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

Industrial Technology Innovation Advisory Committee Meeting

October 29, 2024
9 am – 5 pm ET

U.S. Department of Energy
Washington, D.C. & Virtual (ZoomGov)

We will start momentarily…

Meeting Recording Announcement

This Zoom call, including all audio and images of participants and presentation materials, may be recorded, saved, edited, distributed, used internally, posted on DOE's website, or otherwise made publicly available. If you continue to access this call and provide such audio or image content, you consent to such use by or on behalf of DOE and the Government for Government purposes and acknowledge that you will not inspect or approve, or be compensated for, such use.

Housekeeping Reminders

- General audience does not have the ability to unmute and/or turn on camera during this presentation.
- The chat has been disabled.
- Public comments:
    - The deadline for submitting public comments to share during this meeting was 5:00 pm EDT on October 25
    - You may send a written statement to ITIAC@ee.doe.gov

ITIAC Nominations

- DOE is continually seeking ITIAC nominations for consideration for future membership vacancies and to maintain balance in points of view
- Submissions should include the nominee's name, resume, biography, and any letters of support
- Committee members are appointed for a two-year term and may be reappointed for up to two successive terms
- Submit nominations/questions to ITIAC@ee.doe.gov

See website for more details: https://www.energy.gov/eere/iedo/industrial-technology-innovation-advisory-committee#candidates

Welcome & Opening Remarks

Sharon Nolen
ITIAC Chair

Dr. Zach Pritchard
Technology Manager
ITIAC Designated Federal Officer
Industrial Efficiency and
Decarbonization Office

Agenda – October 29, 2024 ITIAC meeting

Welcome and opening remarks	9:00 am
Office of Clean Energy Demonstrations presentation	9:15 am
Break	10:15 am
Debrief on *Transforming Industry* Workshop/RFI	10:30 am
Discussion on Industrial Modeling Needs	11:15 am
Lunch	11:30 am
ITIAC Subcommittee on Report Outline report out	1:00 pm
ITIAC Subcommittee on Industrial Sectors report out	1:45 pm
Office of Electricity presentation	2:30 pm
Break	3:15 pm
ITIAC Subcommittee on Cross-cutting Technologies & Opportunities report out	3:30 pm
Discussion	4:15 pm
Adjourn	5:00 pm

We are on a break and will return at 10:33 am ET

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INDUSTRIAL EFFICIENCY & DECARBONIZATION OFFICE

Transforming Industry workshop and RFI– presentation for ITIAC

Joe Cresko

IEDO Chief Engineer

October 29, 2024

Agenda

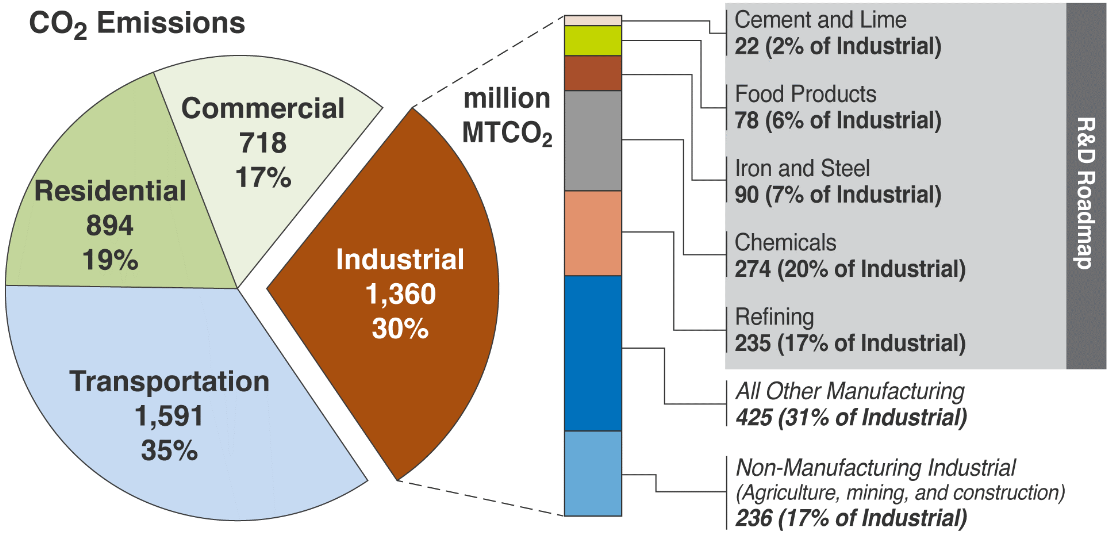
- "Pathways for U.S. Industrial Transformations"
    - Vision study overview

- "Pathways" study Stakeholder Engagement
    - Workshop high-level summary – cross-cutting topics, non-technical challenges, subsector-specific overview
    - RFI high-level summary– subsector-specific overview

U.S. Industrial CO_2 Emissions as shown in 2022 Roadmap

Industrial sector is comprised of
manufacturing | agriculture | mining | construction

ACCOUNTS FOR **30%** of energy-related CO_2 emissions



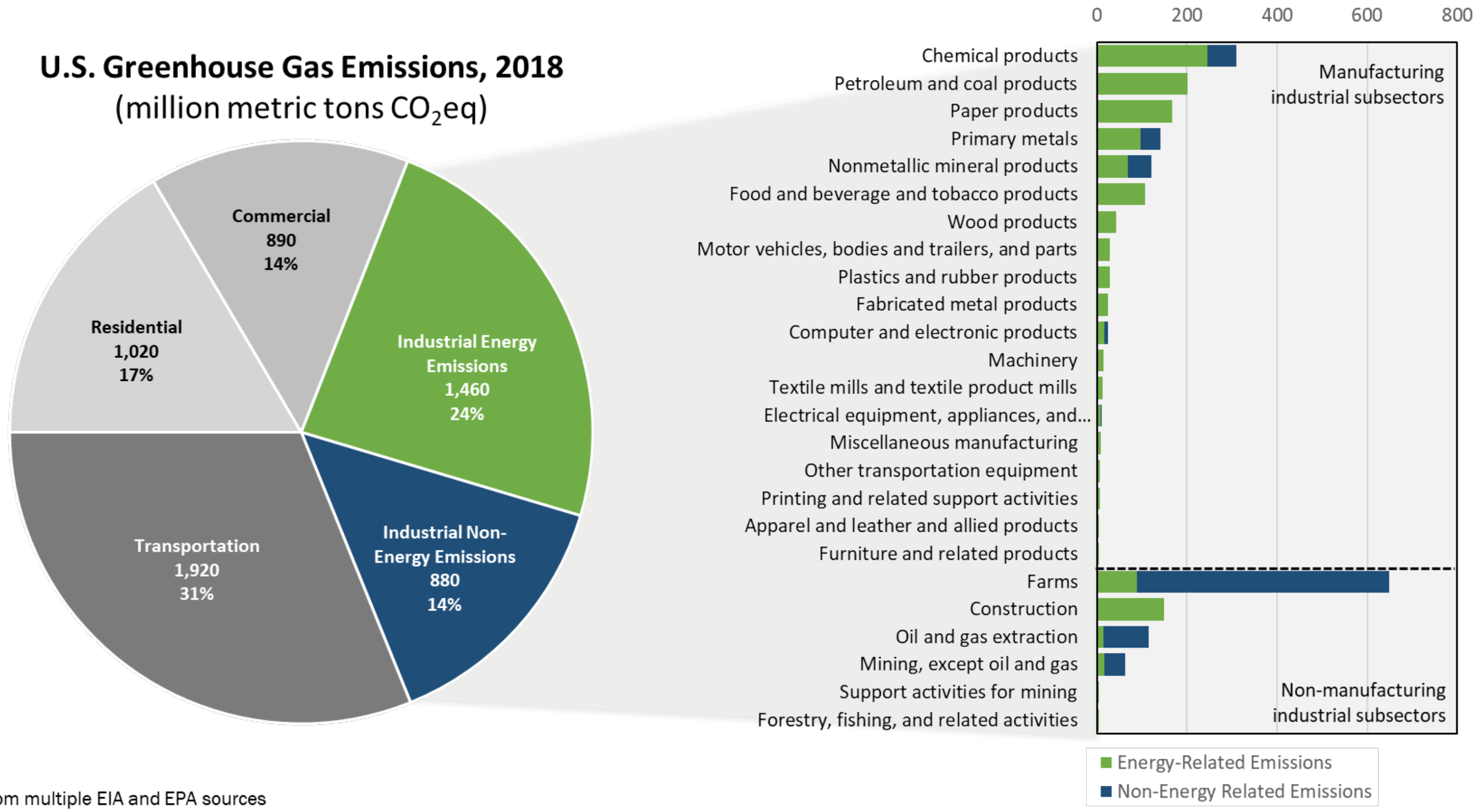
Energy-Related CO_2 emissions, 2020
(million metric tons)

EIA, *Annual Energy Outlook 2020 with Projections to 2050*. Source: [Industrial Decarbonization Roadmap].

U.S. Industrial GHG Emissions: energy + non-energy emissions

Industrial sector is comprised of
manufacturing | agriculture | mining | construction

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



Data compiled from multiple EIA and EPA sources

DOE Industrial Decarbonization Roadmap

Industrial Decarbonization Pillars

Energy Efficiency	Industrial Electrification	Low-Carbon Fuels, Feedstocks, and Energy Sources (LCFFES)	Carbon Capture, Utilization, and Storage (CCUS)

Decarbonization pillars: strategies to pursue in parallel within and across industrial subsectors*

Iron & Steel	Chemicals	Food & Beverage	Petroleum Refining	Cement

Industrial Decarbonization Roadmap. U.S. DOE (2022). (*Roadmap focused on five subsectors)

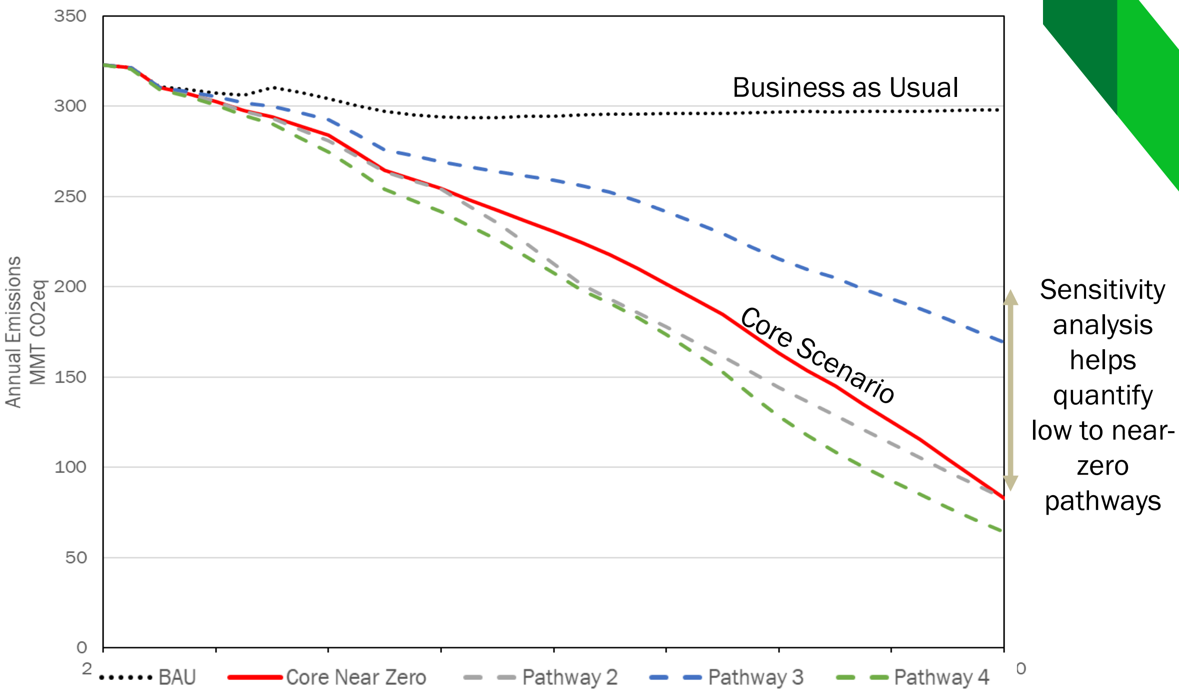
Approach for Industrial Pathways Study

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

Decarbonizing industry is a systems challenge

- Unit operations → Facilities → Beyond the plant boundaries
- Energy & Materials systems
- Environmental and Societal considerations
- Coordination is needed within, across and outside of industry



<u>Representative</u> chart highlighting Pathway options and their decarbonization potential, 2018-2050.

<u>Key Definitions</u>

Net-Zero = Achieve balance of zero GHG emissions.
Near Zero = Achieve very low GHG emissions intensity.
Core Scenario = A set of assumptions that determine a probable future and on which sensitivity analysis is based.
Sensitivity = Parameters that are adjusted to model uncertainty in the future, e.g., H2 availability, CCS cost.
Pathway = See next slide.

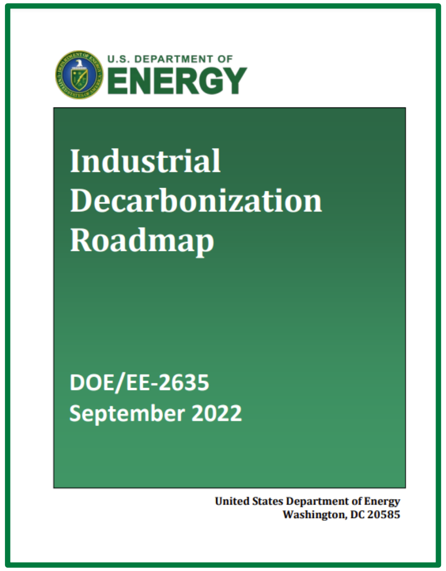
Framework for Industrial Decarbonization Pathways

Near-Zero Emissions Pathway: A set of specific actions needed to achieve progress in and across the decarbonization pillars, while remaining informed and supplemented by RD&D to advance viable solutions that will need to be adopted at scale in the marketplace.

- Major production routes
- Emissions reduction
- Factors impacting how facilities will evaluate and choose technologies
- Timing for technology deployments
- Major uncertainties, risks, and barriers
- Consider retrofits vs. greenfield facilities

A Strategy Built Upon Prior DOE Work

- Prioritized near- and mid-term objectives
- Provided limited resolutions for ~2/3 of emissions where cost-effective solutions do not yet exist



- Brought opportunity space into focus
- Highlighted a range of opportunities without charting a course with multiple pathways

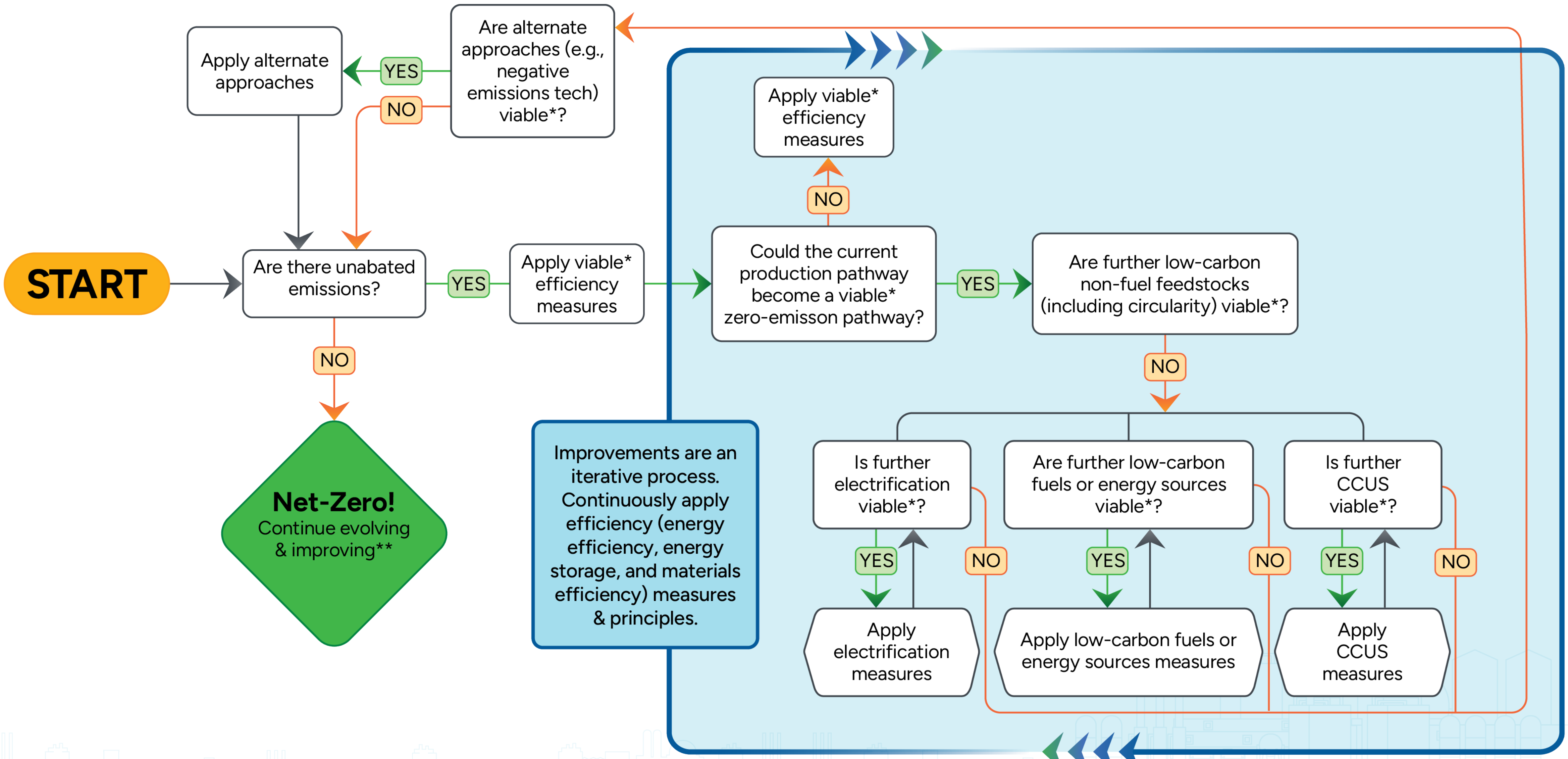
New Vision Study:
Pathways for U.S. Industrial Transformations will…

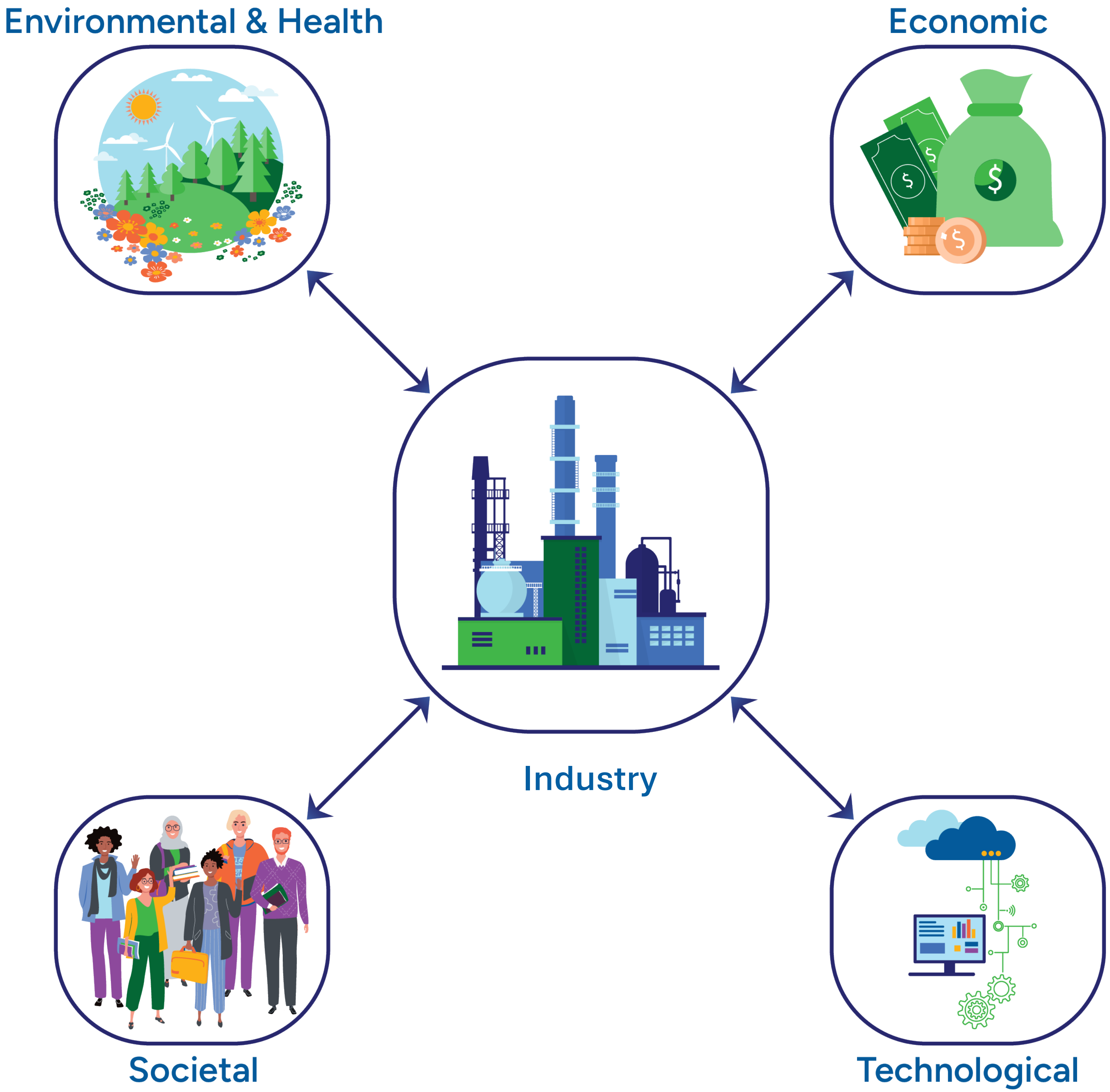
- Expand solutions for ~2/3 of emissions where cost-effective technologies don't yet exist
- Identify **subsector-specific strategic pathways** to net-zero greenhouse gas (GHG) emissions by 2050
- Identify barriers to pursuing pathways
- Address the **technological, economic, societal, and environmental & health impacts** of an industrial transformation

INDUSTRIAL DECARBONIZATION
Decision Tree ⟺ [Model Framework]

*Viable implies currently available, cost-effective, and that the measures are deemed effective through social and environmental criteria and necessary

** Morrow, William III et al. 2017. "U.S. Industrial Sector Energy Productivity Improvement Pathways." [U.S. Industrial Sector Energy Productivity Improvement Pathways (aceee.org)](aceee.org)





Environmental & Health
Economic
Industry
Societal
Technological

“Pathways for U.S. Industrial Transformations” vision study stakeholder engagement

- *Transforming Industry* Workshop – May 14-15, 2024, Arlington, VA
- *Transforming Industry* RFI – Closed June 24, 2024
- Virtual Workshop to Inform Impacts of Energy Equity and Environmental Justice on Decarbonizing the Industrial Sector – August 27

Links:

- **May Workshop:** https://www.energy.gov/eere/iedo/events/us-department-energy-workshop-transforming-industry-strategies-decarbonization
- **RFI:** https://www.energy.gov/eere/iedo/articles/doe-seeks-input-strategies-decarbonize-americas-industrial-sector
- **August Virtual Workshop:** https://www.energy.gov/eere/iedo/events/pathways-us-industrial-transformations-workshop-inform-impacts-energy-equity-and

Workshop Structure

Primarily facilitated discussions to maximize input from participants

Basic Agenda

Timing	Activity
May 14, Tuesday Morning	Plenary Session (Speakers, panel)
May 14, Tuesday Afternoon	Cross-cutting Facilitated Discussion
May 15, Wednesday Morning	Non-Technical Facilitated Discussion
May 15, Wednesday Afternoon	Sector-specific Facilitated Discussion

Facilitated Discussions – Day 1 PM and all of Day 2

- **Plenary Session** (Day 1 Morning) – Context and framing (slides available online)
  - Welcome – *Ali Zaidi, White House*.
  - Industrial Decarbonization at DOE – *Avi Shultz, DOE IEDO*
  - Panel: Envisioning a Net-Zero Future
    - *David Turk – DOE*
    - *Carolyn Snyder – DOE EERE*
    - *Andres Clarens (Moderator) – OSTP*
  - Broad Trends and Ideas Shaping Industrial Decarbonization
    - *Perry Stephens, EPRI*
    - *Lauren Ross, DOE EJE*
  - Pathways for U.S. Industrial Transformations – *Joe Cresko, DOE IEDO*

Cross-Cutting Facilitated Discussion

Structure: Three rotations of 50 min facilitated discussion, topical breakout rooms

- ~5 min presentation followed by 45 min for focus questions

Questions

- Challenges, barriers, etc. to help inform study scenarios and sensitivities

High-level takeaways

- **Resource intensity to decarbonize industry** – Impacts to natural resources (e.g., water, land, minerals) are anticipated along with concerns of resource availability, competition, quality, and community impacts.
- **Infrastructure needs** – Infrastructure build-out is needed - e.g., beyond the plant (electric grid, H_2 storage/transport) and at the plant (retrofits, equipment upgrades)
- **Data availability, transparency, and standardization** – Needed to better inventory and track emissions as well as gauge non-energy and non-emissions impacts.
- **EJ and community considerations** – Impacts due to natural resource extraction, EWD, employment changes, community/local impacts.

Breakout Room Topics

- CCUS
- Electrification and the grid
- Energy efficiency
- Hydrogen and other low carbon fuels, feedstocks, and energy sources
- Material efficiency
- Natural resources

Non-Technical Facilitated Discussion

Structure: 60 min facilitated discussion

<u>Theme</u> (example): Uncertainty around the value of decarbonization from actors across industrial supply chains and communities.

Example Challenges	Example Approaches/Solutions
• Demonstrating the value of clean energy across the value chain • Lack of data availability and transparency	• Success stories • Life cycle assessment/comparative analysis • Clearinghouse for approaches and data to support decarbonization • Provide solid analytical basis for industry, utilities, investors, and policymakers to plan

<u>Example Metrics</u>

• Amount of avoided carbon • $/CO_2$ • Levelized cost of carbon reduction • Number of jobs created • Net social impact • Length of time for permitting	• Market penetration / market adoption • Tracking public will (permits issued vs. projects killed) • Projects announced vs completed

<u>Focus Questions</u>

- What are the <u>**most pressing non-technical barriers**</u> preventing progress towards decarbonization?
- What is needed to overcome them? How can the specific solution be achieved?
- What metrics are needed to measure success? (How do we define success?)

Subsector-Specific Facilitated Discussion

Structure: No rotations, topical breakout rooms by subsector, (15 min presentation on modeling results, 2 hours focus questions)

Direct feedback on modeling (examples of feedback)

- **Decision tree** – Decision tree is too linear. Decisions are considered in parallel depending on multiple factors, including market conditions, economics, site-specific constraints
- **Waterfall chart (representing inputs ←→ results)**– Prioritization is dependent on the individual plant's characteristics and constraints and not necessarily at the pillar level
- **Production routes/assumptions** – Provide flexibility to incorporate technologies that may not yet exist
- **Sensitivities**
  - Demand side outcomes based on policy levers (e.g., price of carbon, offtake agreements, etc.)
  - New technology deployment, including those that may not exist
  - Infrastructure build-out for feedstocks, H_2, CCUS, grid
  - Regional constraints

Focus Questions

Participants were asked two categories of questions:

1. Direct feedback on modeling – decision tree, waterfall charts, production routes/assumptions, sensitivities
2. Brainstorming – challenges and solution pathways

Cement & Concrete – Example Stakeholder Input

CCUS is a key pillar for cement decarbonization

LCFFES: need to determine share of emissions abatement from fuel switching vs. low carbon feedstocks (e.g., supplemental cementitious materials (SCMs), clinker alternatives)

Example Challenges	Example Approaches/Solutions
LCFFES: regulations–prescriptive building codes and standards	• Educate concrete users (e.g., contractors, construction organizations, engineers) that standards exist and are able to be use • Standards for these products exist but are not adopted or widely used • Demand-side incentives, e.g., federal procurement policy for low-carbon concrete

CCUS: no one size fits all solution – Unique geographical features and regionality of each facility may require a different set of approaches	• Federal coordination of CO_2 transport and storage infrastructure (CO_2 hub, similar to H_2 hubs) and cap T&S costs
	    • Share risk with producers
	    • Increase equitable access to CCUS for all plants
	• Scale-up and reduce costs for cement/concrete products that leverage carbon utilization/mineralization.

CAPEX – upfront cost of installing new technologies, including energy efficiency, electrification, low-carbon fuels and feedstocks (SCMs), CCUS	• Stronger and longer demand-side incentives (e.g., Buy Clean, volume guarantees, double-side auctions) • Production investment credits and tax credits • Federal support

Chemicals – Example Stakeholder Input

Example chemicals-specific considerations

- Manufacturing transition challenges
  - Complexity of shifting to low-carbon processes
  - Concerns over co-product yields and pathway maturity
- Feedstock dynamics
  - Market shifts affecting availability and pricing
  - Impact of declining fuels demand on petrochemical feedstock market
- Integrated process adaptation
  - Retrofitting challenges for complex plants
  - Costliness of adapting highly integrated processes

Example Challenges	Example Approaches/Solutions
Chemical industry is centralized (e.g., Gulf Coast assets) – challenge for new processes that want to take advantage of stranded assets	• Regional markets for agrochemicals • Require multi-material, matchmaking ability, e.g., CO2 is a waste product for some, but someone else needs it.
Cost of technologies and deployment in market	• Support demand for product (e.g., green chemicals), incentivization of demand for low-carbon chemicals • Adopting inexpensive feedstocks (e.g., waste) • Determine cost and impacts to incentivize chemical products, report to Congress to justify why products need to be incentivized

Iron & Steel – Example Stakeholder Input

Example Key Sensitivities

- Unclear what role electrolysis route for iron will play in subsector by 2050
- Quality and availability of scrap: Lots of residual, but copper is the key problem.
- Demand change: consider clean energy infrastructure build out (e.g., transmission lines, wind turbines, etc.) and how it may affect demand

Example Challenges	Example Approaches/Solutions
Deterioration of scrap quality and quantity	• Prioritize and develop scrap/steel impurities removal technologies, including processes for contaminant removal after shredding, scaling of in-melt copper removal • Work with processors to provide cleaner post-consumer scrap • Work with automakers to make extraction of copper easier • Develop product designs for low-copper scrap.
Availability of carbon alternatives for EAF	• Development of alternative sources, e.g., bio-carbon, bio-polymers, tires • Fund industry and projects to test alternatives
EAF: Natural gas, carbon, and electricity	• Improve efficiency • Electrify reheat furnaces • Biocarbon as an alternative carbon source • Grid decarbonization

Pulp & Paper – Example Stakeholder Input

Example stakeholder feedback

- DOE/USDA collaboration on stakeholder engagement
- Broader partnerships and involvement among industry stakeholders can leverage different areas of expertise to exploit opportunities
- Develop a standard framework for defining, measuring and quantifying "net zero" for the subsector
- Declining market is not present for many coproducts like soap
- Most plants already have integrated processes it is based on market drivers for coproducts

Example non-energy and emissions related metrics	Example energy and emissions related metrics
• Water and land-use metrics needed to properly evaluate sustainability (gallons/day or gallons/ton of product) • Air and water quality impacts from local plant operations • Investment/impact ratio to apply across the sector. • Capture safety and health impacts of new processes	• # safety incidents • Increasing employment figures (absolute numbers or %) • % waste directed to landfills (similar to European targets) • % annual reduction in packaging waste (reduce over-packaging) • % "forever chemicals" in waste streams

RFI Overview

The Industrial Efficiency and Decarbonization Office (IEDO) issued a request for information (RFI) to gather information for the forthcoming vision study *Pathways for U.S. Industrial Transformations: Unlocking American Innovation*.

Input categories:

1. Industrial Decarbonization Barriers, Challenges, and Cross-Cutting Strategies
2. Framework for Industrial Decarbonization Pathways
3. Impacts and Evaluation Criteria for Industrial Decarbonization Pathways; and
4. Net-zero Decarbonization Pathways for Specific Industrial Subsectors
   A. Cement
   B. Chemicals
   C. Food & Beverage
   D. Iron & Steel
   E. Pulp & Paper
   F. Petroleum Refining
   G. Rest of Industry - Data centers

4D: Net-zero Decarbonization Pathways for Specific Industrial Subsectors – Iron & Steel

Iron & Steel

4D.1 How do you expect the US demand and production of steel (and specific steel grades) to change by 2050 and why?

4D.2 What do you think of the net-zero subsector emissions by 2050 pathway described above and detailed in the pathways analysis summary document (if reviewed)?

4D.3 What do you think are the primary production routes needed to decarbonize the iron and steel subsector between now and 2050?

4D.4 What specific barriers or risks do you expect from the increased consumption of scrap for US steelmaking?

4D.5 What technical and/or technology solutions does the subsector need that are not currently available?

4D.6 What other solutions should be considered in characterizing/modeling a net-zero emissions iron and steel subsector by 2050?

4D.7 What sensitivities should be considered in characterizing/modeling a net-zero emissions iron and steel subsector by 2050?

4D.8 Are there any other subsector-specific barriers, criteria, metrics, or targets that DOE should be aware of as a decarbonization strategy for this subsector is developed?

4A Cement – Example Stakeholder Input

Example Needed Technologies/Solutions

- CCUS technologies spanning across LCFFES and CCUS, by permanently mineralizing carbon during cement production processes to help replace clinker consumption
- Accelerated material performance testing of low-carbon concrete mix designs that account for various quantities of admixtures and SCMs, age and conditions of sites, combined with long-term material durability/performance prediction methods to accelerate testing timelines
- New pre-calciner and alternative fuel kiln technologies such as oxy-fuel, calcium looping, electrification, and low-carbon/clean hydrogen that can meet the needs of unique cement kiln configurations
- Additive manufacturing technologies for concrete
- Mechanically activated clay, electrification of beneficiation process to enable the use of much larger quantity of viable clay resources and at wider range of geographies
- Higher-efficiency ultrafine grinding technologies, to address single-digit efficiencies of existing practices
- Small volume scalable clinker technologies, to better serve markets where demand exists while helping to avoid transportation costs and producing cement with low-carbon materials where they exist

4C Chemicals – Example Stakeholder Input

Example Growth Areas by 2050

- Performance-enhanced, recyclable/biodegradable molecules and materials
- Specialty chemicals due to increased demand in certain sectors, e.g., healthcare, electronics, automative
- Circular chemicals and feedstocks, e.g., recyclable molecules and materials, circular carbon-based chemicals
- Bio-based chemicals, bio-products, and biotechnology

Example Needed Technologies/Solutions

- Further development of scaled and economic electrolysis cell manufacturing, particularly for solid oxide-based technologies.
- More data on feedstock composition and variation, impurities, the fade of catalysts, scalability, etc.
- Biobased feedstocks: deployment largely hindered due to cost, instead of technology readiness
- Advanced chemical recycling, which relies on sufficient waste streams through adjustment of existing waste collection schemes. Technology to maximize reductions in carbon emissions and waste utilization, coupled with efforts to continue developing effective means to lower carbon emissions

4D Iron & Steel – Example Stakeholder Input

Example Needed Technologies/Solutions

- Crosscutting technologies to improve/maximize the potential of various decarbonization pathways: CCUS, low-cost, low emission oxygen production
- Nuclear energy, biomass-based replacement for coke and natural gas, thermal battery developments and applications, mineralization applications
- Cost competitive low-carbon DRI production though hydrogen or other low-carbon fuel
- Electricity-free electrolysis technology eXEROTM capable of converting blast furnace gas into clean hydrogen
- Encourage manufacturers of steel products to redesign their components to make it easier to remove metals that might dilute the quality of the scrap
- Decarbonization of stainless steel requires the development of technologies for decarbonizing chromium and nickel production
- At-scale demonstration and deployment of MOE and electrowinning
- Decarbonized secondary steel able to fulfill quality requirements of automotive and defense industries

4E Pulp & Paper – Example Stakeholder Input

Example Decarbonization Pathways

- Will vary for integrated and non-integrated mills, but could include:
    - Process electrification integrated with renewable energy (plus energy storage)
    - Production of value-added chemicals
    - Increased use of recycled materials
    - CCUS (capturing biogenic emissions)

Example Needed Technologies/Solutions

- Advanced electrochemical reactor design and process control that can process pulp and lignocellulose into value added chemicals
- Steam demand reductions beyond black liquor membrane systems
- Enhanced recycling technologies
- Carbon capture of biogenic emissions from the bark/recovery boiler streams
- efuel production, carbon dioxide removal credits

Important Example Decarbonization Considerations

- Accounting for and reducing Scope 3 emissions, role of sustainable forestry
- Growing challenges related to environmental conditions put stress on pulp production and water scarcity
- Range in energy/carbon footprint for non-integrated vs. integrated, recycled vs. virgin mills

4G Rest of Industry – Data Centers – Example Stakeholder Input

Growth by 2050

- Rapid growth in data centers energy demand expected from multiple applications: digital services, artificial intelligence, large language models (LLM), hyperscale data centers, cloud/edge computing, automation, 5G wireless technology, etc.
- Data centers' locations are dependent on proximity to power and data connectivity, and the location necessity limits the ability for data centers to run on renewable energy

Example Decarbonization Pathways

- Clean electricity generation located close to data centers (or onsite) to minimize dependency on the grid and reduce transmission losses
- Increase efficiency and reduce physical footprint of mechanical, electrical, and plumbing equipment

Example Needed Technologies/Solutions

- Enhanced thermal management solutions
- Build integration industry/energy development with three phases: site selection and feasibility studies, design and development, and construction and pilot implementation.

Example Metrics

- Technical [e.g., rack power density (kW/rack)]; sustainability [e.g., power usage effectiveness (PUE), water use efficiency (WUE), carbon usage effectiveness (CUE)]; economic [e.g., total cost of ownership (TCO)]

Thank you!

We are on a break and
will return at
1:00 pm ET

Subcommittee Report-Out: Report Outline

Report-Out: Subcommittee on Report Outline Lead: Sharon Nolen	1:00 – 1:45 PM

Report Consideration

1. What level of detail is wanted for the report?
    - Answer to be inputted following discussion
2. What is the target length for the report?
    - Answer to be inputted following discussion
3. Formatting discussion
    - Reports from other federal advisory committee tend to be bulleted & recommendation oriented
    - Examples
        - Secretary of Energy Advisory Board: Powering AI and Data Center Infrastructure Recommendations July 2024.pdf – 12 pages
        - 21st Century Energy Workforce Advisory Board: Strategy for a 21st Century Energy Workforce – 62 pages

Subcommittee Report-Out: Industrial Sectors

Report-Out: Subcommittee on Industrial Sectors Lead: Subodh Das	1:45 – 2:30 PM

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

Industrial Sectors Subcommittee Report – October 29, 2024

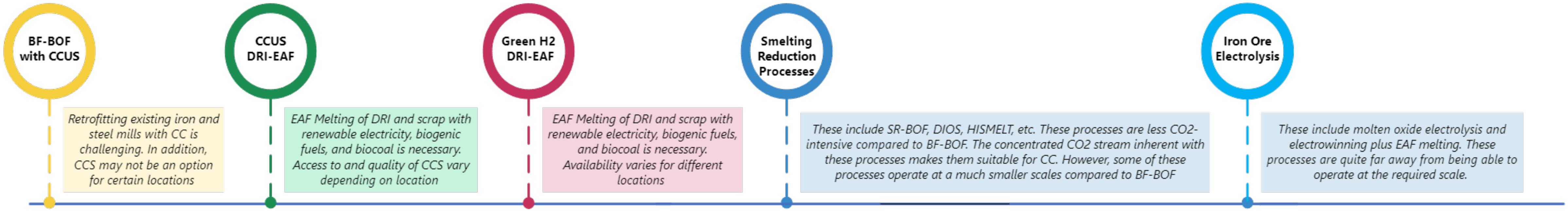
Team Members:

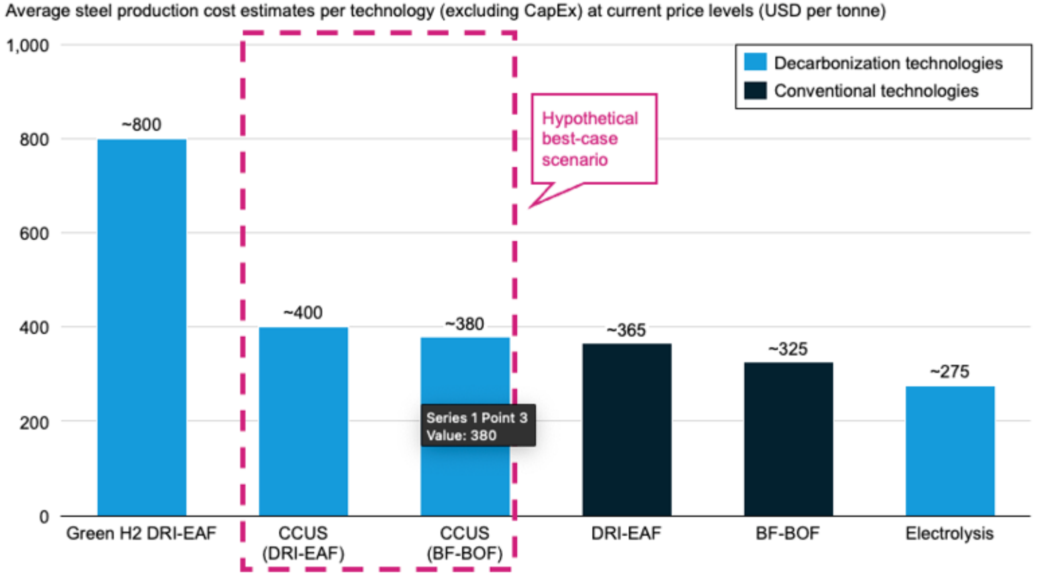
Subodh Das: Lead
Sridhar Seetharaman: Co-lead
Sunday Abraham: Co-lead
Elizabeth Dutrow
Joe Powell
Jolene Sheil

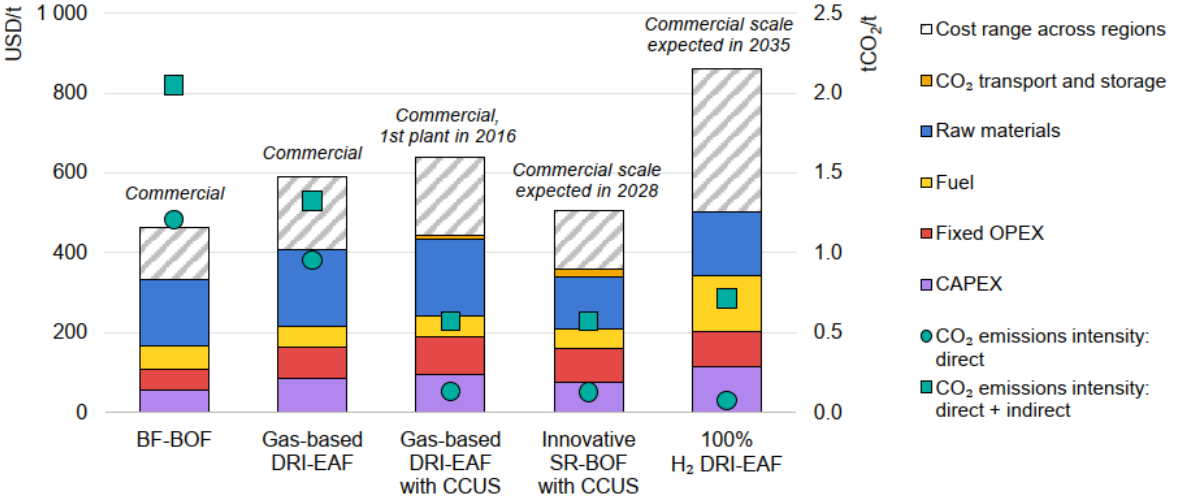
Sectors Covered:

Iron and Steel
Aluminum
Cement
Paper and Pulp
Data Center
Chemicals

Pathways to Decarbonization for the Iron and Steel Industry







Process Heating and Preheating Technologies

- Replacement of fossil natural gas with hydrogen and biofuels for reheating in reheat furnaces and metallurgical vessel preheating
- Electrification and induction heating technologies for reheat furnaces
- Microwave plasma heating technology

Process Description	Process	Source of CO_2	Emission Scope	CO_2 Emissions (t_{CO2e}/t_{steel})	Cross-Cutting Technology
Reheat Furnace	Reheating of As-cast Products	Natural Gas Combustion	1	0.082	Electrification, Induction Heating, Microwave Plasma, Hydrogen, Renewable Natural gas, and Other Biofuels
EAF Chemical Energy	Fossil Natural Gas	Combustion Process	1	0.0162	Renewable Natural Gas and Other Biofuels
Metallurgical Vessels & Equipment	Preheating	Natural Gas Combustion	1	Not Available	Microwave Plasma, Hydrogen, Renewable Natural gas, and Other Biofuels
Casting	Conversion of Liquid Steel to Slab	Natural Gas Combustion for Cutting	1	0.018	Hydrogen, Renewable Natural Gas, Natural Gas, and Other Biofuels
Heat Treatment	Microstructure Development	Power Consumption and Natural Gas Combustion	1&2	Not Available	Electrification, Induction Heating, Microwave Plasma, Hydrogen, Renewable Natural gas, and Other Biofuels

Waste Management and Energy Efficiency

- Recovery of off-gases from integrated steelmaking process for electricity generation
- Dry quenching of coke
- Incorporation of oxygen enrichment in hot stoves
- Coke oven gas use in blast furnace to decrease coke use
- Enhanced utilization of waste heat
- Recycling of EAF baghouse dust to recover iron and zinc
- Use of slags in cement industry as a substitute for limestone. *A waste in one industry may be a useful raw material in another.*
- Recover ferrous units from mill scale and slags (EAF and BOS)
- Improve scrap utilization and mitigate impurities like copper

Comments on the DOE Lift Off report

"By 2030, up to 40% of emissions could be abated with external factors to facilities or existing net-positive (10% estimated internal rate of return) decarbonization levers when IRA incentives are included."

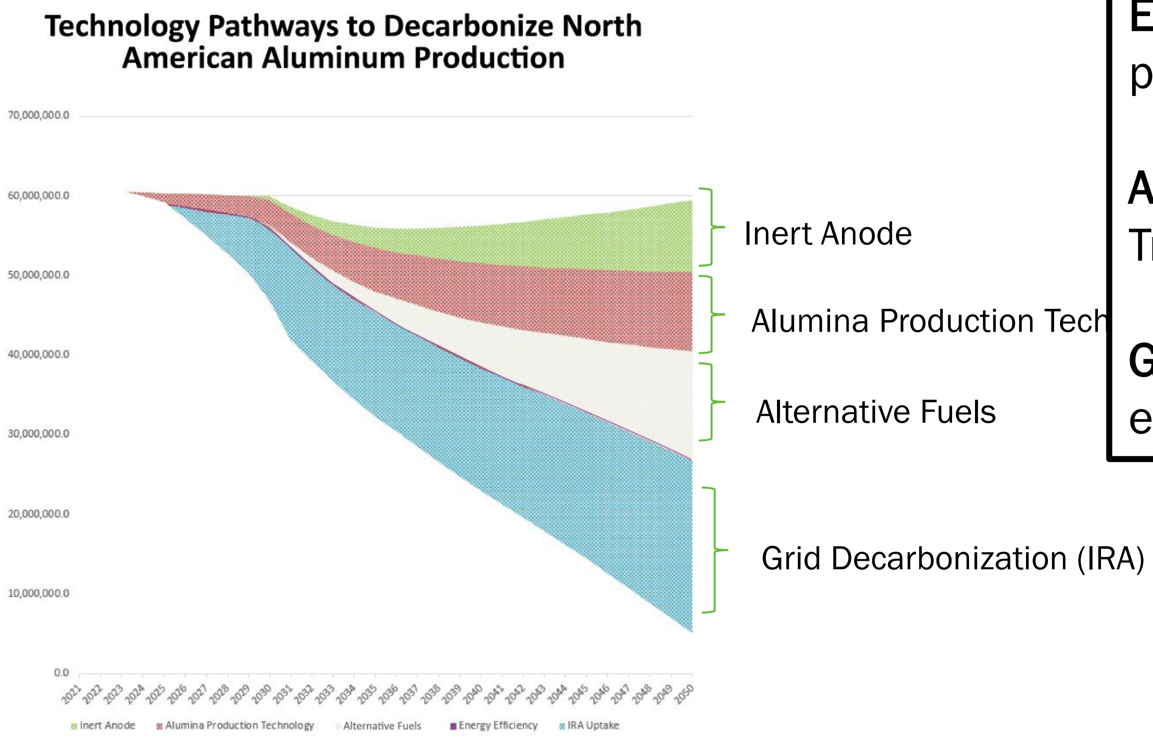
For iron and steel the report lists:

- **"Transition from BF-BOF to EAF"**
  - This faces several challenges and can not offset the current demand for pig iron unoess you address:
    - (a) Availability of scrap
    - (b) As the demand for scrap increases, scrap quality will deteriorate.
    - (c) DRI/HBI use (with H_2 or NG) rin EAF equires high grade iron ore, which is not available in the USA

- **"Alternative ironmaking processes to deliver pig iron are deemed deployable"**
  - What are these technologies? Some technologies, such as the Molten Oxide Electrolysis and Electrowinning, face significant headwind in terms of scalability. These technologies may not be scalable for commercial application for iron and steel production anytime soon.

A Roadmap for North America

Potential Pathways to Net Zero



Aluminum Production Technology & Efficiency: New technologies and plant efficiency.

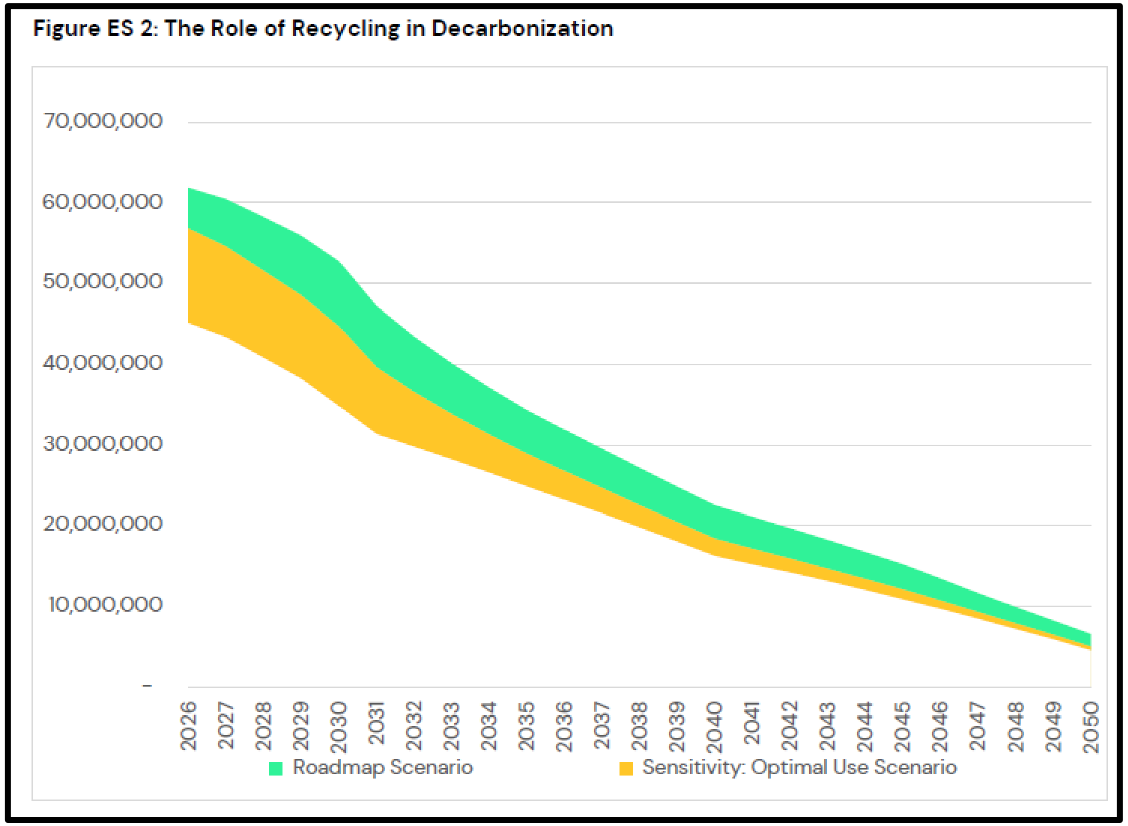
Alternative Fuels & Carbon Capture: Transition to new energy sources.

Grid Decarbonization: Cleaner grid enabled by Inflation Reduction Act

1/3	2/3
Aluminum industry efforts	Broader shifts in manufacturing/ energy

The Role of Recycling

Speed Down the Decarb Curve

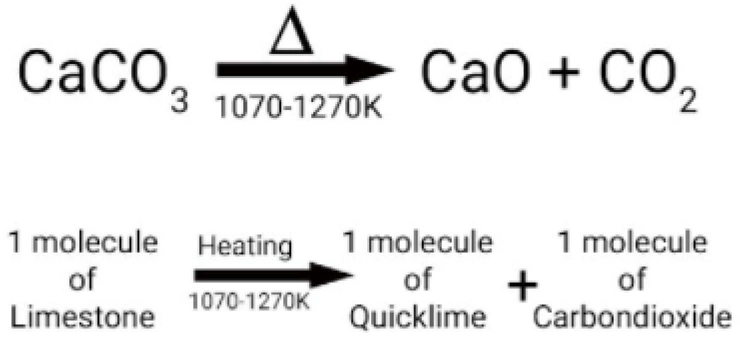


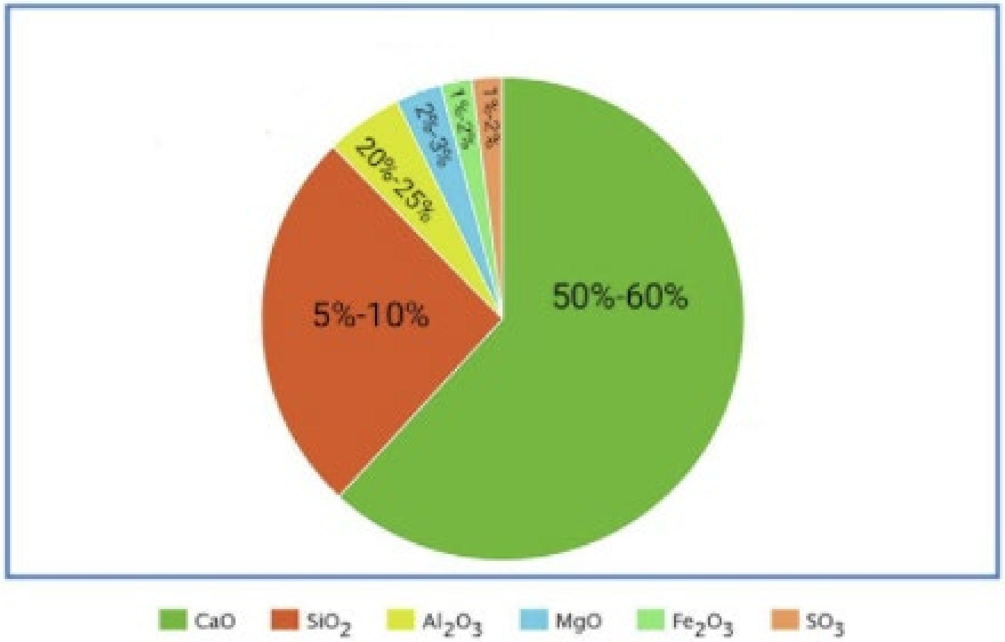
Baseline Scenario: 127 million metric tons of CO2e reduced by more recycling (constrained scrap)

Optimal Utilization Scenario: An additional 160 million metric tons of CO2e by 2050

The Delta = Taking 38 million cars off the road for a year

Cement: CO_2 is a byproduct





Portland cement

1300-1450 °C (2372- 2642 °F)

Made by calcining limestone → lime + CO_2

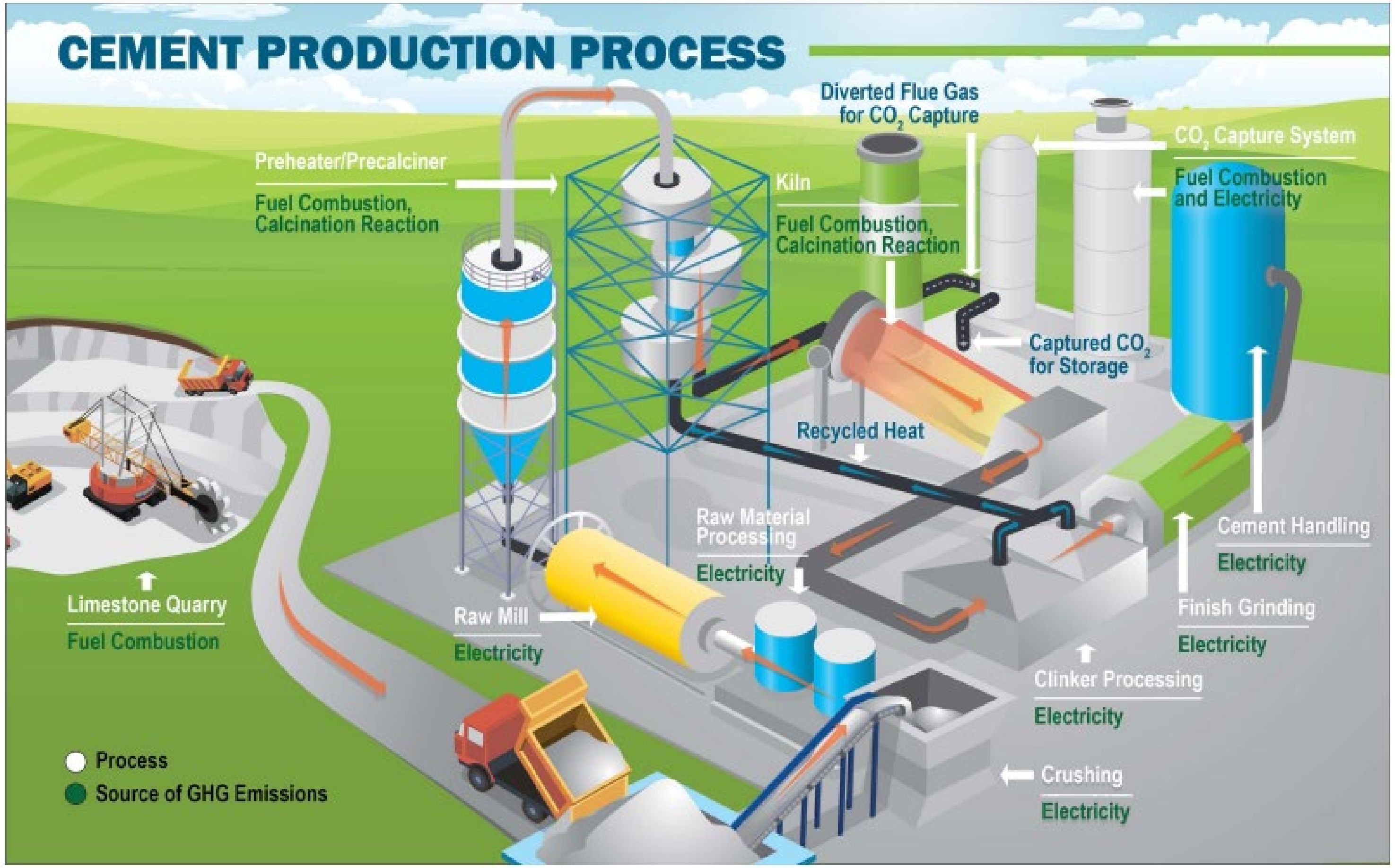
Lime reacts with clay at high temperature to form "clinker". 2 bags of lime per bag of clay

Add 2 – 3% gypsum (calcium sulfate) to make cement

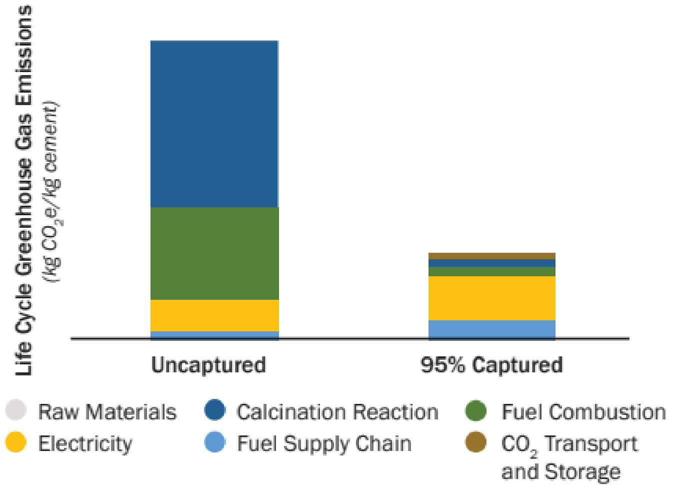
Add water for cement to bind with sand / rock to form concrete

https://www.toppr.com/ask/content/story/amp/cement-composition-and-uses-46663/

Cement



Carbon dioxide emission rates throughout the life cycle of the cement production process with and without carbon dioxide capture



https://www.energy.gov/sites/default/files/2023-11/Industry%20Guide%20to%20CCS%20at%20Cement%20Plants_Nov%2029%202023_0.pdf

Decarbonization of cement

Substitute clean H_2 or electrical heat to provide the process energy to make lime from limestone: 40% of total CO_2 footprint. High temperature calcination heat.

CO_2 capture is ideal: cannot avoid CO_2 by product!

Substitute other reactions to bind calcium carbonate and incorporate more CO_2 into final product → change the chemistry.

Substitute carbon fibers from methane pyrolysis to make structural products (turquoise hydrogen).

General Comment

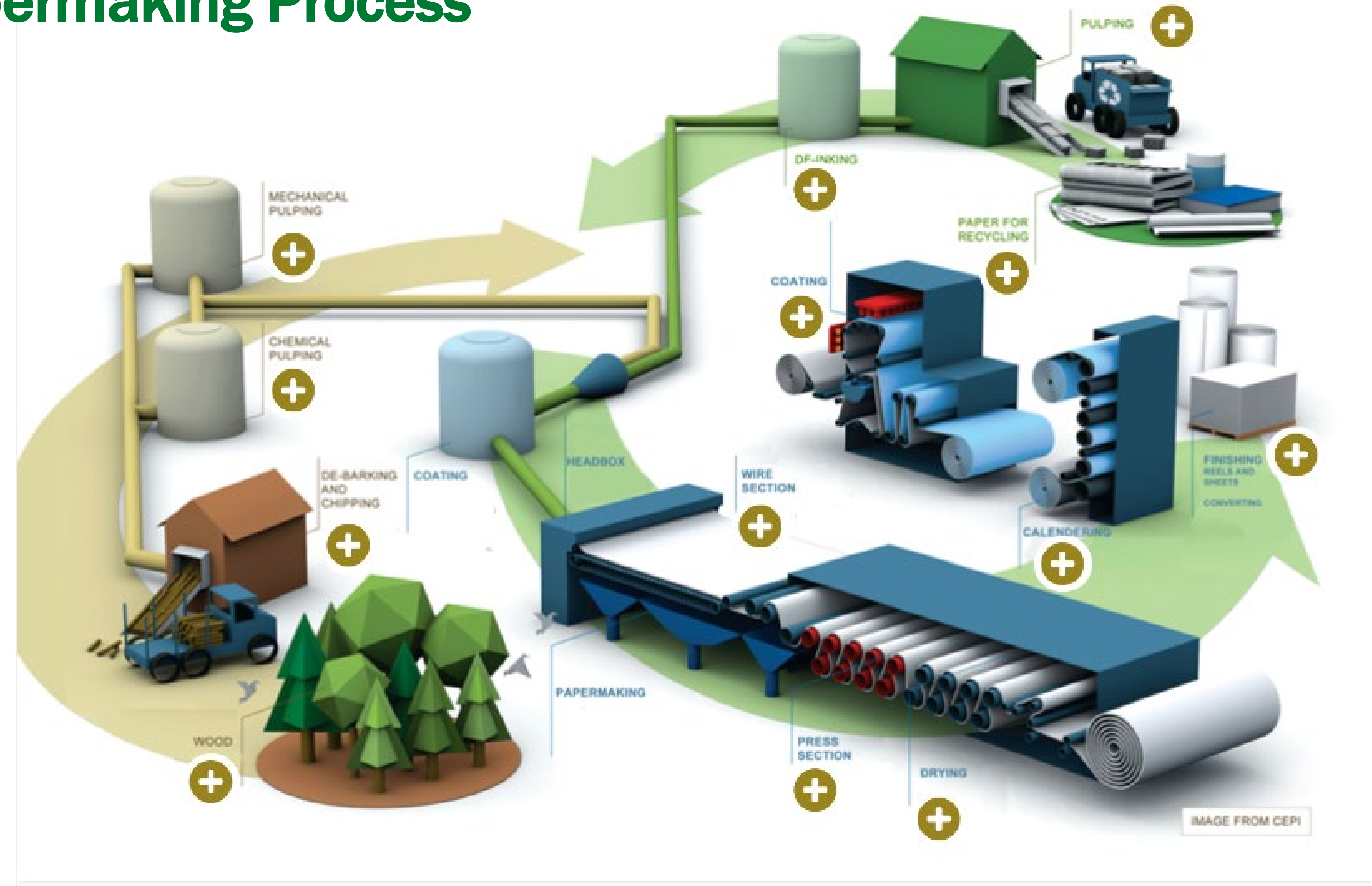
- The Lift Off report or Decarbonization road map report do not address agriculture, forestry, and land use. Trees are more efficient as far as CO_2 sequestration is concerned. Also, it is important to understand DOE's position and guideline on biocoal use more clearly.

- The reports do not consider data centers.

US Grid Output vs. Power Needs of Data Centers

Include projected energy needs in larger automation/smart manufacturing projects as part of LCA an NEPA?

Papermaking Process



https://paper.org.uk/CPI/CPI/Content/Information/Papermaking-Process.aspx

Energy Consumption Pulp and Paper Process

Figure 1: Total energy consumption by end use, pulp mill

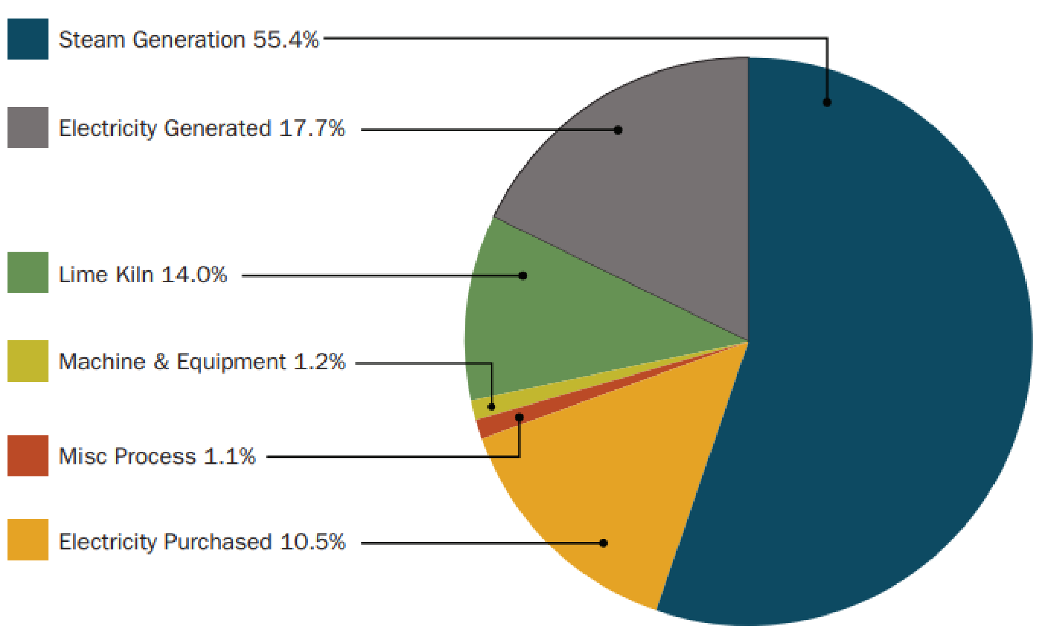
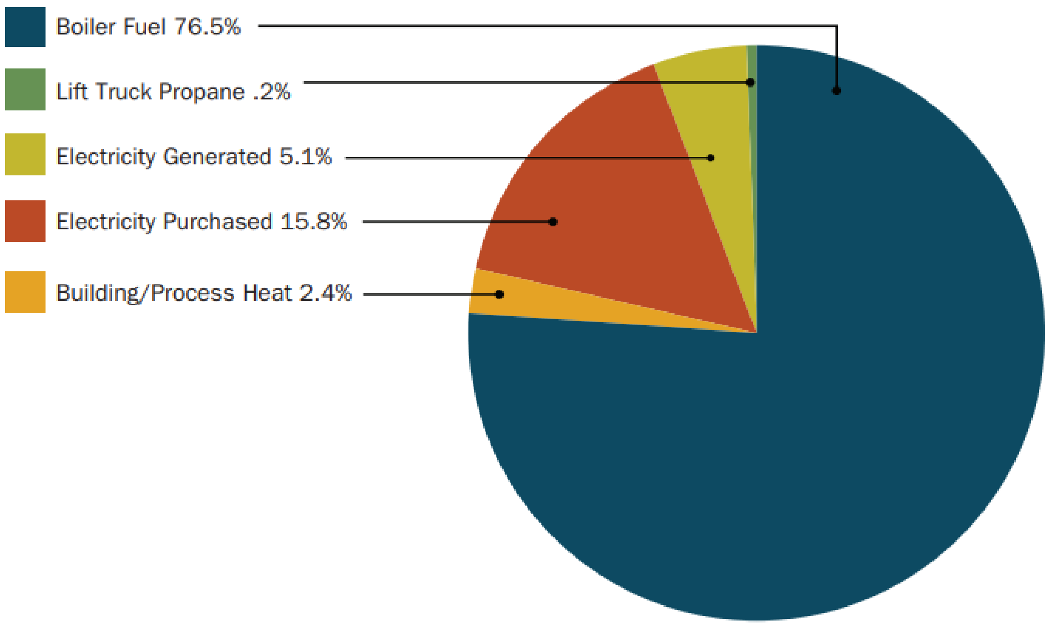
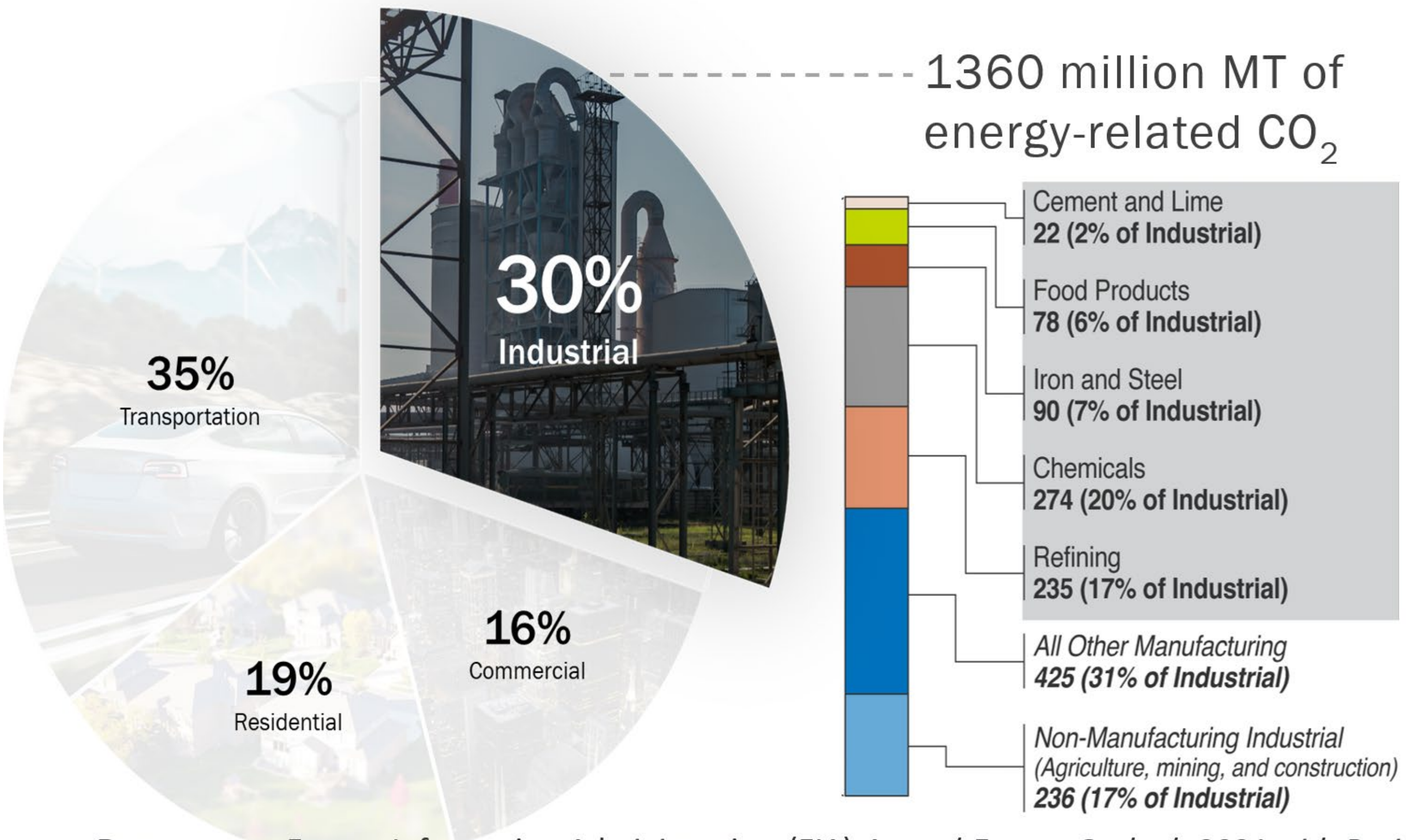


Figure 2: Total energy consumption by end use, paper mill



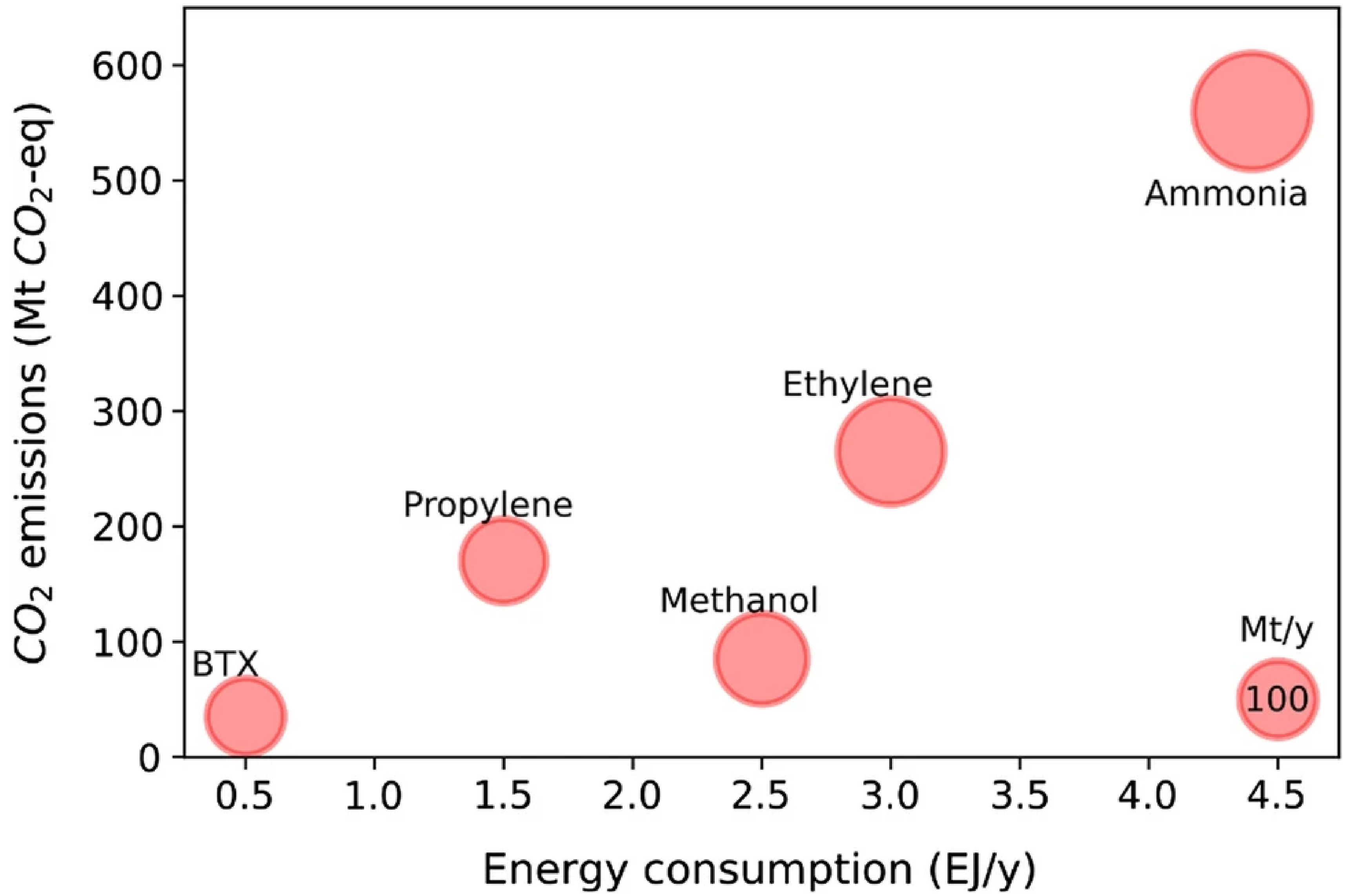
Pulp and Paper Energy Best Practices Guide ©2024 Wisconsin Focus on Energy

US CO2 Emissions



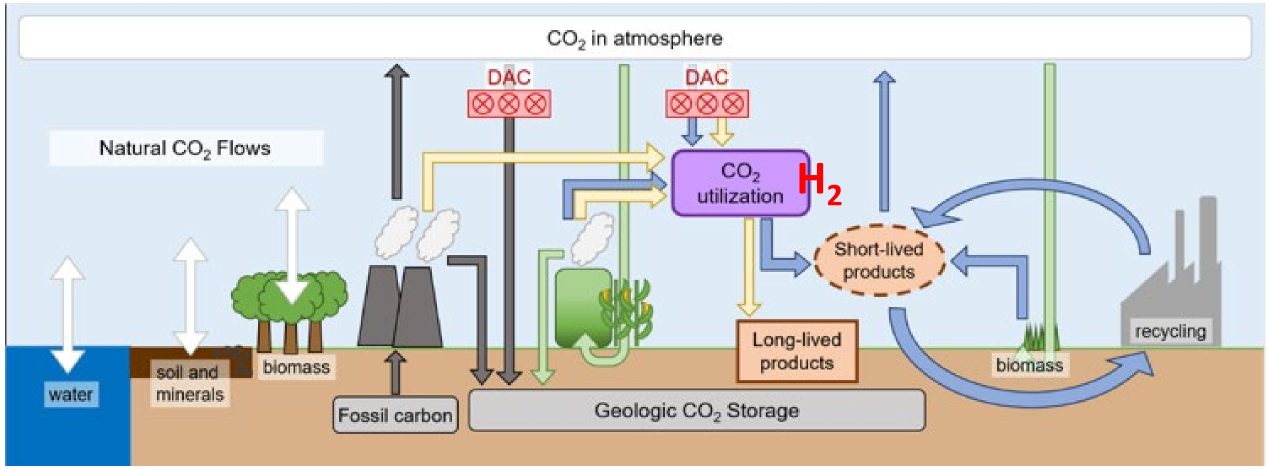
Data source: Energy Information Administration (EIA) *Annual Energy Outlook 2021 with Projections to 2050* and other EIA & EPA sources.

https://www.eia.gov/outlooks/aeo/pdf/AEO_Narrative_2021.pdf



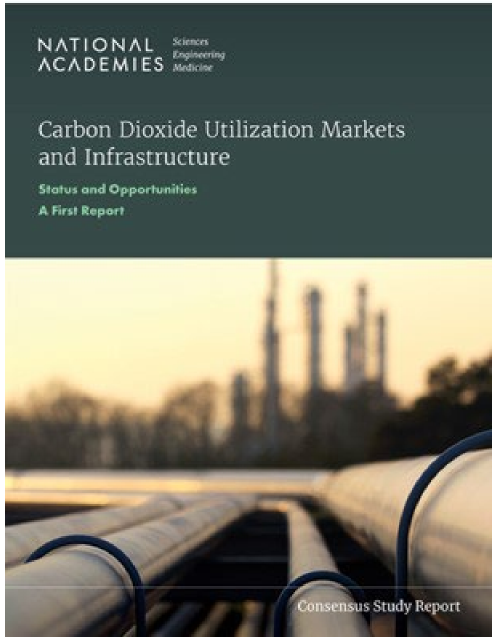
IEA. Technology roadmap energy and GHG reductions in the. Technol Roadmap. 2013. pp. 1–60.

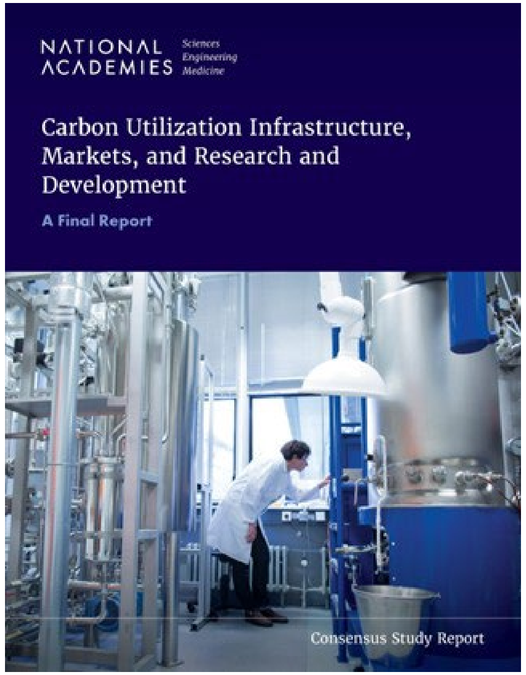
Carbon Capture Utilization & Storage (CCUS)



Schematic of main carbon flows in a circular carbon economy, showing sustainable pathways for the production of short- and long-lived carbon-based products as well as natural flows of carbon into and out of the atmosphere. Natural flows are white. Flows of fossil carbon and emissions are grey. Flows of biogenic carbon are green. Flows of recycled materials are blue, as are flows of carbon associated with short-lived products. Flows to be used for long-lived products are yellow. DAC = direct air capture. This schematic does not include all carbon flows that will exist in a circular carbon economy; for example, recycling could be an option for long-lived products. SOURCE: Committee generated.

https://www.nationalacademies.org/our-work/carbon-utilization-infrastructure-markets-research-and-development

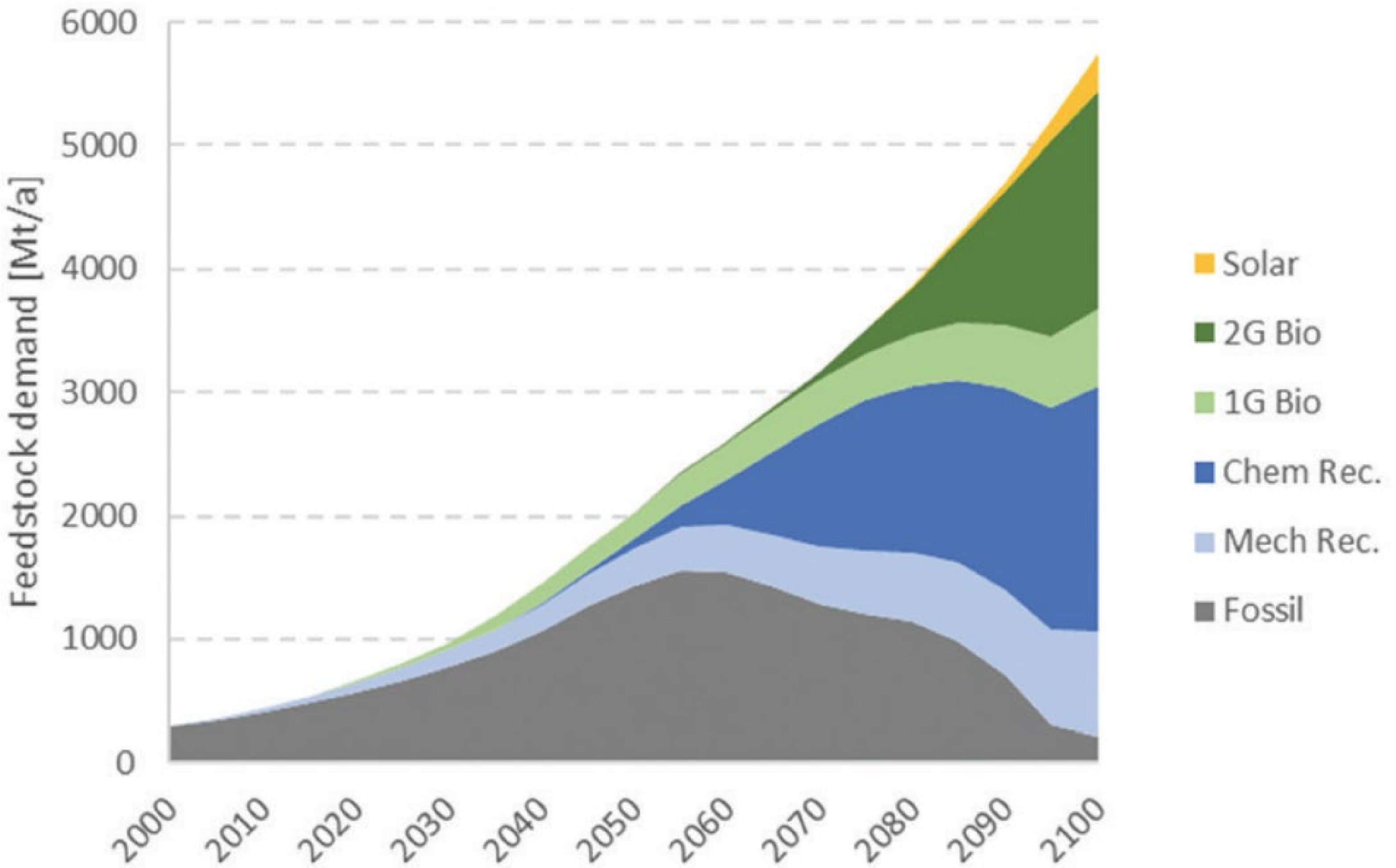




DOE CO_2 Direct Air Capture Hub: TEA & LCA

Carbon inputs to Future Circular Chemical Economy

Chemical industry inputs



J.-P. Lange, Towards circular carbo-chemicals – the metamorphosis of petrochemicals, *Energy Environ. Sci.*, 2021, **14**, 4358–4376

Responsibilities and Gaps

Sector	DOE Decarb Road Map	DOE Liftoff Report	Sub Committee POC	Comment
Iron*Steel	Y	Y	Sunday/Sridhar	
Chemicals	Y	Y	Joe Powell	
Cement	Y	Y	Joe Powell	
Paper/Pulp	Y	Y	Jolene/Altfather/Hasbargen	
Food & Beverage	Y	Y	Joe Powell/External	
Aluminum	N	Y	Subodh	
Other non-ferrous (Cu, Ni, Co, Mn REE etc.)	N	N	N	Enabler of clean technologies
Glass	N	Y	N	
Agriculture	N	N	N	Agriculture land can be large CO_2 sink
Forrest management	N	N	N	Forrest land can be large CO_2 sink
Data centers	N	N	N	Large consumer of energy (electric power)
Mining	N	N	N	

Thank you!

ITIAC Cross-Cutting Subcommittee

- Neal Elliott, lead (replacing Eric Masanet)
- Sridhar Seetharaman
- Jeffrey Rissman
- Jolene Sheil
- Neal Elliott
- Comas Haynes
- Sharon Nolen

- Neil Brown, Eastman Chemicals (outside expert on Direct Use of Heat from Renewable Sources/Bioenergy)

3. Cross-cutting Technologies & Opportunities

a. Energy efficiency
b. Material Efficiency
c. Circular Economy
d. Electrification
e. Dynamic load management
f. Use of low-GHG hydrogen by industrial firms
i. Carbon capture, utilization, and storage (CCUS)
j. Infrastructure needs for industry
k. Non-CO2 GHG emissions (N2O, CH4, and F-gases)

Energy efficiency

Lead: Sharon Nolen

Definition/description: Energy efficiency is generally seen as the first and most cost-effective lever of decarbonization. It can include everything from standardized maintenance practices to installation of more efficient equipment to process redesign. Energy efficiency can also benefit from advanced analytical techniques including optimization and anomaly detection.

Overlaps with other subcommittees:

- Material efficiency

Market or policy actors:

- ENERGY STAR Industrial Partnership
- DOE Better Plants Program
- ACEEE
- Utilities

Materials efficiency

Lead: Neal Elliott

Definition/description: Material efficiency is the amount of materials needed to produce a given good or service, reducing the required resources including energy, water, waste, pollution, labor, and environmental damage.

Overlaps with other subcommittees:

TBD

Market or policy actors:

Manufacturers

Customers

Purchasing agents

Policy makers

Notes: Material efficiency can include the substitution of information services for physical materials.

Circular Economy

Lead: Jeff Rissman

Definition/description: Two to three sentences …

Overlaps with other subcommittees:

- TBD

Market or policy actors:

Notes:

Electrification

Lead: Lead: Sridhar (w/ Jeff Rissman)

Definition/description: Electrification of process heating at all temperature ranges (using technologies such as high-temperature heat pumps, electric resistance, electromagnetic induction, electric arcs, infrared heating, etc.). Also, electricity can sometimes replace heating entirely (e.g., non-thermal use of electricity, such as electrolysis, UV curing of epoxies and coatings, or other electrochemistry).

Overlaps with other subcommittees:

Electrification has some overlap with, low-GHG hydrogen, and self-generation subcommittees/topic areas.

Market or policy actors:

Center for Climate and Energy Solutions (C2ES)

Renewable Thermal Collaborative (RTC)

Use of low-GHG Hydrogen by Industry

Lead: Comas Haynes

"Low-GHG hydrogen" herein regards hydrogen that is sourced from primary compounds and processes that have little-to-no associated cogeneration of "greenhouse" gases. Industry is thus able to use this hydrogen as a "clean" chemical feedstock and/or fuel source of energy.

Overlaps with other subcommittees:

TBD

Market or policy actors:

Industrial "offtakers" (i.e., users of low-GHG hydrogen) spanning chemicals and energy sectors

Industrial "suppliers" (i.e., providers of low-GHG hydrogen)

Regulatory bodies / authoritative standards committees

Policy makers

Notes:

chemical processing industry (clean feedstock or co-reactant alternative); and

the energy sector as stored energy

Direct Use of Heat from Renewable Sources/Bioenergy

Lead: Neil Brown (Eastman)

The replacement of the direct or indirect (e.g., steam) fossil fuels use with solar thermal or geothermal heat source, or bioenergy resource.

Overlaps with other subcommittees:

The direct use of heat from renewable sources and bioenergy category has some overlap with the electrification, low-GHG hydrogen, and self-generation subcommittees/topic areas.

Market or policy actors:

TBD

Notes:

Direct use of heat from solar thermal or geothermal heat sources, inclusive of storage (not electricity generation)

Bioenergy (solid, liquid, gaseous) as feedstock or burned for energy

Self generation

- Lead: Sharon Nolen

  Definition/description: Self generation has typically referred to combined heat and power plants where steam and electricity are co-generated. In addition, self generation can refer to the on-site generation of electricity using solar, wind, geothermal or hydroelectric technologies.

- Overlaps with other subcommittees:

  Carbon, capture, sequestration (if needed to abate fossil fuel CHP)

  Infrastructure needs for industry (if more electricity is purchased)

- Market or policy actors:
  - CIBO
  - Utility regulators/FERC/RTOs

Carbon capture utilization and sequestration (CCUS)

Lead: Neal Elliott

The capture of CO2 from industrial processes or from combustion of fuels, and 1) its use to produce a product or 2) its permanent storage or sequestration.

Overlaps with other subcommittees:

Industrial sectors

DOE work and gaps

Market or policy actors:

State and local governments and regulators

Notes:

Utilization excludes enhance oil recovery

Infrastructure needs for industry

Lead: Neal Elliott

Physical infrastructure that supports the delivery of resources necessary for decarbonization such as electricity, hydrogen and water, and take away material from the site such CO2, waste water and solid waste.

Overlaps with other subcommittees:

Barriers

Industrial sectors

Market or policy actors:

DOE

EPA

FERC

NARUC

- Electric utilities
- Water/waste water utilities
- State and local governments and regulators

Non-CO2 GHG

Lead: Jeff Rissman

Definition/description: Two to three sentences ...

Overlaps with other subcommittees:

TBD

Market or policy actors:

Notes:

Dynamic Load management

Lead: Neal Elliott

Using advanced control system to optimize processes and onsite distributed energy resources to adjust grid demand and electricity exports to support grid operation and renewable generation.

Overlaps with other subcommittees:

- Electrification
- Industrial sectors

Market or policy actors:

- Clean Energy Buyers Alliance
- Utilities
- NARUC
- Industrial controls providers

Adjourn

Thank you!