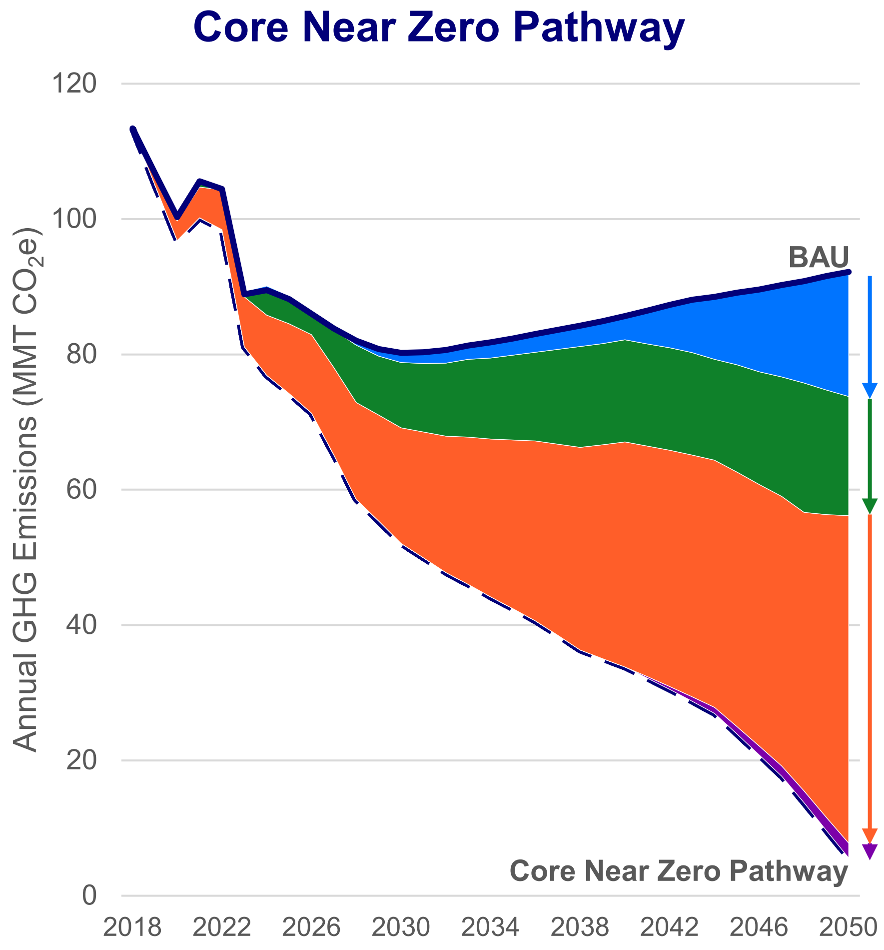
IRON AND STEEL





Acronyms/abbreviations: BAU (business as usual), CCS (carbon capture and storage), CO_2e (carbon dioxide-equivalent), DRI (direct reduced iron), EAF (electric arc furnace), GHG (greenhouse gas), H_2 (hydrogen), MMT (million metric ton)

PULP AND PAPER



Improve energy efficiency *of key unit processes, including pulping, debarking, and drying.*

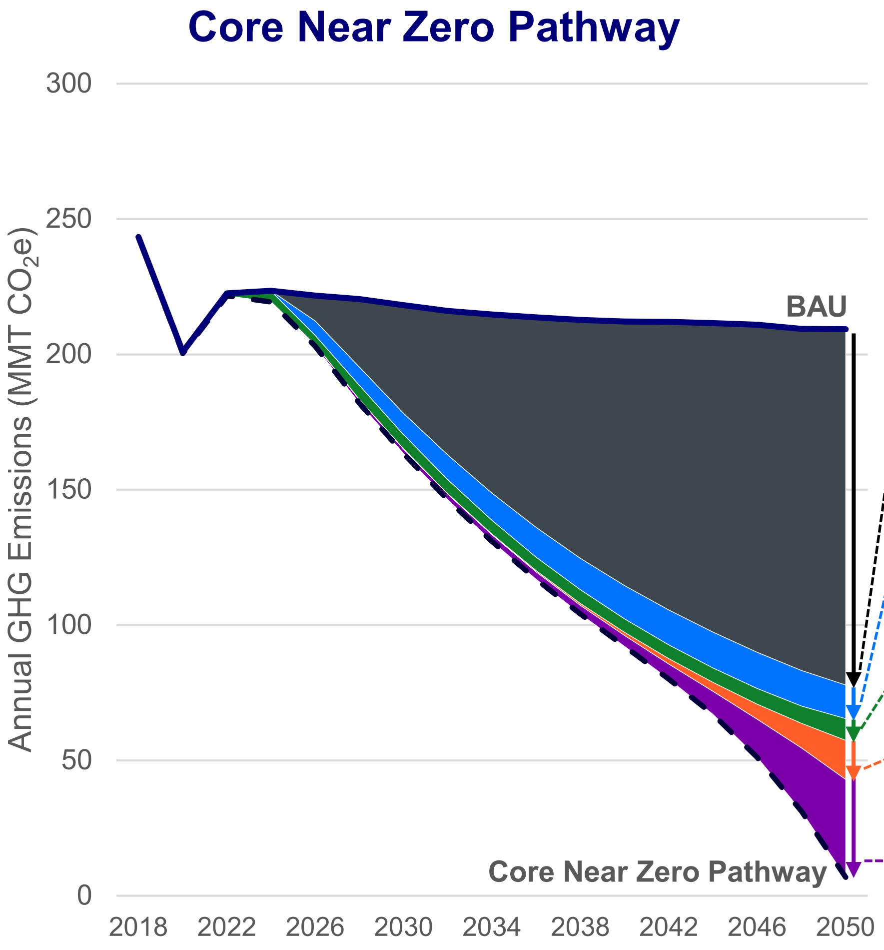
Electrify *20% of auxiliary boilers, clean grid by 2050.*

Fuel switching *to biomass, e.g., wood chips and other solid biomass, and some RNG.*

Carbon capture *of fossil-based emissions. Limited to 33% of remaining emissions in 2050.*

Acronyms/abbreviations: BAU (business as usual), CO_2e (carbon dioxide-equivalent), GHG (greenhouse gas), MMT (million metric ton)

REFINING



Demand Reduction
Global decline in use of liquid transportation fuels

Energy Efficient Technologies
Advanced heat exchangers, waste heat recovery, cogeneration, advanced furnace design, digitalization

Low Carbon Utilities
Decarbonized grid, purchased low CI hydrogen, RNG/biogas

Carbon Capture
Retrofit of onsite H_2 SMR plants (or alternatively, electrolytic production routes, cogeneration, other individually large combustion sources

Biofuels
Renewable diesel/SAF, coprocessing bio-oils

Acronyms/abbreviations: BAU (business as usual), CI (carbon intensity), CO_2e (carbon dioxide-equivalent), GHG (greenhouse gas), H_2 (hydrogen), MMT (million metric ton), RNG (renewable natural gas), SAF (sustainable aviation fuel), SMR (steam methane reforming)

CROSS-CUTTING TAKEAWAYS

Although specific subsectors will need specialized decarbonization pathways, cross-cutting strategies can be implemented across all U.S. industrial subsectors.

Energy efficiency is often the lowest-hanging fruit, provides cost savings, and is the first intervention considered by industrial entities.

- Efficiency must also be considered in combination with other interventions, such as electrification and low-carbon fuels, to maximize their decarbonization potential.
- Efficiency measures should be applied continuously as technologies, processes, and operations evolve.

Material and resource efficiency will have an essential role in decarbonizing the industrial sector and improving sustainability across the industrial ecosystem.

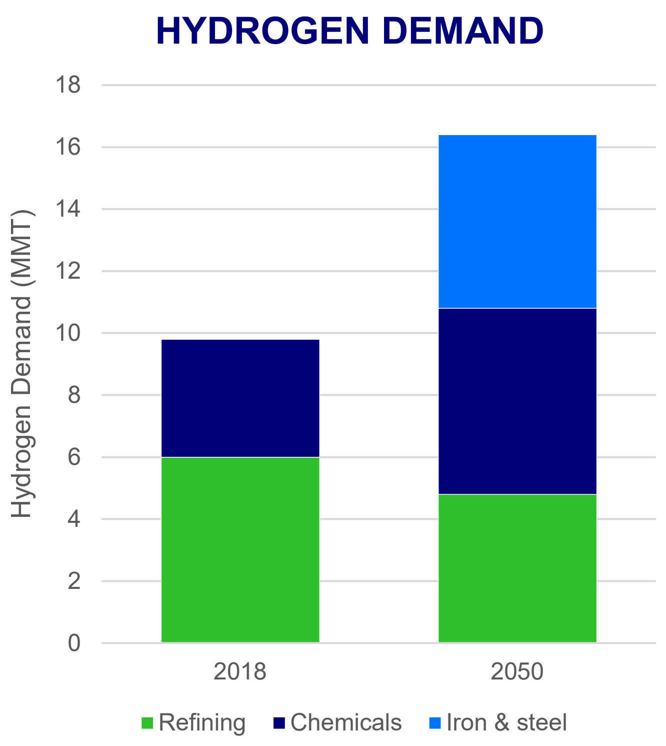
- Key opportunities include scrap reuse in steelmaking and recycling of post-production and post-consumer products, such as plastics, concrete, and paper.
- Efficient resource utilization is challenging to quantify since impacts encompass embodied energy and carbon across supply chains.
- Material efficiency initiatives may increase costs and complexity in the short term as supply chains are reconfigured to handle alternative materials.

SUBHEAD TITLE

CROSS-CUTTING TAKEAWAYS

Low carbon fuels, feedstocks, and energy sources have broad applicability as a decarbonization lever.

- Hydrogen demand from the modeled subsectors is projected to grow 1.5x by 2050, largely driven by the H_2-DRI pathway in the iron and steel subsector.
- Other opportunities include biomass as a process feedstock and fuel, renewable energy sources for process heat, such as geothermal, and concentrating solar thermal and direct replacement of fossil-based feedstocks, such as charcoal in lieu of pulverized coal and SCMs to reduce clinker content, among others.

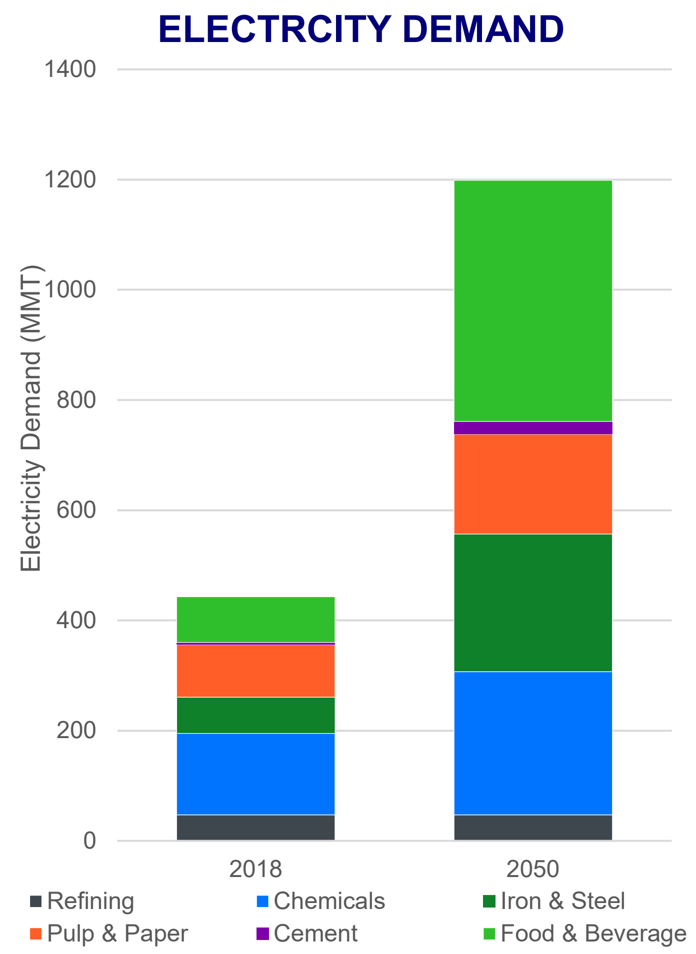


SUBHEAD TITLE

CROSS-CUTTING TAKEAWAYS

Electrification will play a significant role in decarbonizing low- to medium-heat processes—such as steam generation, separations, and drying—that are common across many industrial subsectors.

- Electricity demand from the modeled subsectors is projected to **nearly triple** by 2050.
- In some instances, high temperature processes are already electrified, e.g., EAF, but more is needed.



SUBHEAD TITLE

CROSS-CUTTING TAKEAWAYS

Carbon capture, utilization, and storage will likely be a necessary intervention to achieve near zero industrial emissions.

- Its utility as a decarbonization lever will depend on several factors including the availability of alternative pathways that may diminish its need, proximity to sequestration sites, and physical facility constraints.
- Implementing CCUS inherently adds cost from the high capital and the energy required for their operation.
- CCUS also faces system-level challenges that must be addressed, including a lack of CCUS infrastructure (e.g., pipelines and storage), uncertainty of merchant and captive CO2 markets, and a need for accounting guidelines for captured, reused, and stored carbon

SUBHEAD TITLE

CONSIDERATIONS FOR U.S. INDUSTRIAL TRANSFORMATION

An industrial transformation will be challenging. It will require ambitious action from many actors in the industrial ecosystem that may have far-reaching impacts across domestic and international supply chains and markets.

The following key considerations can begin to clarify the actions that are needed to realize this vision.

- Innovations are needed to catalyze an industrial transformation
- An industrial transformation must include efficient utilization of energy, resources, and materials across the industrial ecosystem
- A transformation of the industrial sector will require actionable measures
- People, communities, and the environment are a central part of an industrial transformation

Thank you!

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U.S. Department of ENERGY | Office of Energy Efficiency & Renewable Energy

Industrial Efficiency & Decarbonization Office

CLEVELAND-CLIFFS INC.

January 2025

OPERATIONAL FOOTPRINT

Sites not shown: Alabama (Sylacauga Downstream Assets), Florida (FPT Scrap Processing Facilities), North Carolina (Piedmont Downstream Assets) Tennessee (FPT Scrap Processing Facilities, Cleveland Downstream Assets)

Source: Company Filings

CLIFFS

MAJOR END MARKETS FOR CLEVELAND-CLIFFS STEEL

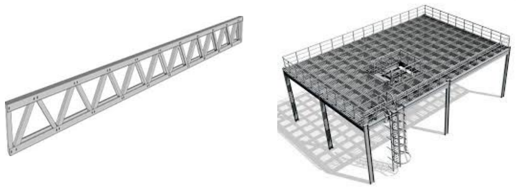
Automotive

Primarily galvanized, cold-rolled, aluminized, NOES, stainless

Appliance

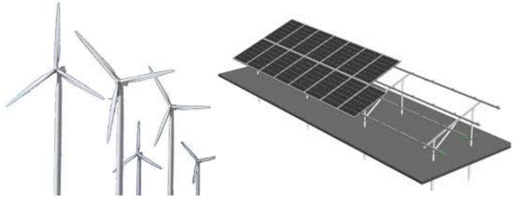
Primarily galvanized, cold-rolled, stainless

Construction



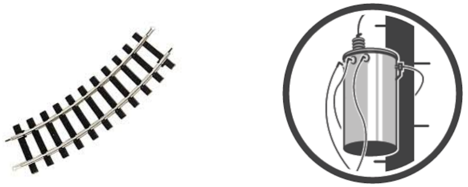
Primarily hot-rolled, cold-rolled, galvanized

Energy



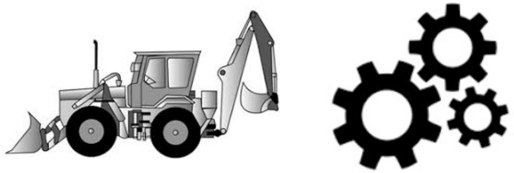
Primarily galvanized, hot-rolled, plate

Infrastructure



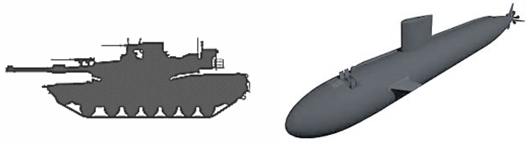
Primarily galvanized, GOES, plate, rail

Machinery & Equipment



Primarily hot-rolled, galvanized, plate

Military



Primarily plate

CLIFFS

ENERGY EFFICIENCY AND SUSTAINABILITY

Cleveland-Cliffs' Energy and Sustainability Goals

Energy efficiency goal of 10% improvement of energy intensity over 10 years

Purchased municipal city water consumption goal of 25% reduction over 10 years

Recognized by DOE Better Climate Challenge in 2023 as a goal achiever for 2030 GHG emissions goal ahead of schedule

New GHG reduction goals for 2035 from 2023
- Reduce Scope 1 and 2 GHG Intensity 30%
- Reduce Material Upstream Scope 3 GHG Intensity 20%

New GHG reduction goal of Near Net Zero by 2050

Support from IEDO and DOE

Technical support, Energy tools, In-plant Training
- Energy Treasure Hunt (2023)
- Compressed Air (2024)

Industrial Technology Validation (ITV) Program - analysis and technical support for two projects improving process water use and quality in Cleveland, OH

Three Iron and Steel research projects with >$11M funding from IEDO to Universities and National Labs with Cleveland-Cliffs as a partner

Two projects selected for $575M funding from OCED Industrial Demonstrations Program
- Butler, PA - Steel Slab Electrified Induction Reheat Furnace Upgrade
- Middletown, OH - Hydrogen-Ready Direct Reduced Iron Plant and Electric Melting Furnace Installation

CLIFFS

Resilient Ammoxidation of Small Hydrocarbons (R-ASH) Using Forced Dynamic Operation for Maximal Flexibility

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UNIVERSITY of HOUSTON

Resilient Ammoxidation of Small Hydrocarbons (R-ASH) Using Forced Dynamic Operation for Maximal Flexibility

Technology: A small-scale, flexible catalytic reactor and process for distributed manufacture of acrylonitrile (ACN) using externally forced dynamic operation. Modulating feed composition leverages the dynamic O_2 storage capacity of the industry-standard catalyst, affording higher cycle averaged yields, lower temperature, and longer catalyst life.

Key Team Members and Partners:

Idaho National Laboratory

Pacific Northwest NATIONAL LABORATORY

UNIVERSITY of HOUSTON

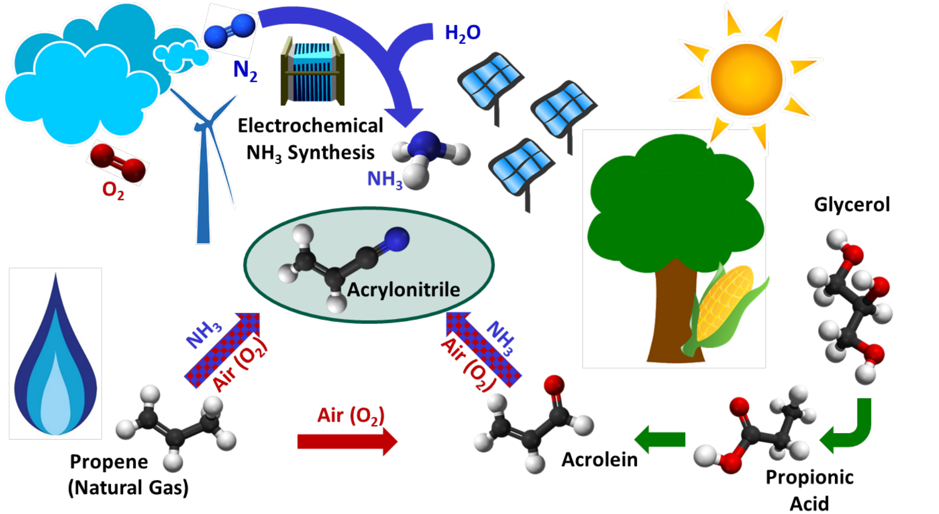
UNIVERSITY of VIRGINIA

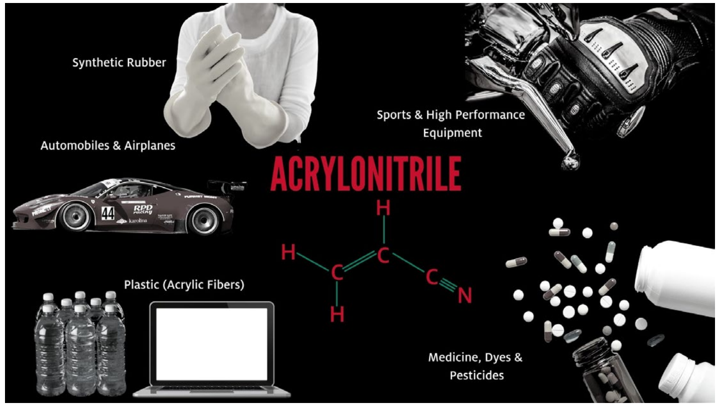
KX2 Development

Supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Industrial Efficiency and Decarbonization Office, Award Number DE-EE0009410.

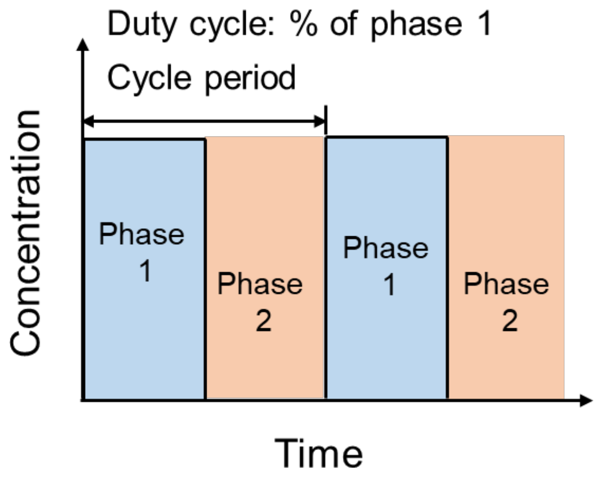
Impact: ACN is among the most energy-intensive chemicals and is dangerous to transport and store. The innovative, dynamic process addresses intentional and unintentional variability in chemical manufacturing and synergizes with distributed ACN use, and NH_3 and biodiesel production.

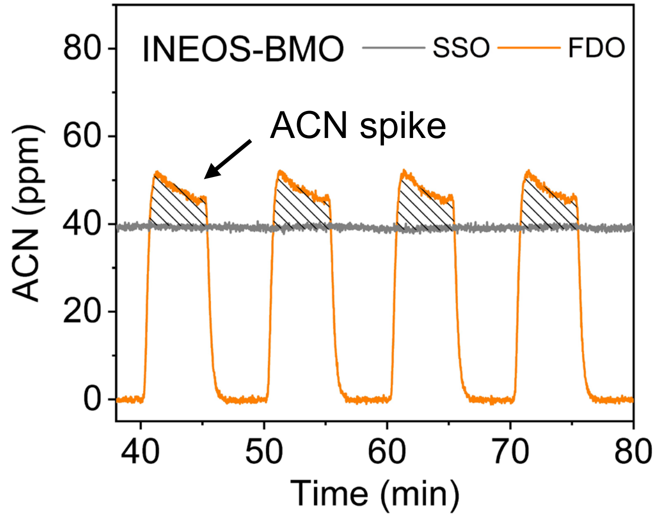
$$C_3H_6 + NH_3 + 1.5\ O_2 \rightarrow C_3H_3N + 3H_2O$$

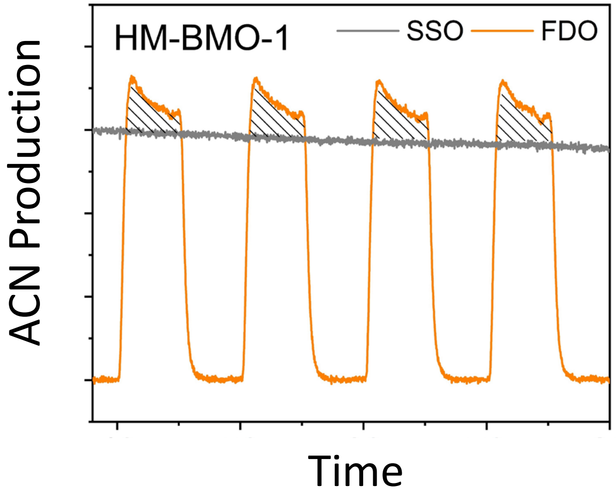




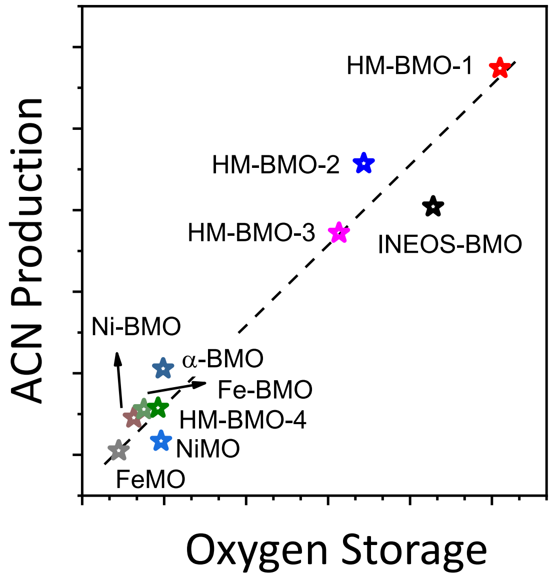
Forced Dynamic ACN Synthesis





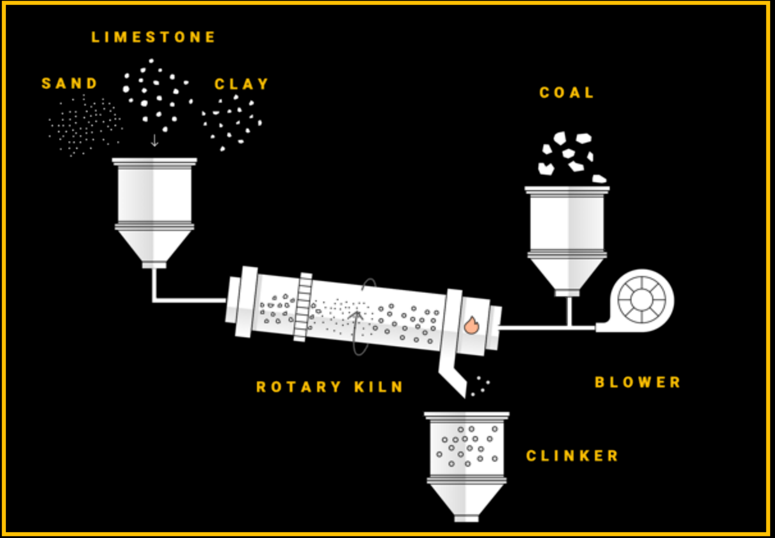


- R-ASH ACN process has a lower cash cost of production as well as lower capital investment compared to the scaled-down SOHIO process.
- Significant logistics cost savings enables a new smaller distributed R-ASH plant to effectively compete with existing fully depreciated assets at a world-class scale
- We estimated a capital cost of ca. $2,800 per ton of ACN for 25 kta R-ASH process, which is comparable to the specific capital cost of the SOHIO process at world class (250 kta) scale.



M. Moniruzzaman, L. C. Grabow, M. P. Harold, Applied Catalysis A: General 691, 120034, 2025.
Z. Gan, J. F. Brazdil, L. C. Grabow, and W. S. Epling, Applied Catalysis A: General 672, 119585, 2024.
"Forced dynamic operation for acrylonitrile manufacture", W. S. Epling, Z. Gan, L. C. Grabow, J. Brazdil, Provisional Patent Application submitted. Attorney Docket No. 222117-8200.

Sublime is commercializing a clean cement manufacturing technology in America

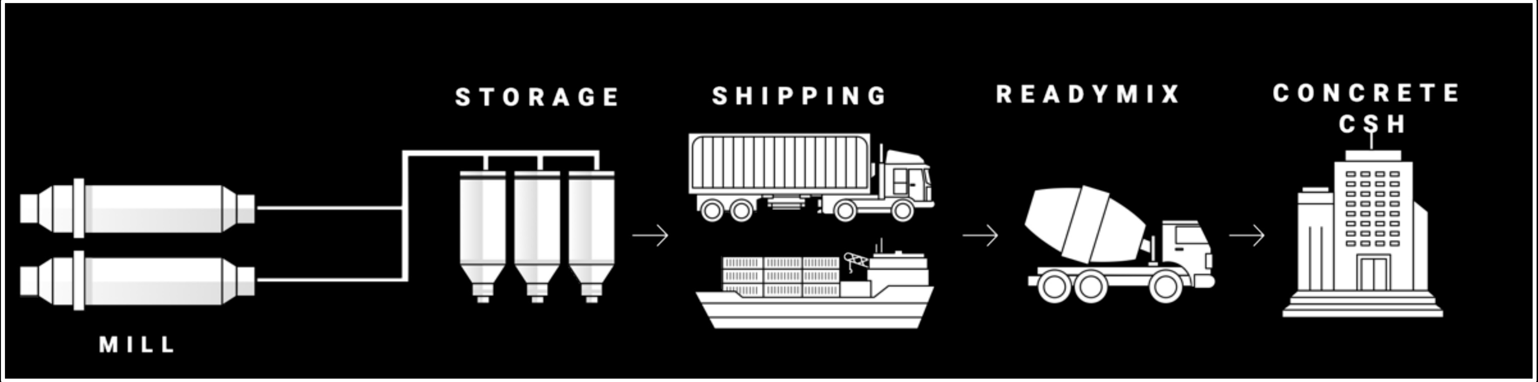


Ordinary Portland Cement (OPC) Process

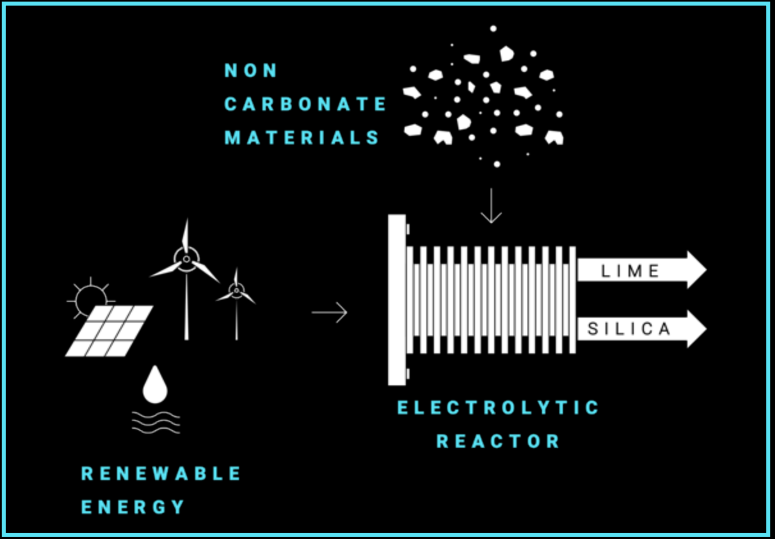
Coal + limestone = CO_2

1 tonne OPC = ~1 tonne CO_2

Downstream process



Drop-in replacement



Sublime Systems

Electricity + non-carbonate rocks = CO_2 avoided

Sublime's innovative manufacturing scale-up leverages DOE's non-dilutive funding and credibility from technical diligence

Original Invention (gram scale)

Massachusetts Institute of Technology

Scale-up to 1st commercial (kiloton scale)

OCED
Office of Clean Energy Demonstrations

$87M Award

Major Advancements

arpa·e

$0.5M Award

Exploring the Next Generation

arpa·e

$3.5M Award

Next-gen pilot scale-up

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

$6.7M Award

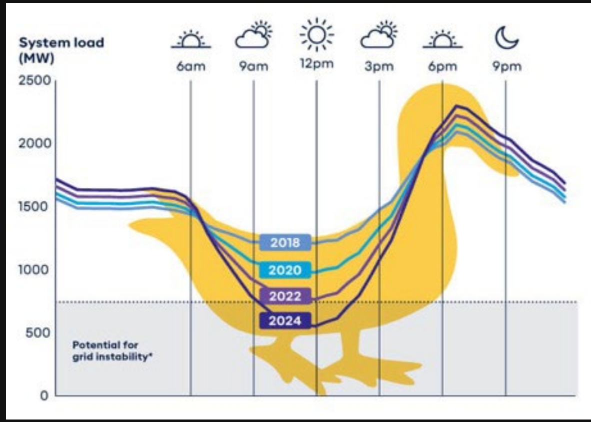
IEDO's funding is an investment in resilient and efficient American manufacturing

- DOE: $6,690,175 Total: $9,274,161
- Scale-up of Sublime's Efficient Electrolyzer
  - Industrial waste as feedstock
  - Lowers energy requirements
  - Lowers plant complexity
  - Operational flexibility
- Supports Nth plant resilience

EAF/BOF Slags

Municipal Waste

Demolition Waste



Improves Intermittent Operation