MN Iron Ore & the Green Economy

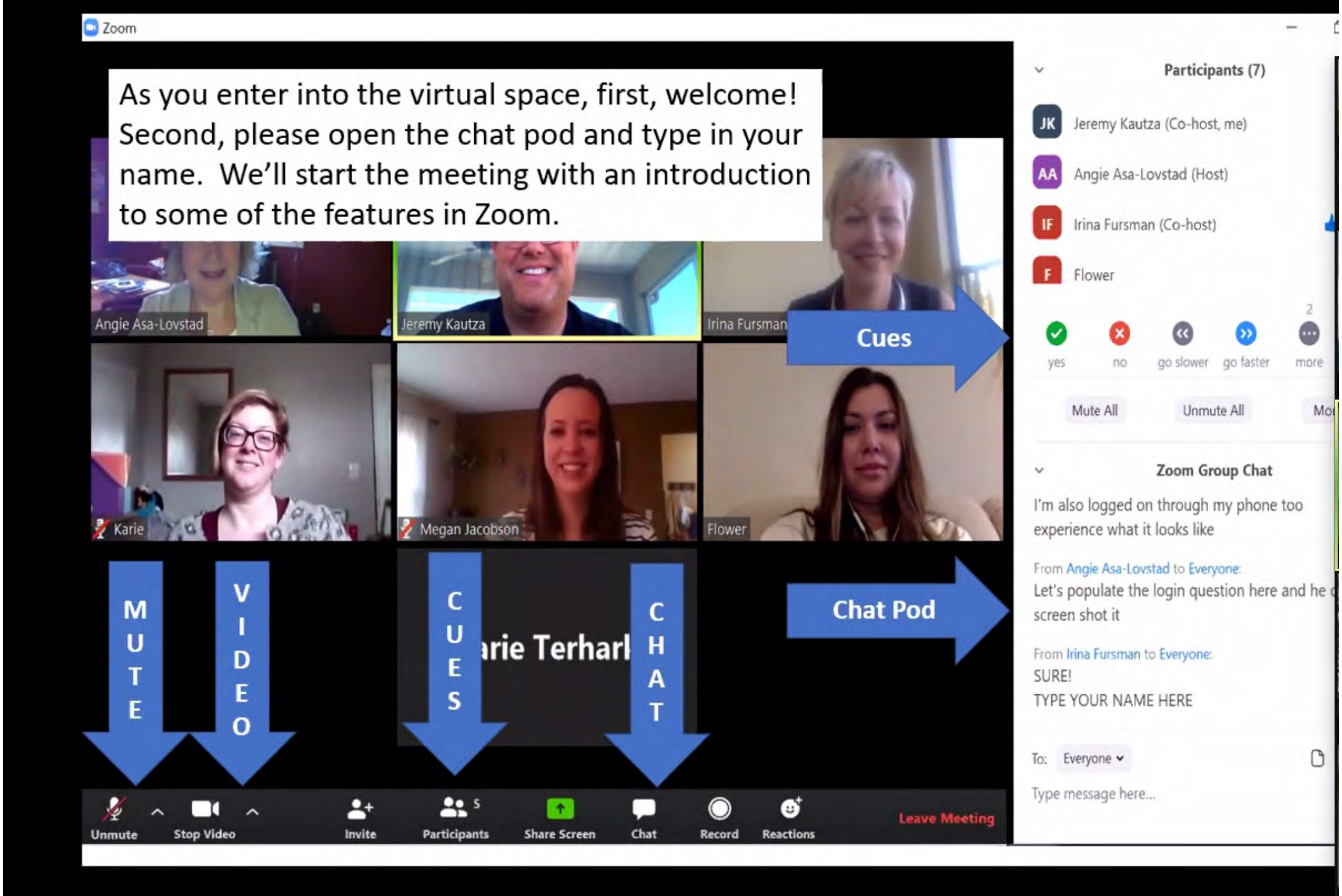
A one-day virtual forum focusing on the role of Minnesota iron in the decarbonized steel of tomorrow.

March 16, 2022 | 9:00 AM – 2:30 PM

AGENDA

9:00	**Greetings & Introductions**
9:10	**Introduction to Greenhouse Gas Emissions**
9:35	**Sustainability in the American Steel Industry**
10:00	**Steel in a Greener World**
11:00	**Company Climate Strategies**
12:00	**LUNCH BREAK**
12:30	**Company Climate Strategies**
1:00	**Emerging Research**
2:20	**Recap & Adjourn**


Zoom & Our Virtual Forum Space


Zoom
As you enter into the virtual space, first, welcome! Second, please open the chat pod and type in your name. We'll start the meeting with an introduction to some of the features in Zoom.
Angie Asa-Lovstad
Jeremy Kautza
Irina Fursman
Karie
Megan Jacobson
Flower
Cues
Chat Pod
MUTE
VIDEO
CUES
CHAT
Unmute
Stop Video
Invite
Participants
5
Share Screen
Chat
Record
Reactions
Leave Meeting
Participants (7)
JK Jeremy Kautza (Co-host, me)
AA Angie Asa-Lovstad (Host)
IF Irina Fursman (Co-host)
F Flower
yes
no
go slower
go faster
more
2
Mute All
Unmute All
Zoom Group Chat
I'm also logged on through my phone too experience what it looks like
From Angie Asa-Lovstad to Everyone:
Let's populate the login question here and he
screen shot it
From Irina Fursman to Everyone:
SURE!
TYPE YOUR NAME HERE
To: Everyone
Type message here...

Greetings & Introductions

Greetings & Introductions

Peter Clevenstine, MNDNR

Jason Janisch, Jasper Engineering

Julie Marinucci, St. Louis County

Introduction to Greenhouse Gas Emissions

Frank Kohlasch

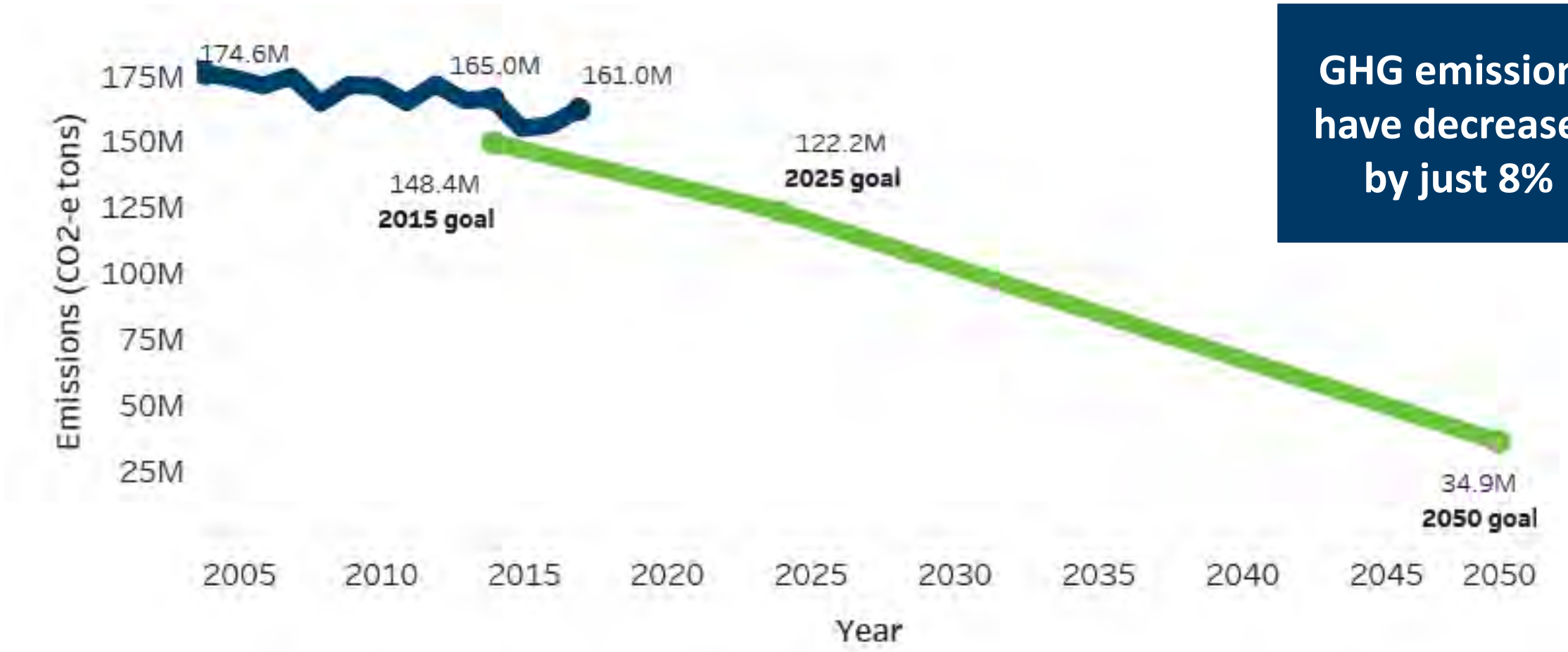
MPCA Climate Director

Greenhouse Gas Emissions in Minnesota

Frank Kohlasch
Climate Director
Minnesota Pollution Control Agency

OUR MINNESOTA CLIMATE

Minnesota is not on track to meet its goals

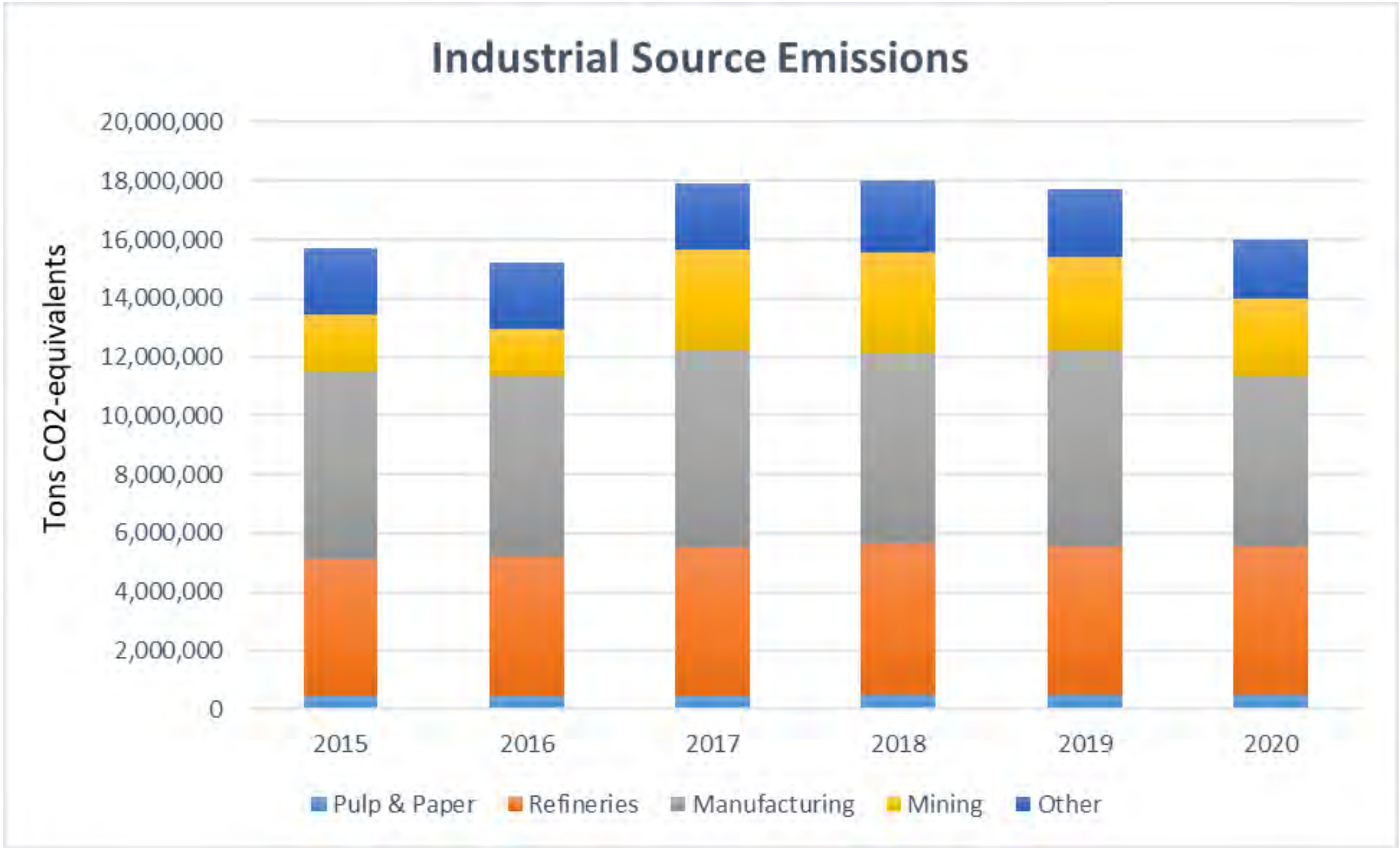


GHG emissions have decreased by just 8%

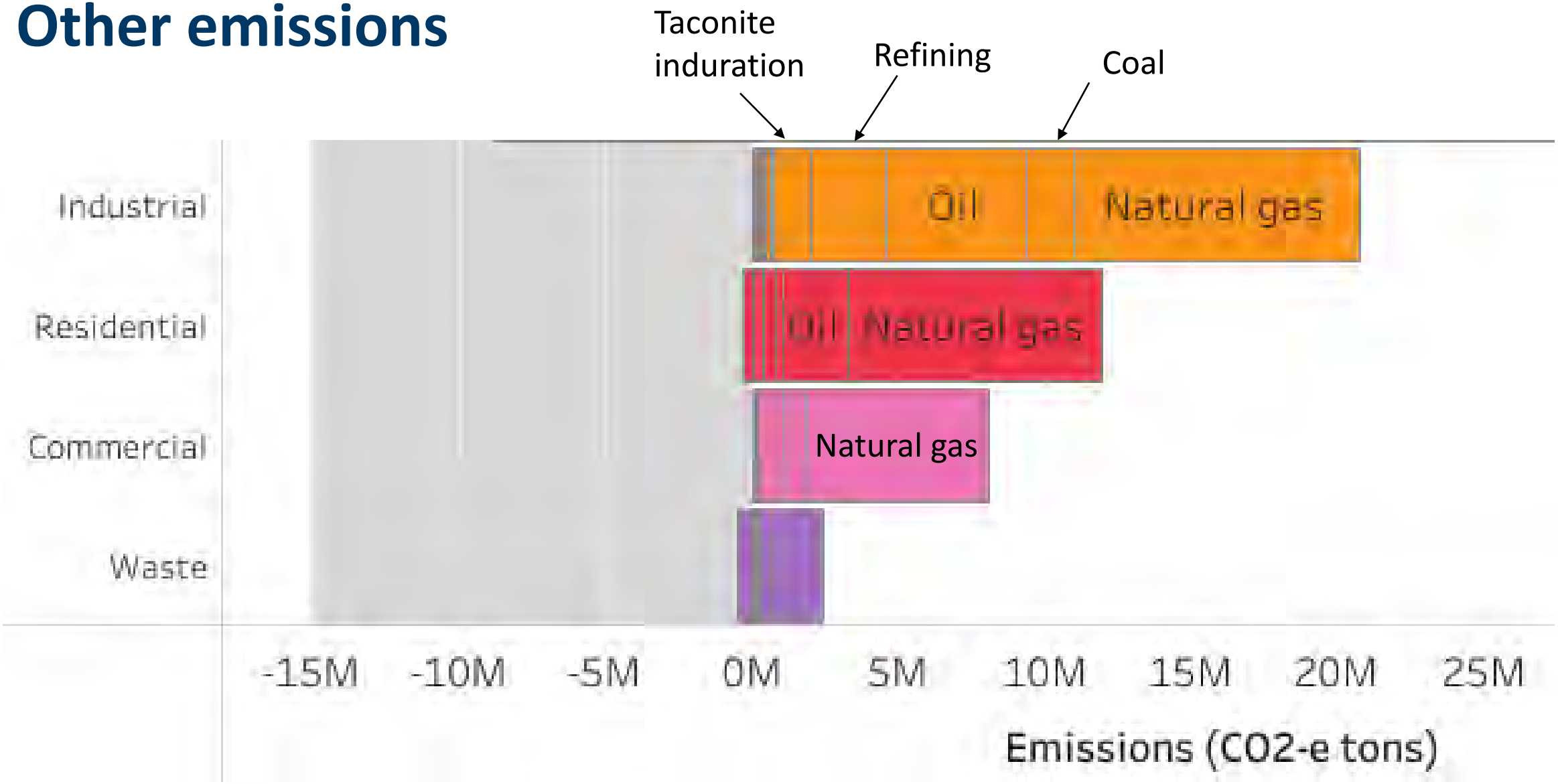
Minnesota's actual GHG emissions, compared to the Next Generation Energy Act goals

Greenhouse gas emissions by sector

Emission change 2005 to 2018	Transportation	Electricity generation	Agriculture, Forestry and Land use	Industrial	Residential	Commercial	Waste
	-3.27M -7%	-16.40M -29%	-0.76M -2%	3.22M 18%	2.83M 32%	1.05M 15%	-0.24M -11%


Industrial Source Emissions
Tons CO2-equivalents
20,000,000
18,000,000
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
2015
2016
2017
2018
2019
2020
Pulp & Paper
Refineries
Manufacturing
Mining
Other

Other emissions



Background

• Climate Change Subcabinet

- Executive Order 19-37 signed by Governor Walz in December 2019
- Identify **polices and strategies** to:
  - Meet or exceed the Next Generation Energy Act **GHG reduction goals**
  - Enhance the climate **resiliency** of natural resources, working lands, and communities
- **Engage** with Minnesotans in identifying and developing strategies

https://climate.state.mn.us/subcabinet

Background

• Advisory Council on Climate Change

- Also established under Executive Order 19-37
- Up to 15 members appointed by the Governor
- Duties include:
  - Identify **opportunities** and **barriers** to the development and implementation of policies and strategies
  - Promote **equity**
  - Promote a **just transition** for impacted workers and communities

https://climate.state.mn.us/advisory-council

Why a Climate Action Framework?

- Organize and share our thinking
- Invite conversation
- Tool for accountability
- Catalyst for action across sectors

What is the Climate Action Framework?

Sets a vision for how Minnesota will address and prepare for climate change

Broadly describes the work that we need to accomplish together

Identifies immediate, near-term actions to support our long-term goals

Vision for Minnesota

Carbon-neutral

Resilient

Equitable

Draft Framework Goals

Clean transportation

Climate-smart natural & working lands

Resilient communities

Clean energy & efficient buildings

Healthy lives & communities

Clean economy

Contents

Key themes

- With challenge comes opportunity
- Equity
- We all have a role to play
- Co-benefits

Climate equity

Some Minnesotans are at greater risk from climate change

- People of color
- Indigenous people
- Older adults
- People with disabilities and chronic illnesses
- Children
- People in rural areas
- People who are socially and economically disadvantaged
- Pregnant persons
- Future generations

We must address equity alongside climate change

2022 Climate Package Investments

MDA	Healthy Soils (**w/BWSR**) - $38M	Forever Green - $3M					
COMM	Weatherization - $58.5M	Decarb. Technology Fund - $35M	Green Bank - $34M	Solar on Schools - $3M	Competitiveness Fund - $20M	Wastewater and Drinking Water Efficiency and Resiliency - $18M	GRID - $15M
DEED	Clean Tech Workforce Training - $8M	EV and EV Charging Grants - $20M	Energy Transition Grants - $2.5M				
MDH	Climate Resiliency - $4M						
Met Council	Electric Buses - $3.2M	Mapping Climate Risks and Opportunities - $5M					
DNR	Climate Adaptation for Natural Lands and Water - $42M	Forest Management Assistance - $5.5M	Public Lands Acquisition - $24M	Restoring Grasslands and Wetlands on WMAs - $10M			
MPCA	Adaptation Action Grants and Water Storage (**w/BWSR**) - $70M	Waste Prevention and Recycling Grants and Loans - $18.9M	Pollution Prevention Loans at Small Biz - $2M				
MnDOT	Maximize Federal Transportation Climate Funding - $6M						
EQB	Technical Assistance for Env. Review - $600K						

- *24 proposals totaling $446 million in FY22-25*

Additional Climate Proposals

- $23.3 million climate-smart drought package
- $280 million for multimodal transportation in FY22-23 (MnDOT)
- $200 million for Blue Line light rail in FY22-23 (Met. Council)

Federal Opportunities

- Agencies are also tracking proposals across the enterprise to identify and leverage the historic federal funds from the Infrastructure Investment and Jobs Act (IIJA):
- Matching funds will be needed
- Justice40

Sustainability in the American Steel Industry

Kevin Dempsey

President and CEO, American Iron and Steel Institute

Sustainability in the American Steel Industry

Kevin M. Dempsey

President and CEO, American Iron and Steel Institute

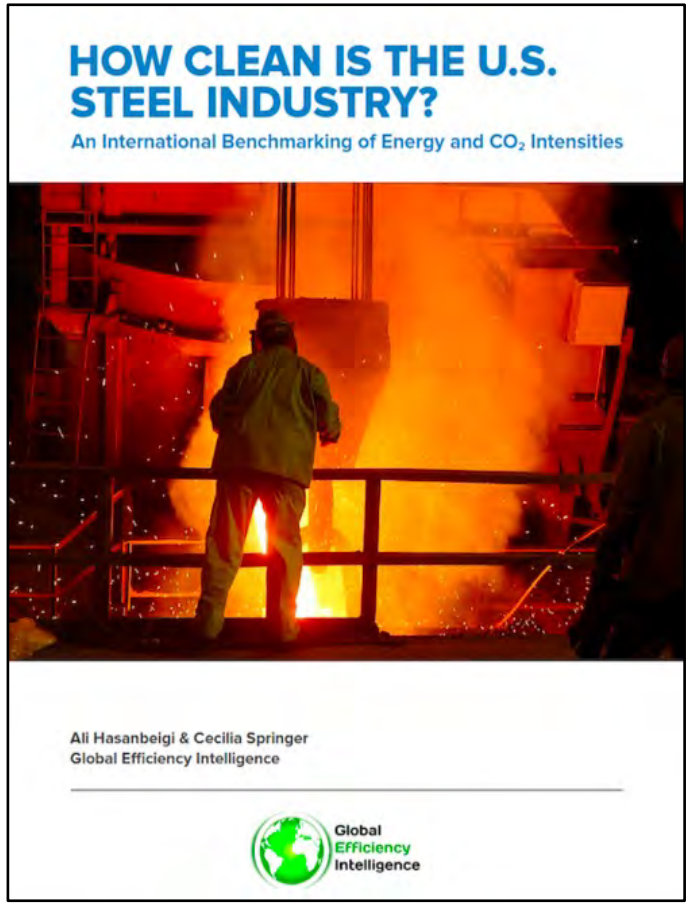
Minnesota Iron Ore & Green Economy Forum

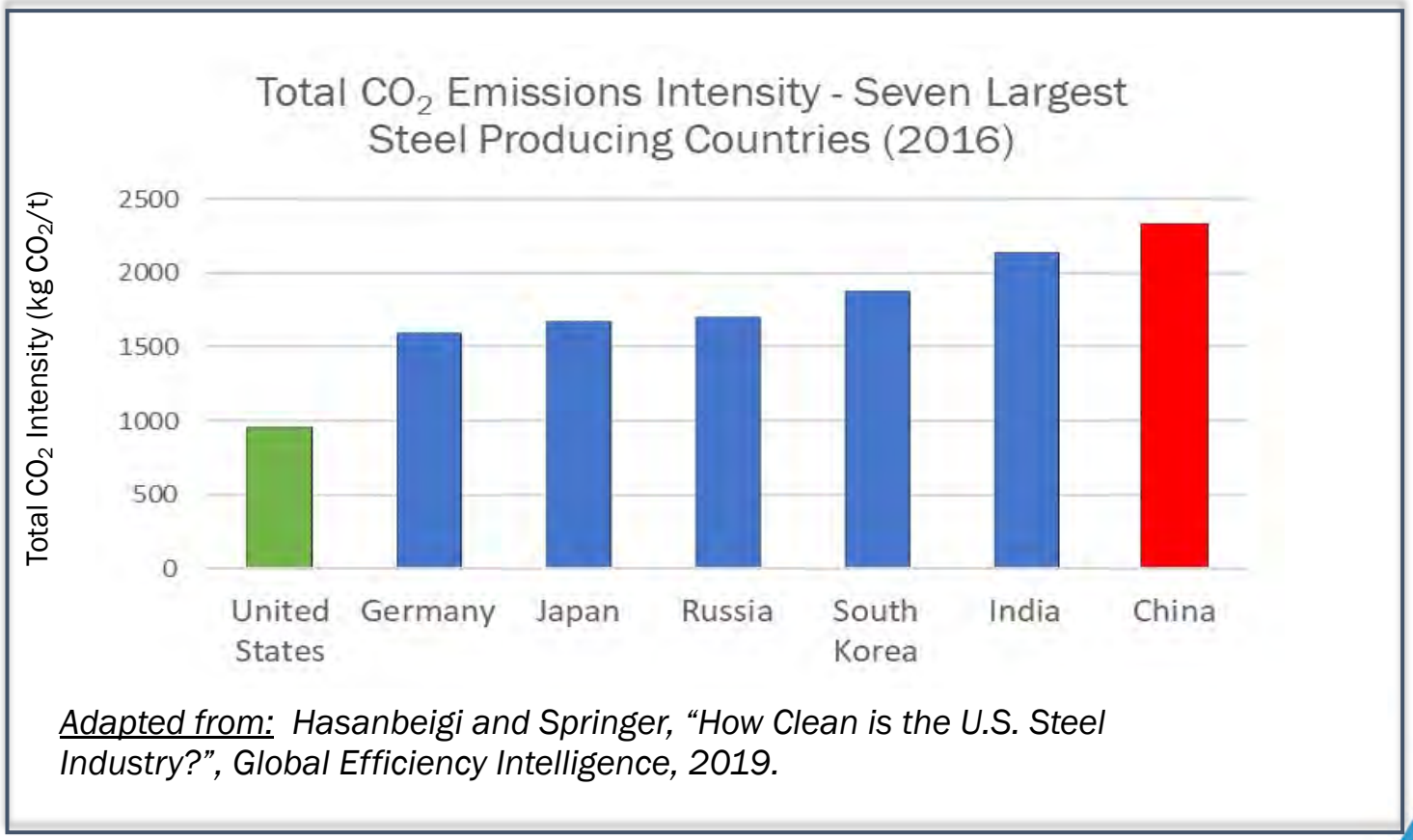
March 16, 2022

Overview: American Steel Industry

- Cleanest and most energy efficient of the major steel industries in the world
- Essential to the U.S. decarbonization strategy, national and economic security, and critical infrastructure
- Supports nearly two million American jobs

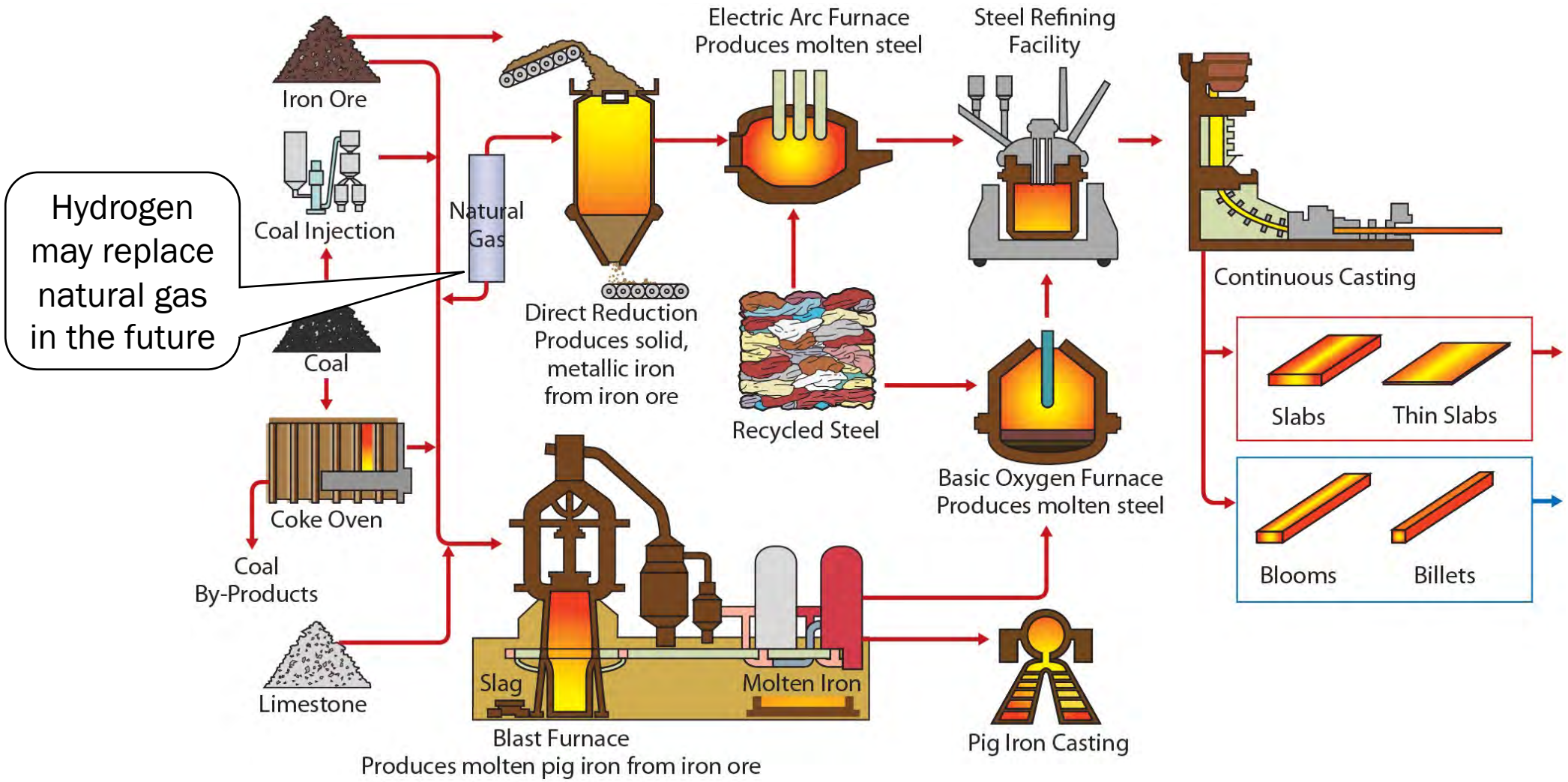
Sustainable American Steel



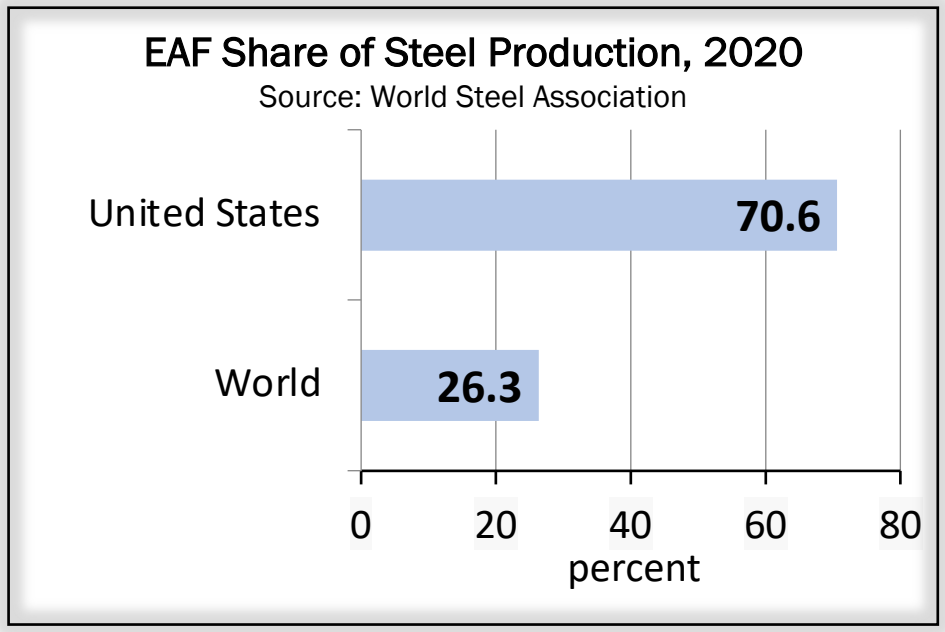


Adapted from: Hasanbeigi and Springer, "How Clean is the U.S. Steel Industry?", Global Efficiency Intelligence, 2019.

Raw Materials Essential to Steelmaking



Sustainable American Steel



- Integrated mills use pelletized iron instead of the more carbon-intensive sintered iron typically used in China and elsewhere
- Significantly greater use of natural gas as an energy source for steel production
- In addition, 60 to 80 million tons of steel scrap is recycled each year into new steel products
- Larger share of electric arc furnace (EAF) production than other regions
- Cleaner electricity grid

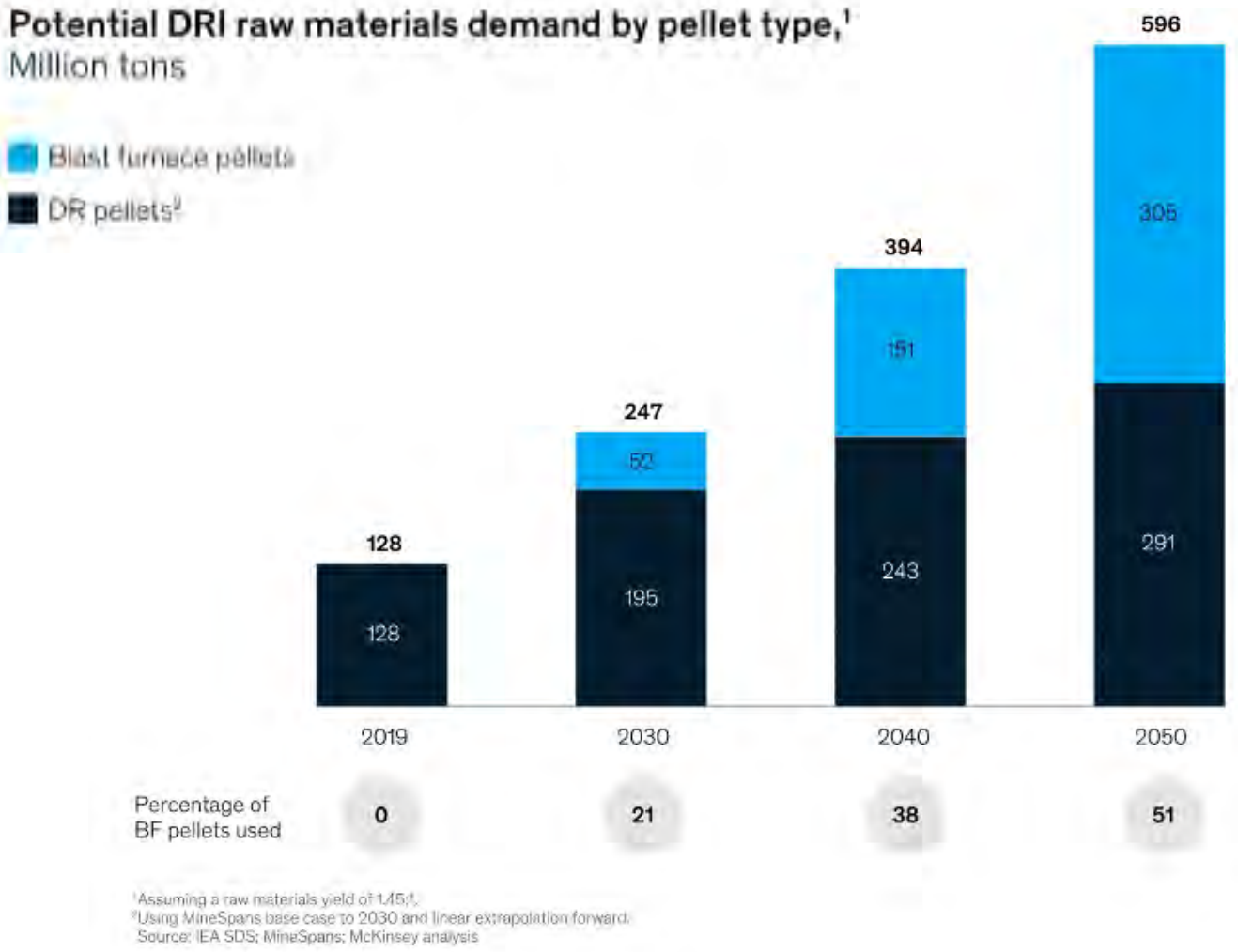
Continuing Efforts To Enhance Sustainability

- Work is also underway on projects to further enhance the sustainability of domestic steelmaking:
  - Advancements in the use of Direct Reduced Iron (DRI) and Hot Briquetted Iron (HBI) in place of coal-based pig iron in both integrated and EAF steelmaking
  - Using renewable energy-based hydrogen as a reduction agent in DRI/HBI production
  - Carbon capture and storage/use
  - Increased use of renewable energy in steel industry facilities

Examples of Industry Leading the Way

A Look Ahead at Iron Ore Demand for DRI

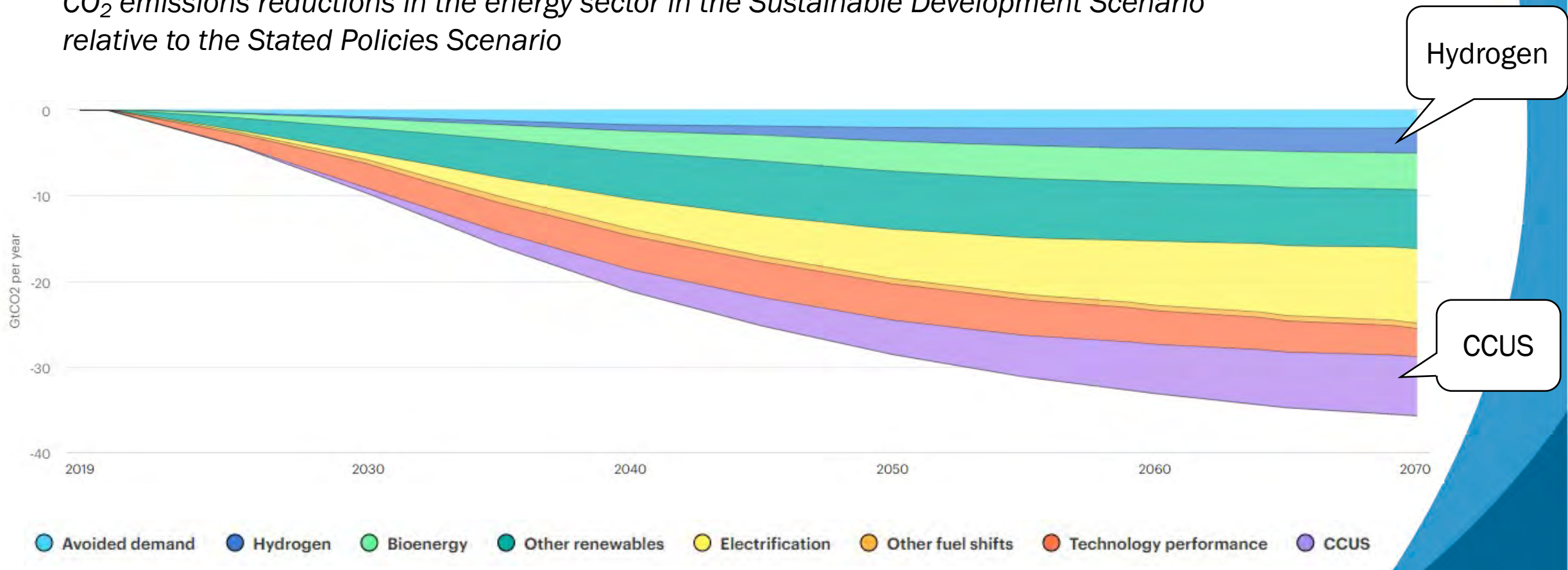
According to McKinsey & Company (July 2021), increasing amounts of BF-grade iron ore could be used to make DRI in the future



https://www.mckinsey.com/industries/metals-and-mining/our-insights/the-dri-dilemma-could-raw-material-shortages-hinder-the-steel-industrys-green-transition

The Role of CCUS and Hydrogen

CO_2 emissions reductions in the energy sector in the Sustainable Development Scenario relative to the Stated Policies Scenario

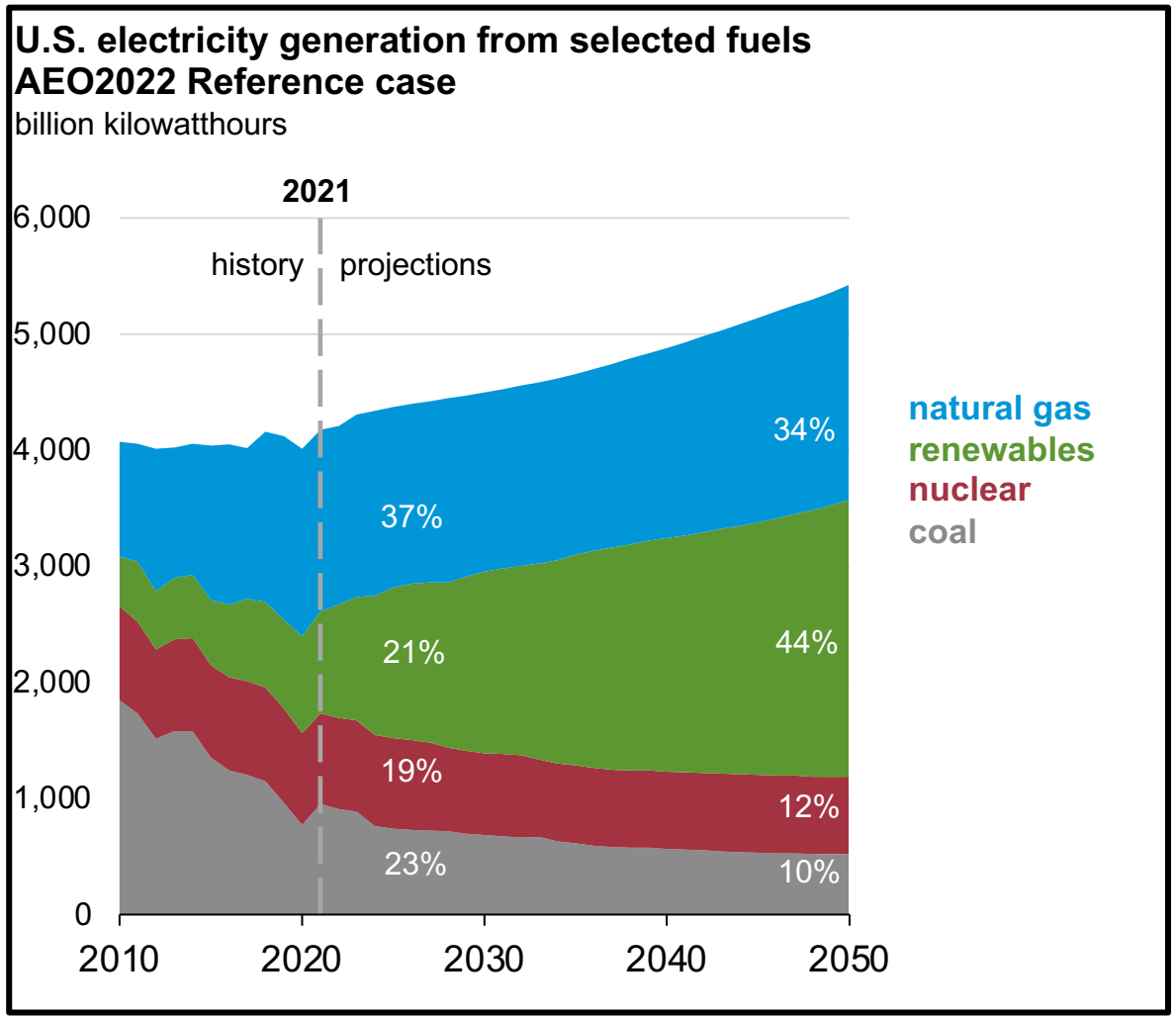


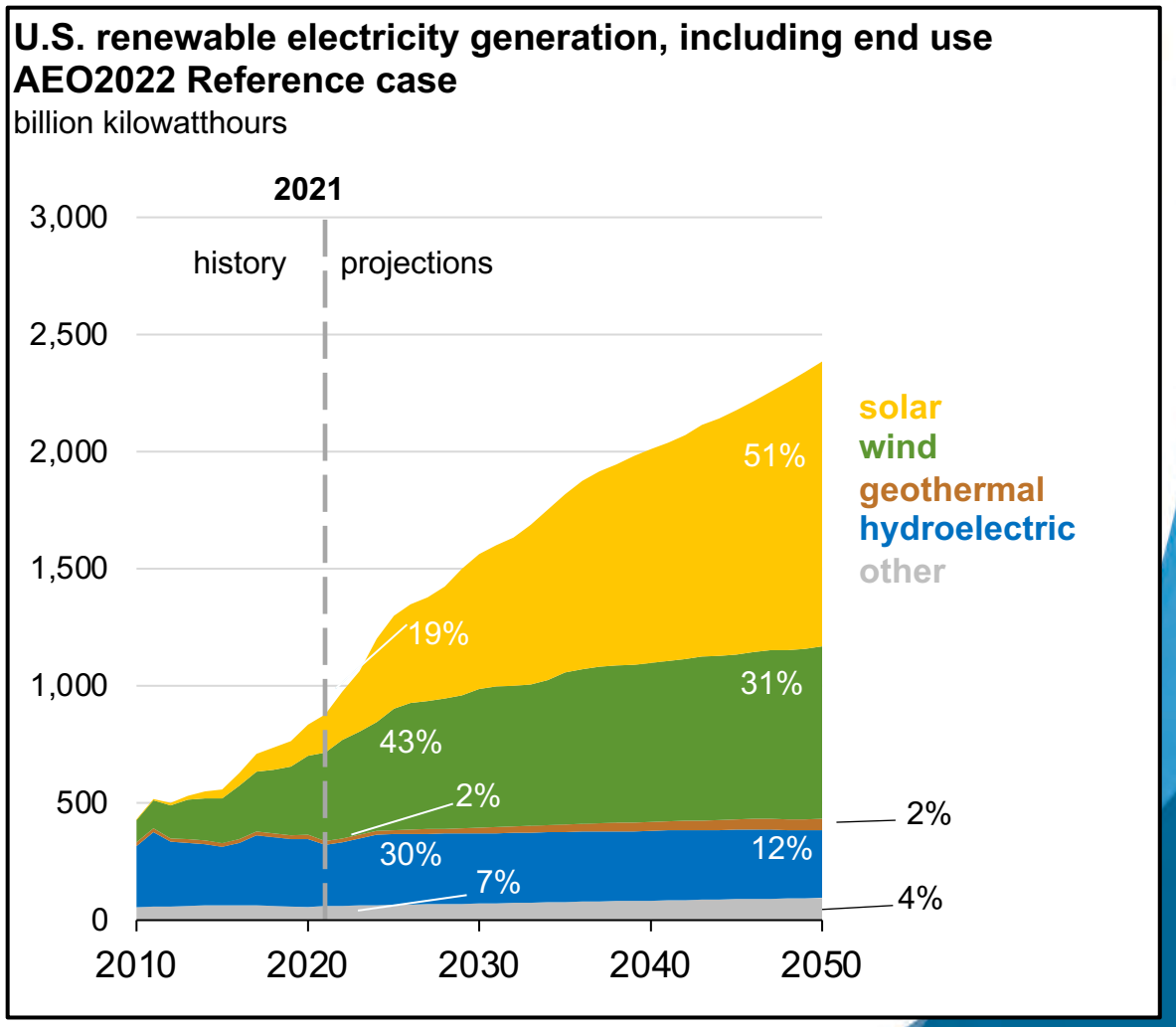
IEA, 2020, CCUS in the transition to net-zero emissions https://www.iea.org/reports/ccus-in-clean-energy-transitions/ccus-in-the-transition-to-net-zero-emissions

Opportunities & Challenges

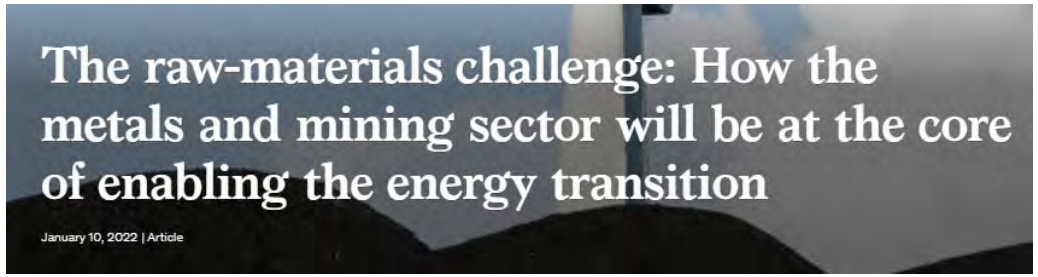
- Proposals for greening the U.S. economy involve major investments in clean energy, infrastructure and upgrading the electric grid – all of which require steel
  - Steel is an enabler of renewable energy technologies
  - Carbon capture systems and pipelines are steel-intensive
  - Significant infrastructure investment in the coming years
- Steel customers increasingly focused on embedded impacts of materials, particularly in construction and automotive applications
- Imported steel – often with higher embedded carbon emissions – and global excess capacity threatens health of the domestic industry

U.S. Electricity Generation and Shares from Selected Fuels and Renewable Sources

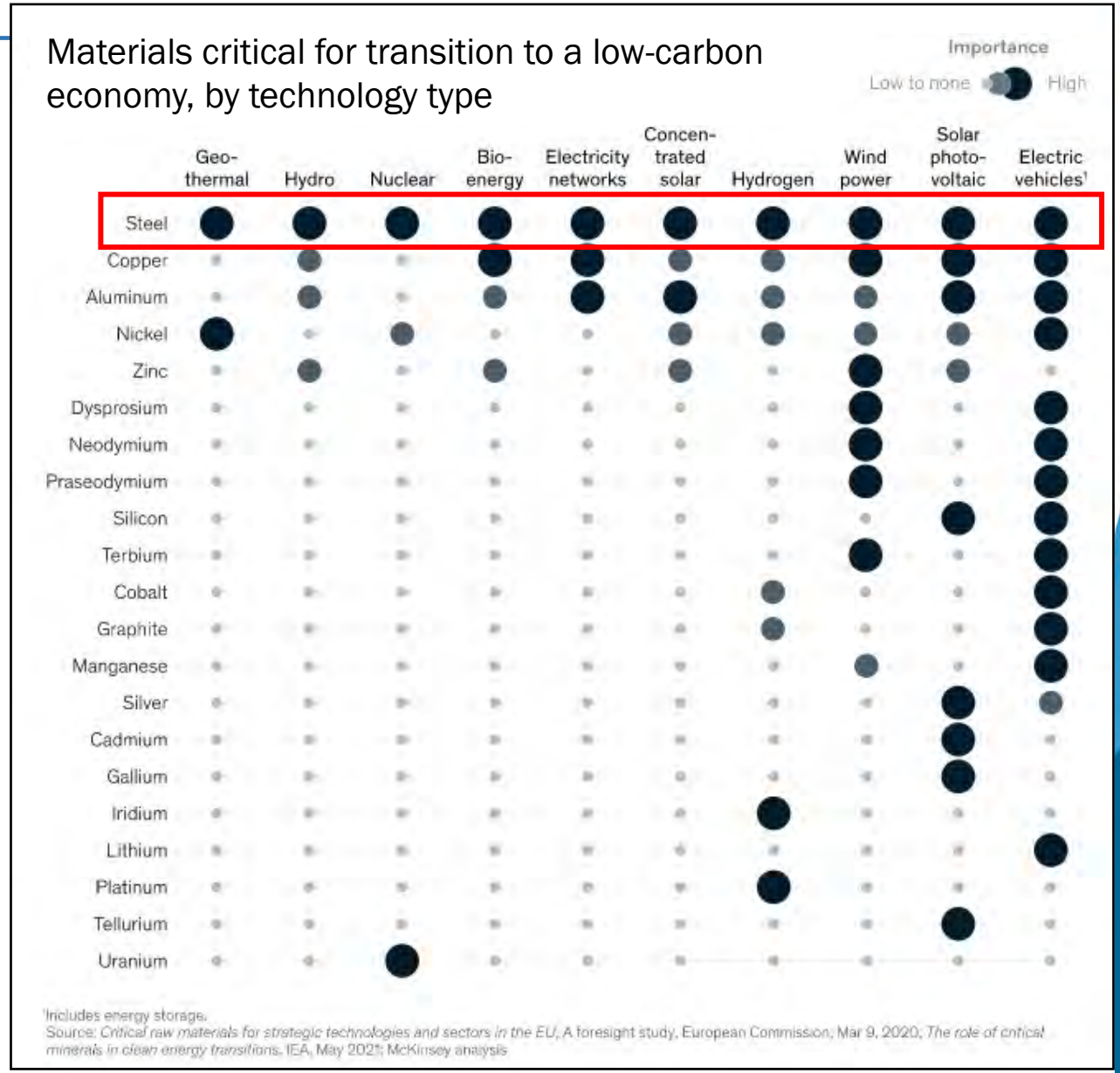




Steel is Vital to Sustainable Energy Technologies



- McKinsey & Company: *"The transition to a net-zero economy will be metal-intensive."*
- Steel is the only material critical to all low-carbon technologies

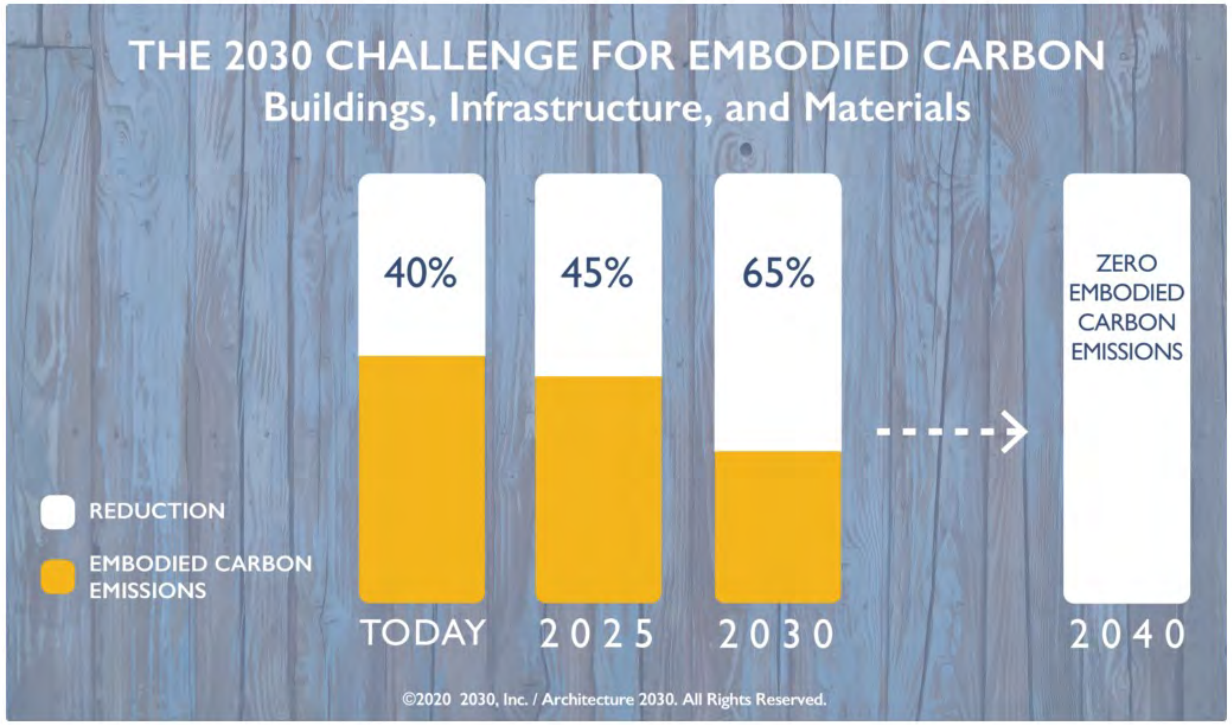


https://www.mckinsey.com/industries/metals-and-mining/our-insights/the-raw-materials-challenge-how-the-metals-and-mining-sector-will-be-at-the-core-of-enabling-the-energy-transition

Steel End-Markets Aiming to Reduce Emissions

SEI STRUCTURAL ENGINEERING INSTITUTE ASCE | SE2050 COMMITTING TO NET ZERO

AIA 2030 Commitment



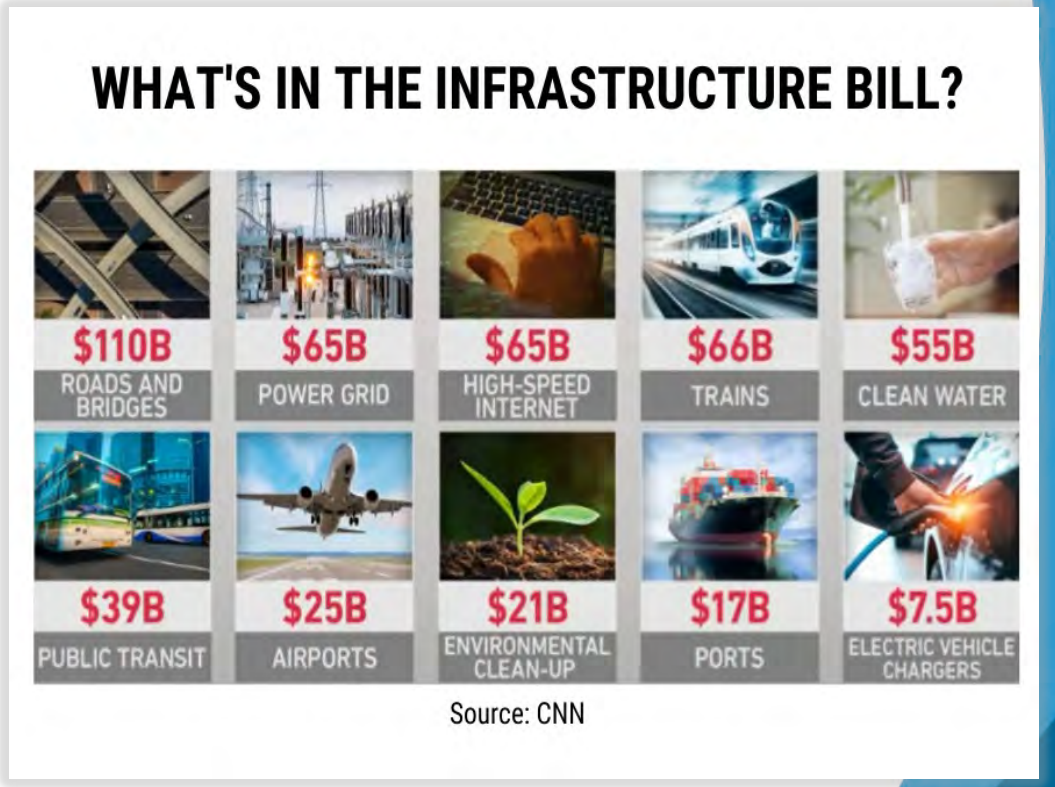
From: NCSEA presentation May 2021 "Sustainable Design & Embodied Carbon: What Structural Engineers Need to Know"

Government Buy Clean and Other Initiatives

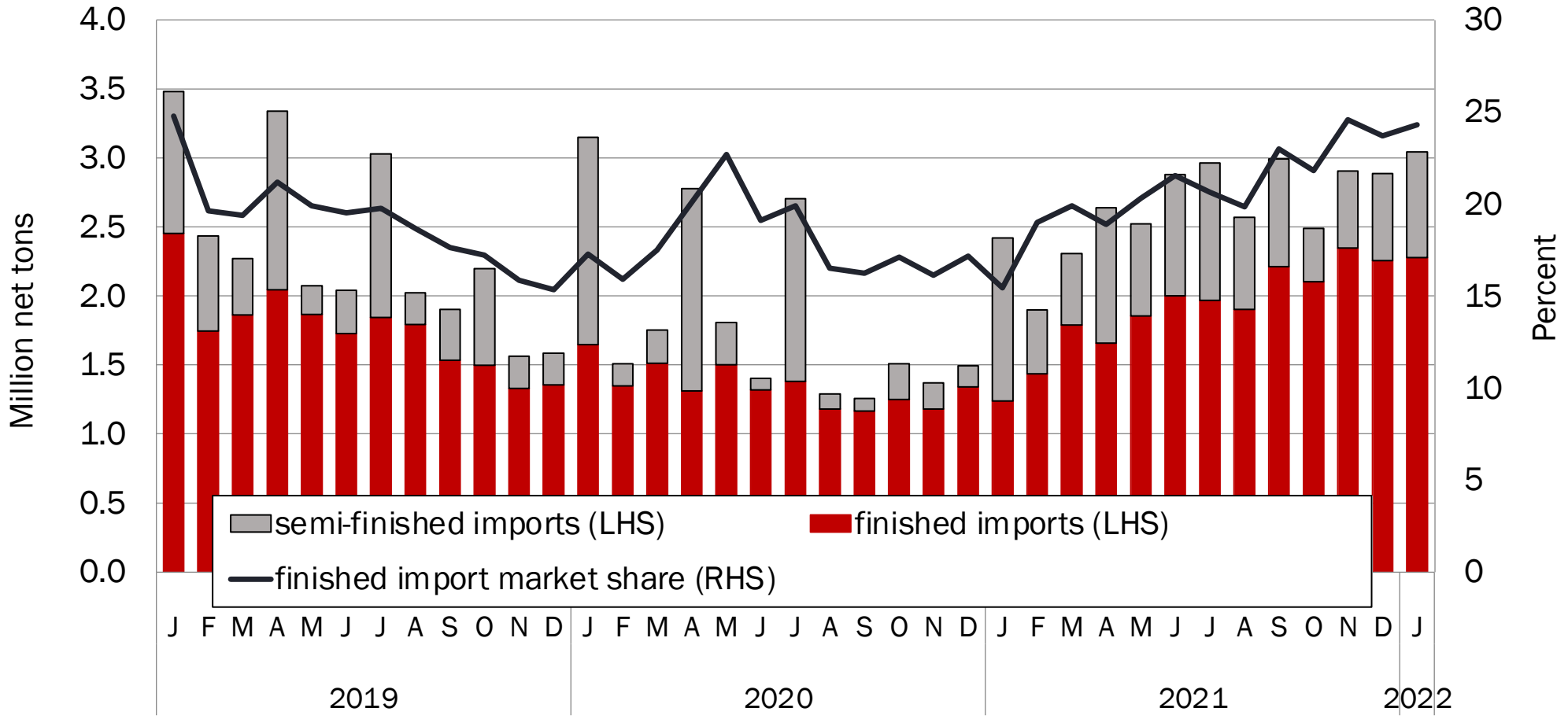
- Buy Clean California Act, October 2017, established embodied GHG emissions thresholds for select materials used in public buildings
- Buy Clean Colorado Act, July 2021, requires policies by 2024
- Other states considering Buy Clean legislation include Washington, Oregon, Texas, Minnesota, New York, and New Jersey
- Executive Order "Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability," December 2021:
  - Federal Buy Clean policy
  - Net-zero emissions for federal vehicles and buildings
  - Climate-resilient infrastructure

Bipartisan Infrastructure Law Increasing Demand

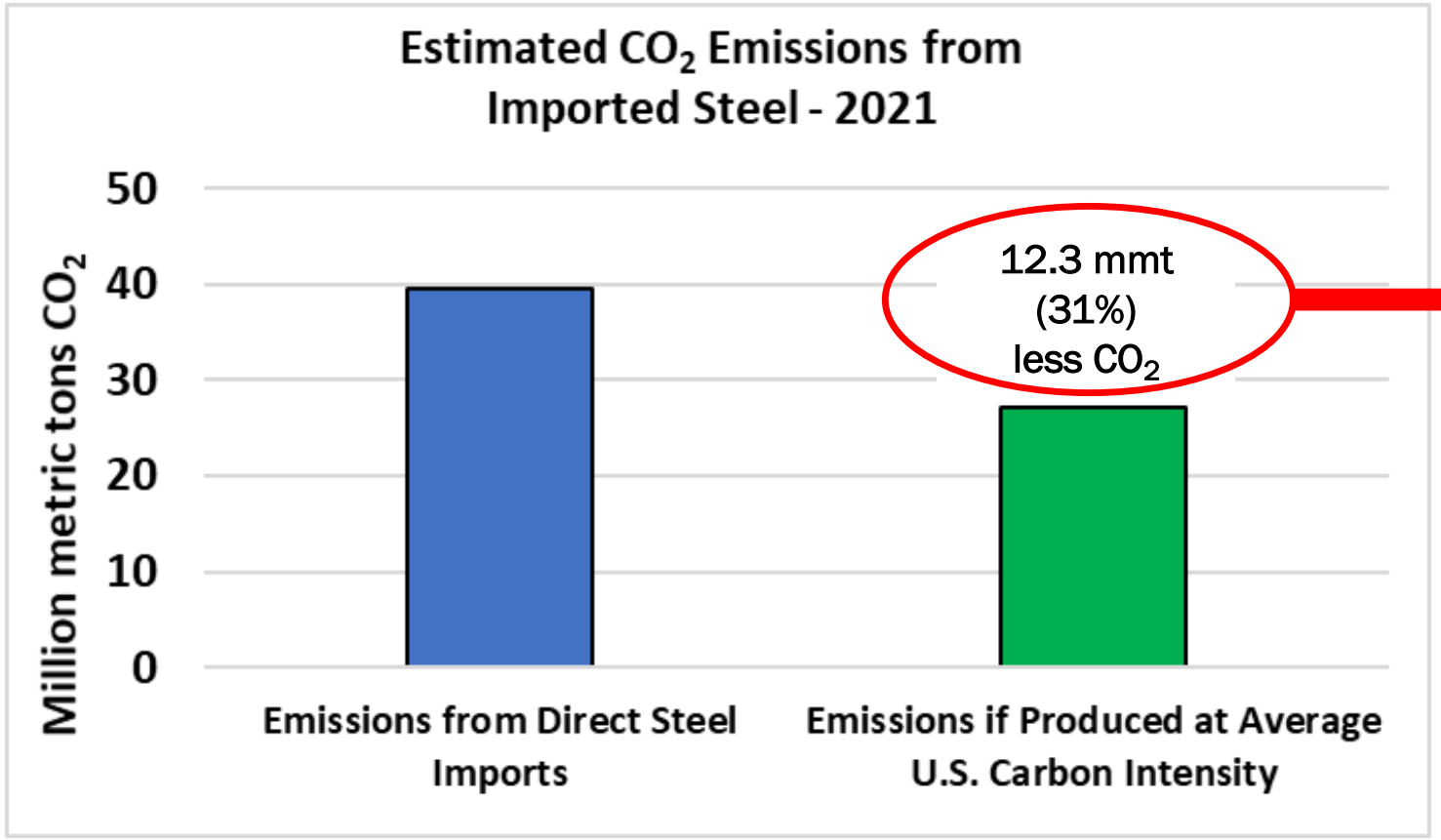
- More than $1 trillion investment
- Modernizes roads and bridges, ports and waterways, water infrastructure, the electric grid, and electric vehicle systems
- $479 million toward construction of the new Soo Lock in MI, through which nearly all of the iron ore mined in the U.S. passes
- Focus on using American-made products, including American-made steel
- Building of more resilient infrastructure to combat the climate crisis, which uses steel



Steel Imports Are on the Rise Again



Imported Steel Equals Increased Emissions



Equivalent to the CO_2 emissions from:

- 2.7 million passenger vehicles driven for one year
- 1.5 million homes' energy use for one year

Sources: AISI analysis of data from U.S. Census Bureau and Hasanbeigi and Springer, "How Clean is the U.S. Steel Industry?", Global Efficiency Intelligence, 2019; EPA GHG Equivalencies Calculator, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Addressing Carbon-Intensity in Steel Trade

U.S.-EU agreement to negotiate new global sustainable steel arrangement

- To discourage trade in high carbon–intensive steel and address global non-market excess capacity
- Will develop methodology for assessing embedded emissions in steel
- Ultimate goal is to develop new carbon border adjustment measure against dirtier imported steel

Summary

- The American steel industry leads the world in terms of low carbon intensity steel production
  - Domestically supplied iron ore is critical to our success
- The American steel industry continues reducing greenhouse gas intensity in response to numerous drivers
  - Steel is essential to clean energy and the greening of our economy
  - Continued innovation in iron reduction, abundant clean energy, and commercially viable CCUS are key to further decarbonization
- Dumping of cheap but dirtier imported steel remains a threat to the American industry and to the greening of our economy

Thank You / For More Information

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Steel in a Greener World

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Head of Consulting, CRU

Jim Kochevar

Cleveland-Cliffs, Inc. Vice President, Iron Ore Operations

Rich Fruehauf

US Steel Senior Vice President, Chief Strategy & Sustainability Officer

Kurt Anderson

Minnesota Power Director, Environmental and Land Management

Company Climate Strategies

Cleveland-Cliffs, Inc.: Climate Commitment Plan

Jim Kochevar

Vice President, Iron Ore Operations

Cleveland-Cliffs Inc.

MN Iron Ore & the Green Economy

MARCH 16, 2022

Jim Kochevar
Vice President, Iron Ore Operations

CLEVELAND-CLIFFS CORE VALUES

SAFE PRODUCTION

ENVIRONMENTAL STEWARDSHIP

ETHICAL BEHAVIOR

CUSTOMER FOCUS

CREATING ECONOMIC VALUE

GROUP AND INDIVIDUAL ACCOUNTABILITY

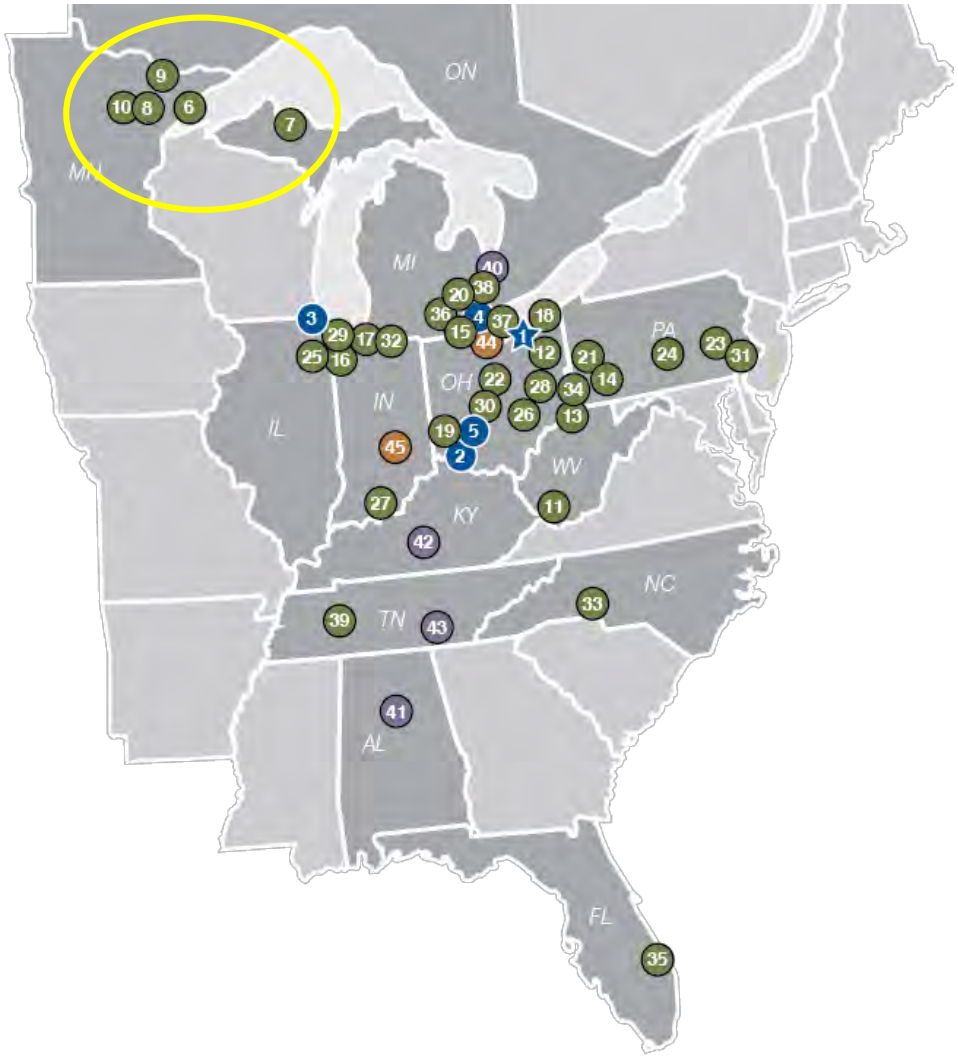
TRUST, RESPECT AND OPEN COMMUNICATION

BIAS FOR ACTION

TEAMWORK

RECOGNIZE AND REWARD ACHIEVEMENT

CLEVELAND-CLIFFS: COMPANY OFFICES AND OPERATIONS



Company Offices

1. Cleveland-Cliffs Headquarters
2. Regional Office – West Chester
3. Regional Office – Chicago
4. Detroit Office -- FPT
5. Research & Innovation Center

Steelmaking

6. Northshore Mining Company
7. Tilden Mine
8. United Taconite
9. Minorca Mine
10. Hibbing Taconite Company
11. Princeton Coal
12. Warren
13. Mountain State Carbon
14. Monessen Coke
15. Toledo Direct Reduction Plant
16. Indiana Harbor
17. Burns Harbor
18. Cleveland Works
19. Middletown Works
20. Dearborn Works
21. Butler Works
22. Mansfield Works
23. Coatesville
24. Steelton
25. Riverdale
26. Zanesville Works
27. Rockport Works
28. Coshocton Works
29. Burns Harbor Plate & Gary Plate
30. Columbus, OH
31. Conshohocken
32. Tek & Kote
33. Piedmont
34. Weirton
35. FPT – Florida Locations
36. FPT – Michigan Locations
37. FPT – Ohio Locations
38. FPT – Ontario Location
39. FPT – Tennessee Locations

Tooling and Stamping

40. Windsor & Ontario
41. Sylacauga
42. Bowling Green
43. Cleveland, TN

Tubular

44. Walbridge
45. Columbus, IN

DIFFERENTIATED, FULLY-INTEGRATED BUSINESS MODEL

- Vertically integrated ferrous raw materials provides for supply chain transparency

Pellets | **HBI** | **Prime Scrap**



- Annual shipments of Approximately 16 million tons

Steel Making & Rolling



- Industry leading automotive market share

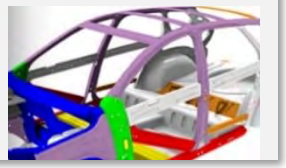
Finishing & Coating



- Innovative and diverse downstream capabilities

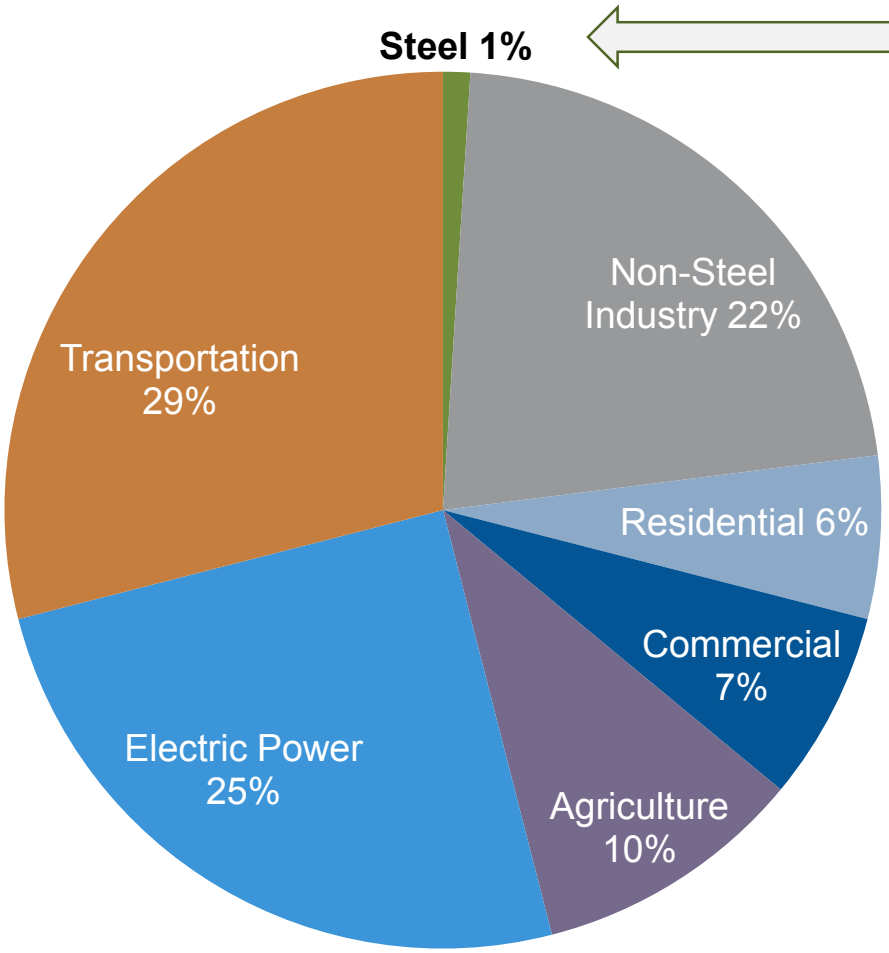
Downstream





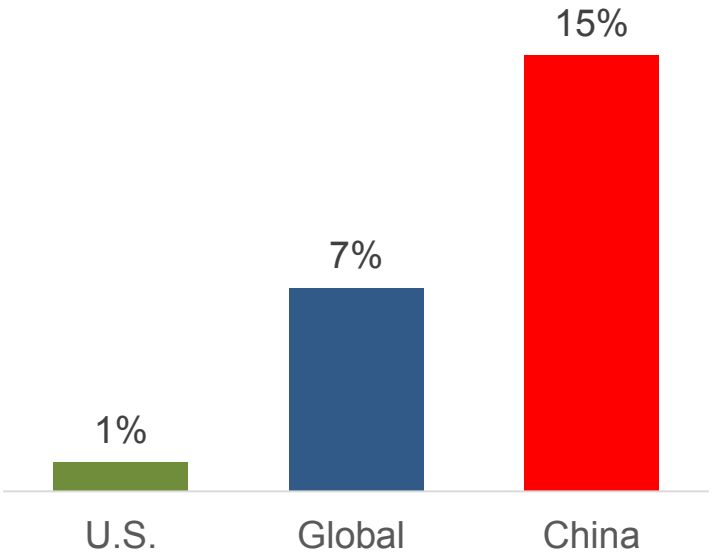
UNITED STATES GREENHOUSE GAS EMISSIONS BY ECONOMIC SECTOR

U.S. GHG Emissions Share



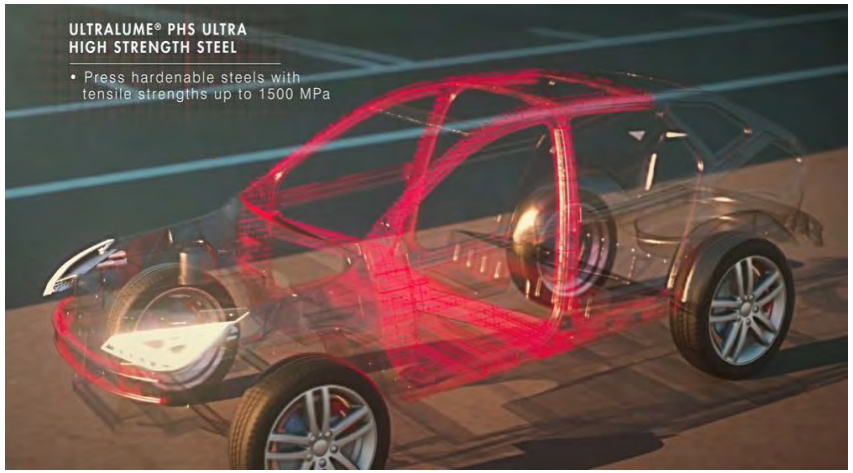
- Domestic steel industry accounts for 1% of total U.S. emissions
- Global average: 7% of total global emissions

Steel Emissions Share



Source: U.S. Environmental Protection Agency (2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019

STEEL FOR THE VEHICLE OF TOMORROW



Leadership position in exposed and lightweight materials has created a strong appetite for the use of Cliffs' steel in new electric vehicle models

CLIFFS' FERROUS RAW MATERIAL PORTFOLIO

Pellets

- 27 million gross tons throughout 5 owned and operated mines in Minnesota and Michigan
- 85% less CO_2 intense than sinter
- Standard, Flux, and DR-grade qualities

HBI

- 1.9 million metric tons of annual capacity
- Used in Blast Furnaces to improve energy efficiency; can be used in Basic Oxygen Furnaces/Electric Arc Furnaces to enhance productivity and quality of finished product
- Flexibility to use hydrogen at Toledo when available

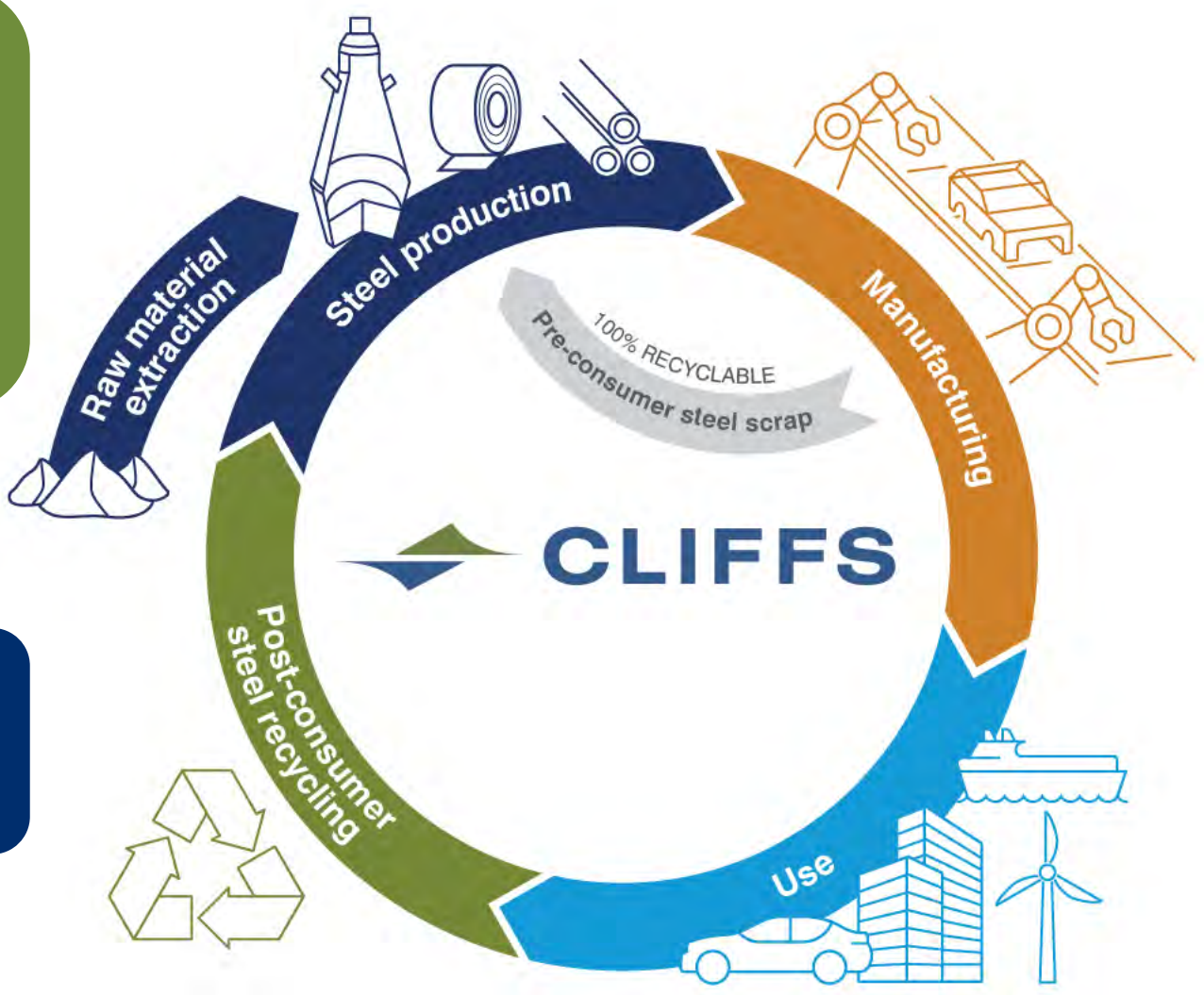
Prime Scrap

- Acquired FPT, immediately secured substantial access to prime scrap
- Several existing scrap offtake arrangements with auto Original Equipment Manufacturers

CLOSED-LOOP STEEL RECYCLING

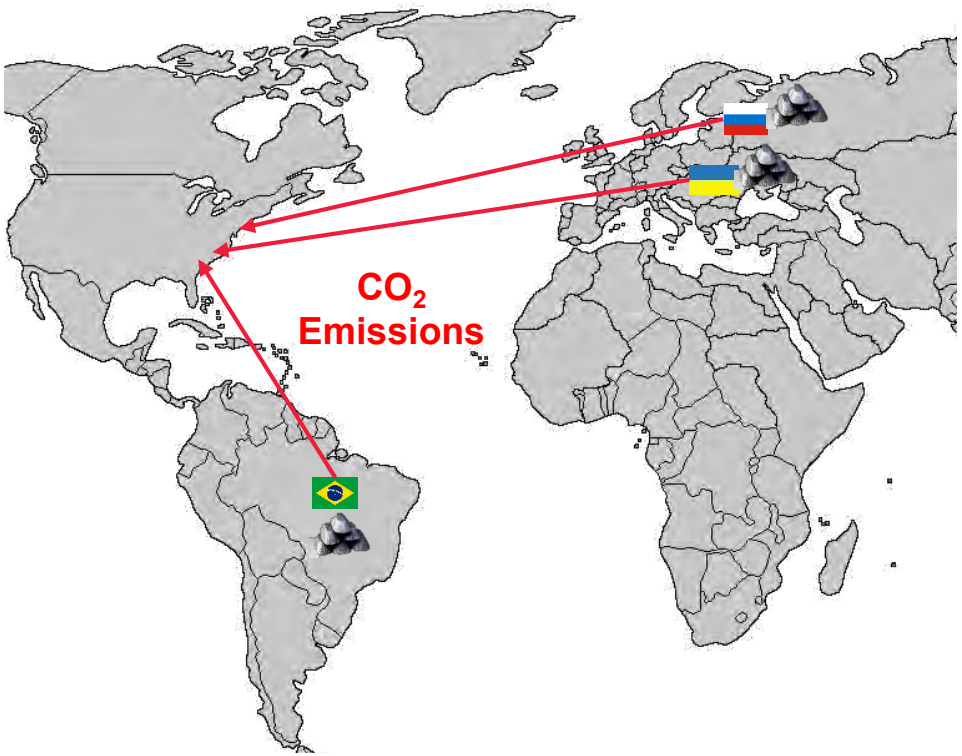
Cliffs' position as the most prominent automotive steel supplier in the U.S. provides a compelling scrap offtake proposition for the OEM

100% of our steel contains recycled steel scrap



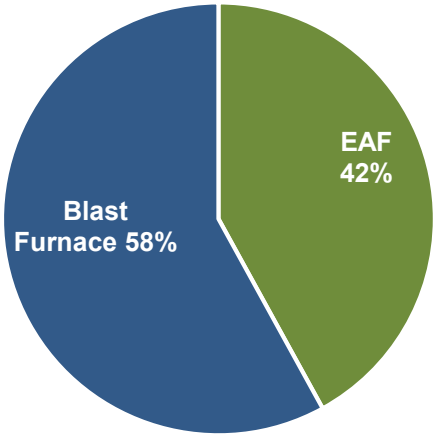
PIG IRON IMPORTS & SCARCE PRIME SCRAP SUPPLY

Flat-rolled mini-mills outsource CO_2 emissions



Imported pig iron and transport is significantly more CO_2 intensive than US blast furnace steel

2020 US Flat-Rolled Steel Production Share



Flat-rolled EAFs are dependent on:

Prime Scrap

Pig iron/ DRI/HBI

Cliffs' advantages:

FPT Acquisition

100%-owned HBI produced in Ohio

Source: Worldsteel

ENVIRONMENTAL AND SUSTAINABILITY COMMITMENTS

Emissions Reductions Targets

Reduce absolute Scope 1 and 2 GHG emissions 25% by 2030

Low CO_2 Intensity Blast Furnaces

Scope 1 and 2 emissions as low as 0.95/ton of steel produced

100% Natural Gas Based HBI

1.9 million metric tons of annual HBI capacity reduced with 100% natural gas

New Scrap Recycling Presence

FPT is the leading recycler of prime ferrous scrap in North America

Technical Capabilities for EV Expansion

Advanced High Strength Steels for lightweight EV bodies and electrical steel for EV motor and charging

Industry High Employee Pay

2021 median employee compensation of $125,000, well above industry average

NATURAL GAS BASED HBI

Production Capacity	1.9 million metric tons

Hot Briquetted Iron

- **Cliffs' Blast Furnaces**
- **Cliffs' EAFs**
- **Cliffs' BOFs**

EMISSIONS REDUCTION

- Reduced with 100% natural gas
- 70% less CO_2 emissions than foreign pig iron
- Can use Hydrogen when commercially available
- HBI used in our blast furnaces improves energy efficiency and reduces amount of coke required when producing iron and steel
- HBI can stretch our hot metal production, lowering carbon intensity, reliance on coke and reducing our CO_2 emissions

DISCLOSING OUR COMMITMENTS & PROGRESS

Cliffs is committed to annual reporting aligned to:

- Global Reporting Initiative (GRI) Standards
- Sustainability Accounting Standards Board (SASB) Standards for Iron & Steel Producers and Metals & Mining

Cliffs is committed to multi-stakeholder engagement & monitoring frameworks:

- Submitted GHG & climate-related information to CDP, a not-for-profit charity that runs a global disclosure system
  - Earned a “B” score for our Climate Change response in 2021, best amongst US steel producers
- Responded to EcoVadis supplier sustainability survey for first time in 2021, earning silver medal for sustainability performance

“B” for Climate Change response

PROGRESS THROUGH KEY PARTNERSHIPS

U.S. Department of Energy

- **Better Plants Program:** Goal of 10% reduction in energy intensity over 10 years companywide
- **Better Climate Challenge:** Goal of 25% reduction in GHG emissions over 10 years companywide

U.S. Environmental Protection Agency – ENERGY STAR Partner

Science Based Targets initiative (SBTi) – Expert Advisory Group (EAG) member

- Through the EAG, Cliffs is contributing to the development of SBT methodologies for the steel sector. The EAG has an advisory role, and decisions on final methodologies will be made by SBTi founders: CDP, UNGC, WRI and World Wide Fund for Nature.

Wildlife Habitat Council Member

- WHC empowers companies to advance biodiversity, sustainability & employee engagement

Better Plants® U.S. DEPARTMENT OF ENERGY

Better Climate CHALLENGE U.S. DEPARTMENT OF ENERGY | PARTNER

energy ENERGY STAR PARTNER

Burns Harbor, IN

CONSERVATION CERTIFICATION WILDLIFE HABITAT COUNCIL WHC Certified

CARBON CAPTURE AND RESOURCE EFFICIENCY

Burns Harbor/DOE Engineering Study of Carbon Capture and Sequestration from Raw Blast Furnace Gas

- Aim to capture ~2M metric tons CO_2 emissions per year from available blast furnace gas at our onsite integrated steelmaking facility

Industrial Technology Validation (ITV)

- In July 2021, the DOE selected five private-sector partners (who are also part of the DOE's Better Plants program) to receive technical assistance to test clean, efficient technologies in real-world industrial environments. At our Cleveland Works facility, we are piloting two water treatment technologies (electro-coagulation systems) in partnership with the DOE and a water technology firm.

Powerhouse Projects – Blast Furnace Off Gas Recycle

- Burns Harbor: Re-use of byproduct fuels from coke ovens and blast furnaces for producing steam and cogenerating on average 140 MWhs of electricity per hour
- Cleveland Works: implementing powerhouse upgrades, including new steam turbine generator to consume additional blast furnace gas to generate 76 MWhs of power per hour

Cleveland-Cliffs Burns Harbor steel operation

ALTERNATIVE FUELS & RENEWABLE ENERGY

HYDROGEN

- Working with private and academic partners to build our H2 knowledge for applications in the steel industry; identifying opportunities and challenges
- “Green” hydrogen is a long-term option; not commercially viable in sufficient quantities for large industrial applications; however, we are investigating potential hydrogen usage
- While our Toledo facility currently reforms natural gas to produce HBI, the facility was designed with H2 in mind; evaluating feasibility of sufficient H2 supply and implementation as fuel replacement

RENEWABLE ENERGY

- Joined Michigan's green pricing program to support growth of renewable power.
- **Cliffs committed to purchase solar power for Dearborn, Michigan integrated mill, to supply 35% of its energy needs starting in 2024 and beyond**
- **Targeting to purchase 2M MWh of renewable energy annually**
  - Would represent ~20% of our purchased electricity for 2021
  - Would rank Cliffs among the largest purchasers of renewable power in the U.S.

SOCIAL SUSTAINABILITY

- **Health & Safety:** Refreshed Safety Policy implemented at every site with full support of executive leadership; company-wide COVID-19 vaccination incentive program developed in partnership with USW, UAW, IAMAW – achieved 75% vaccination rate with a $45 million incentive payout to vaccinated employees.
- **Labor Relations:** 70% of Cliffs' workforce is represented by a union; recipient of Forbes' Best Employers for Veterans 2021
- **Stakeholder Engagement:** Community Relations Representatives in all major operational hubs; accessible channels for receiving and responding to community inquiries; positive and transparent relationships with key stakeholder groups across our footprint
- **Charitable Contributions:** $6.5 million donated to local communities and organizations by the Company and through The Cleveland-Cliffs Foundation, including key partnership with National Fish and Wildlife Foundation that primarily supports sustainability of Great Lakes region.
- **Value Chain Management:** Conflict Minerals and Human Rights policies; $390 million spent with diverse suppliers in 2021

SUSTAINABILITY IN MINNESOTA

Mineland Vision Partnership

- Cliffs is a proud sponsor, as well as participant in meetings and projects relative to our own mining operations such as landscape and reclamation activities of stockpiles on our properties.

Trout Unlimited

- Cliffs is a proud partner; through The Cleveland-Cliffs Foundation, we helped fund a project that provided land access near the Cliffs Erie Railroad (north of our Northshore Mining Operations) to replace a culvert and improve habitat connectivity and trout populations in Fredenberg Creek.

Laurentian Chamber of Commerce

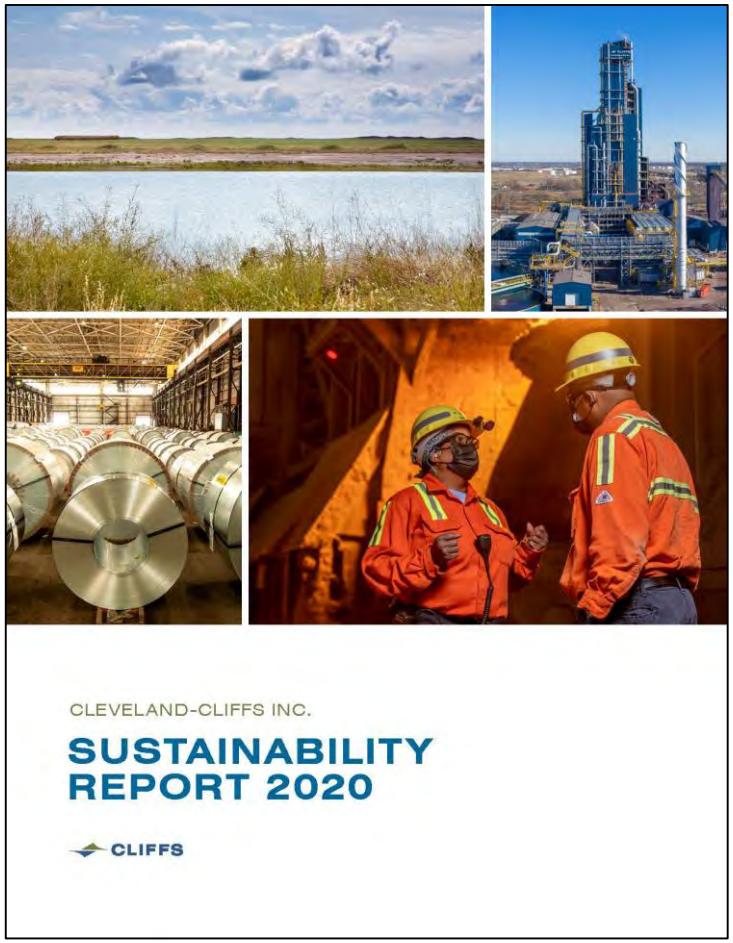
- Cliffs is actively engaged in Minnesota, and CEO Lourenco Goncalves delivered the keynote address at the Laurentian Chamber's Annual Dinner in October.

Community Contributions

- $500,000 annual charitable giving in Minnesota

SUSTAINABILITY REPORTING

Learn more about our sustainability initiatives at clevelandcliffs.com/sustainability




CLIFFS

US Steel:
Best for All

Rich Fruehauf

Senior Vice President,
Chief Strategy &
Sustainability Officer

U. S. Steel Low Carbon Future Overview

Minnesota Iron and the Green Economy

Richard L. Fruehauf, SVP, Chief strategy and Sustainability Officer

March 16, 2022

U. S. Steel “Best for All”




CURRENT LANDSCAPE

USS is committed to developing and maintaining its sustainability strategy

USS is committed to public sustainability disclosures - environmental, social, and governance (ESG).

CHALLENGES WE FACE

USS is required to decarbonize across the global footprint.

USS is required to publicly disclose our sustainability progress and risk analysis

SOLUTION

The Best for All process route of integrated to mini-mill has a positive impact on GHG performance.

USS has announced reduction goals for GHG emissions intensity by 2030 and achieve net-zero by 2050.

PATH FORWARD

Developing and EXECUTING a short and a long-term strategy to decarbonize and improve overall ESG performance.

Continued public reporting of ESG matters and performance

USS will achieve decarbonization of its operations and products

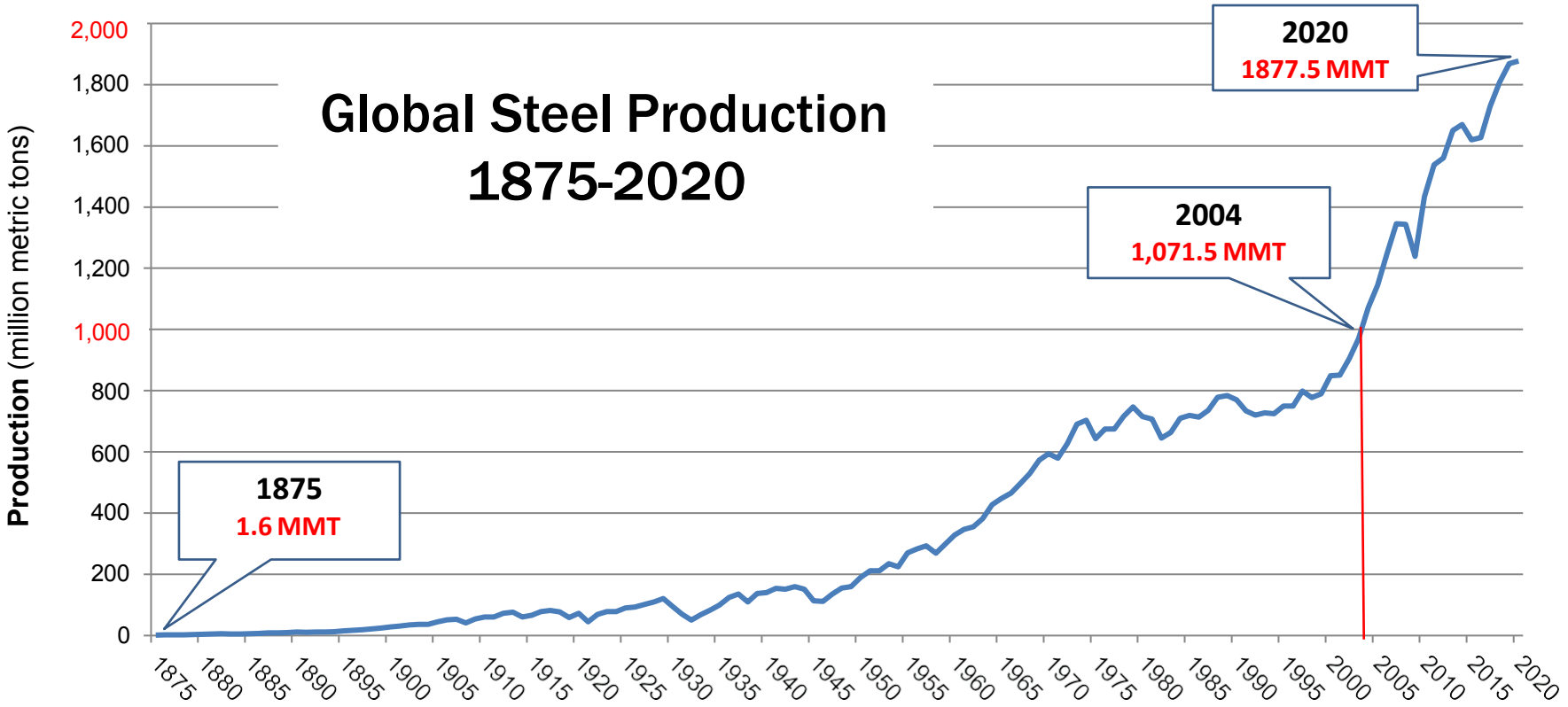
USS will reduce its global GHG emissions intensity by 20% by 2030, based on 2018 baseline levels.

- Deploy EAF steelmaking at Fairfield Works and Big River Steel.
  - Best for All[sm] Strategy
- Process changes and improvements to existing facilities.
  - Integrated facilities as well as EAF facilities.

USS will reach a GHG net zero goal by 2050.

- Expand fleet of EAFs
- Deploy other technologies such as direct reduced iron, renewable energy, and carbon capture, sequestration, and utilization.
- Goal relies on public-private-university-government collaborations.
- Goal includes Scope 1 and Scope 2 emissions

Growth within the Steel Industry

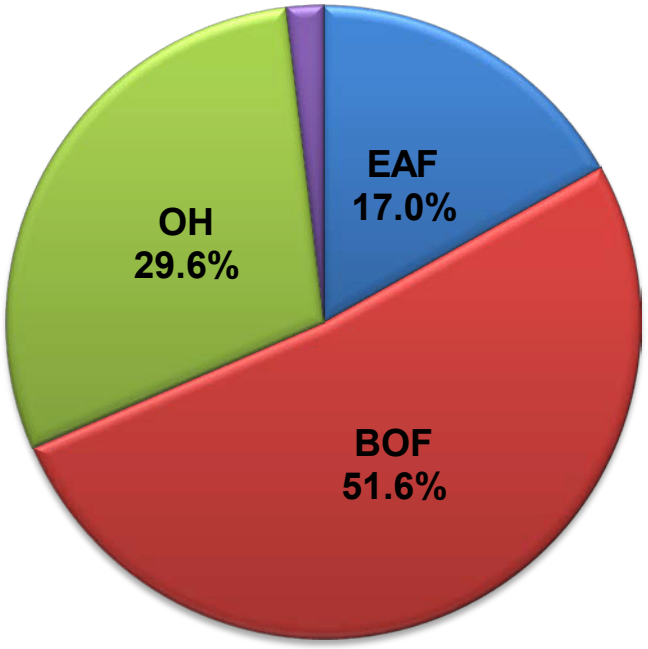


Source: AIST, World Steel Association

Electrifying Steel – BF/BOF vs EAF

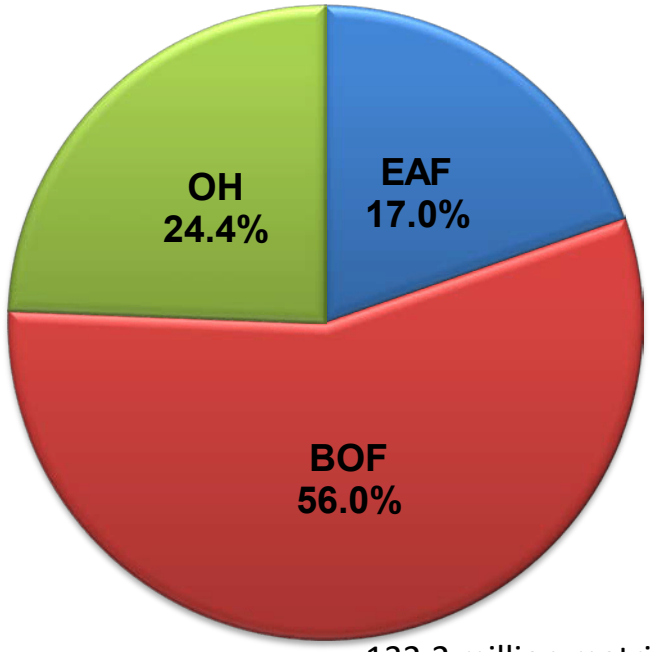
1974

World



708.9 million metric tons

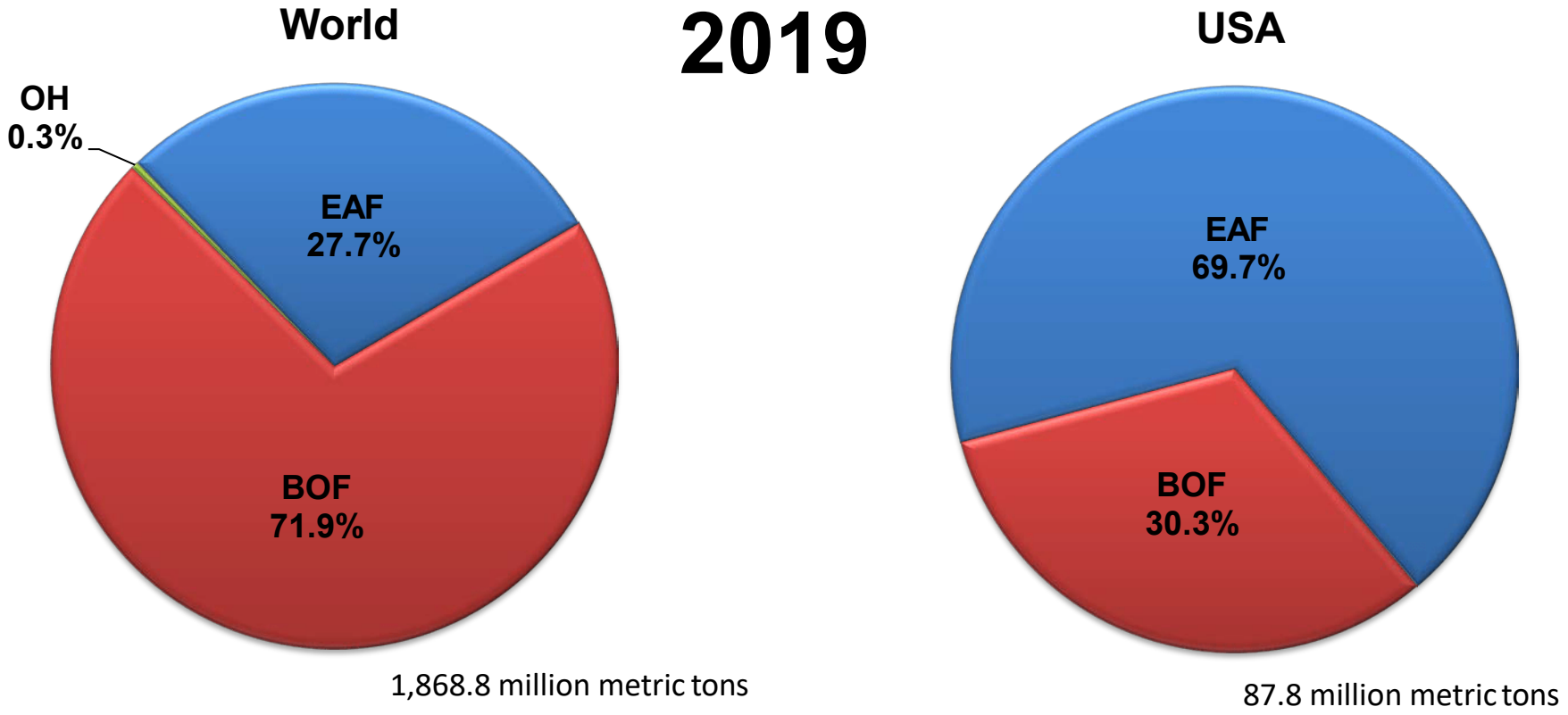
USA



132.2 million metric tons

Source: AIST, World Steel Association

Electrifying Steel – BF/BOF vs EAF



Source: AIST, World Steel Association

Decarbonization Definitions and USS CO_2 impact

Carbon neutrality – balancing greenhouse gas (GHG) emissions by 'offsetting' an equivalent amount of carbon for the amount produced

- Carbon neutrality does not necessarily require a commitment to reduce overall emissions, just provide/obtain the required offsets

Net-Zero – a commitment to reducing greenhouse gas emissions with the goal of balancing the emissions produced and the emissions removed

- USS achieves net-zero by reducing the GHG emissions across all existing and future operations as much as possible.
  - Reduction of direct emissions
  - Use of carbon-free energy

In general terms, today:

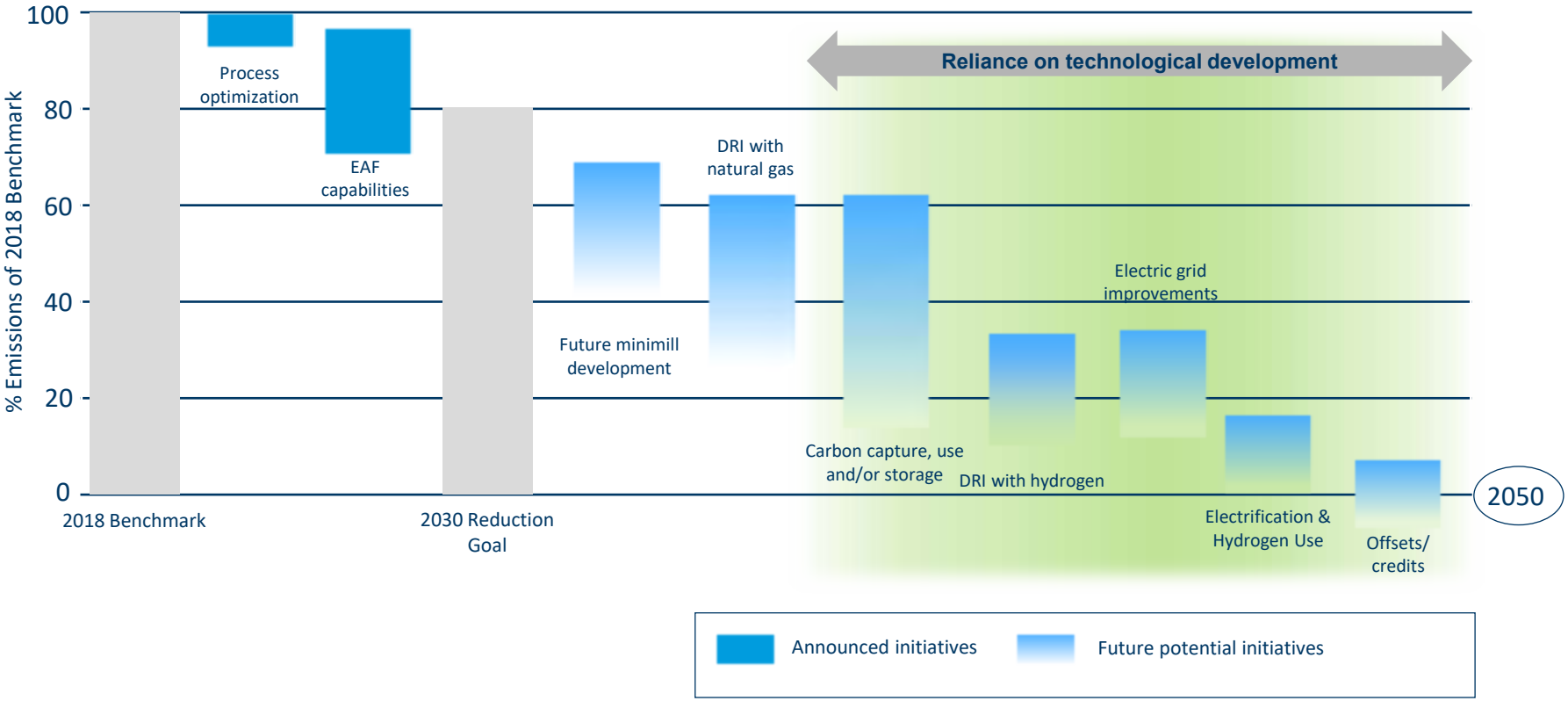
BF/BOF to raw steel (Integrated)

Scope 1	2.1 tonsCO_2/tonRS	90 %
Scope 2	0.2 tonsCO_2/tonRS	10 %
Total BF/BOF	2.3 tonsCO_2/tonRS	100%

EAF to raw steel (Minimill)

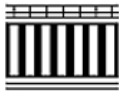
Scope 1	0.2 tonsCO_2/tonRS	50 %
Scope 2	0.2 tonsCO_2/tonRS	50 %
Total EAF	0.4 tonsCO_2/tonRS	100 %

U. S. Steel Net Zero Roadmap

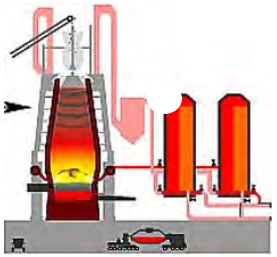


Path Forward – Future USS Footprint Considerations will impact GHG goals

Coal



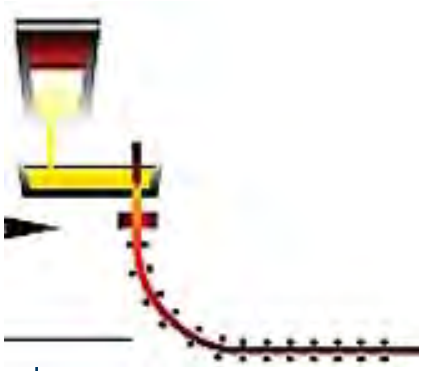
Coke Plant
+ CCUS



Blast Furnace
+ CCUS + H2

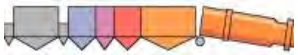
BOF
+ CCUS

Secondary
Steelmaking



Continuous
Casting

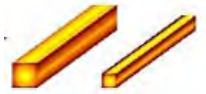
Iron Ore



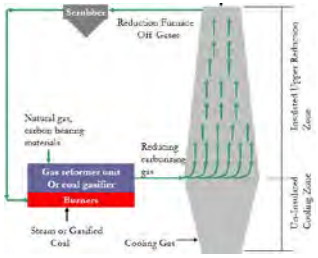
Pellet Plant
+ CCUS + H2

Scrap (recycled
steel)

Thick/thin
slabs



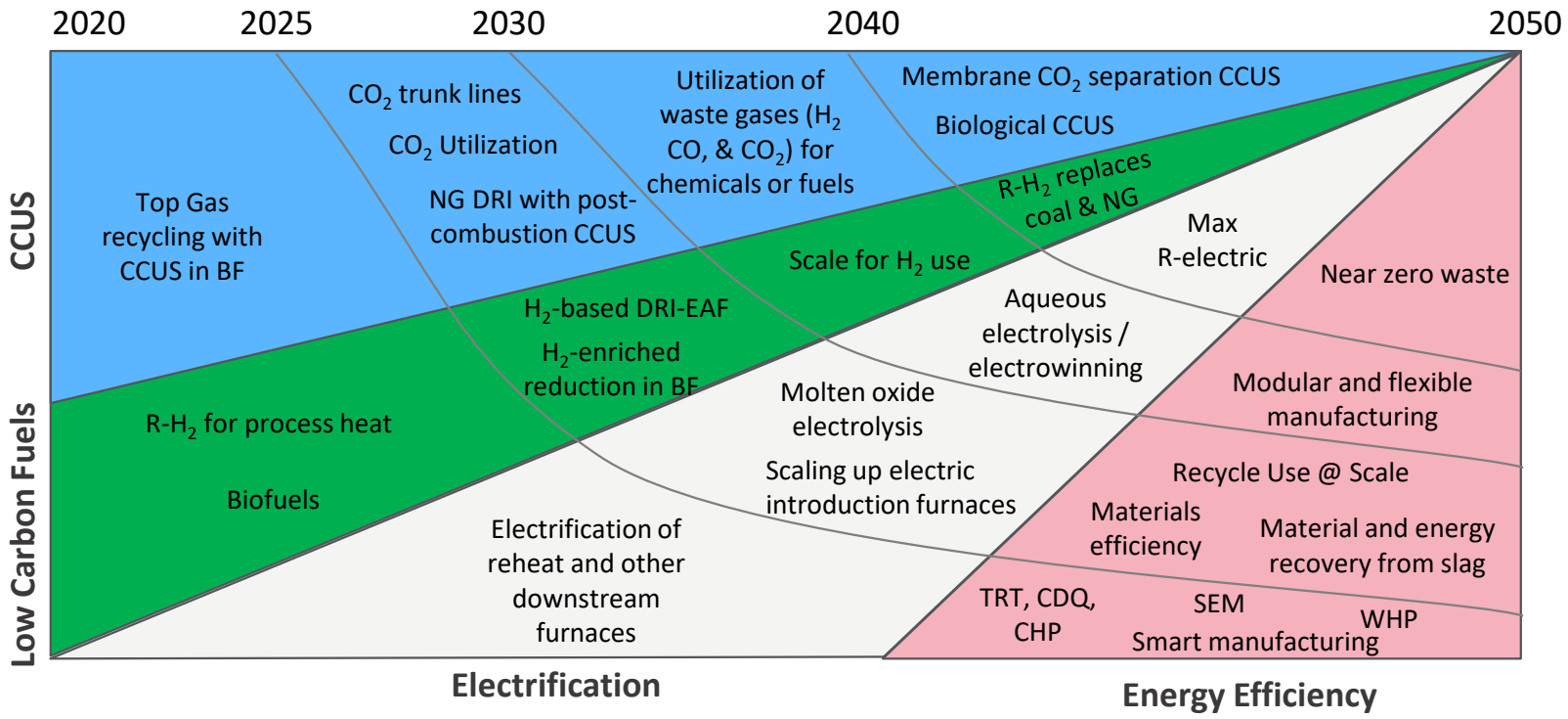
Billets/Blooms



DRI/HBI Plant
+ H2

EAF
+ CCUS

Industry Challenges → Opportunities



Source: Adapted from DOE/AMO webinar introducing Advanced Manufacturing Institute.

Industry Challenges → Opportunities

INPUTS: Sources of iron, scrap, reductants and energy

- Abundance, purity and cost of ferrous raw materials.
  - Traditional hot metal (Blast Furnace liquid iron)
  - Blast Furnace Pig Iron (solidified from blast furnace liquid iron)
  - Direct Reduced Iron (solid state lump iron)
  - Electrolytic Iron (pure iron electrically reduced from iron ore)
  - Scrap (and recycling)

- Abundance and cost of reductants and renewable energy.
  - Carbon as a reductant, requires CCUS
  - Hydrogen as a reductant, from green energy and/or with CCUS
  - Electricity as a reductant, from renewable sources

Industry Leading Announcements

BIG RIVER STEEL

a U. S. Steel company

Low GHG-emission steelmaking

Only LEED® certified steel mill in the United States

Sustainable steel solutions

Helping customers meet their own decarbonization goals

Responsible Steel standards & certification

2050 Net-zero target

Committed to sustainability

Only North American-based steel company to join ResponsibleSteel

Reinforces commitment to our 2050 goal

BREAK FOR LUNCH

SME MN 2022

2022 SME Minnesota Conference

Why Attend? Conference Expo Partners Register About

LEARN, SHARE, RECONNECT

April 11-13, 2022 | Virginia, MN

Register Now

Minnesota Power: Biochar Research and Opportunities for Further Decarbonization in Mining

Kurt Anderson

Director, Environmental and Land Management

minnesota power

AN ALLETE COMPANY

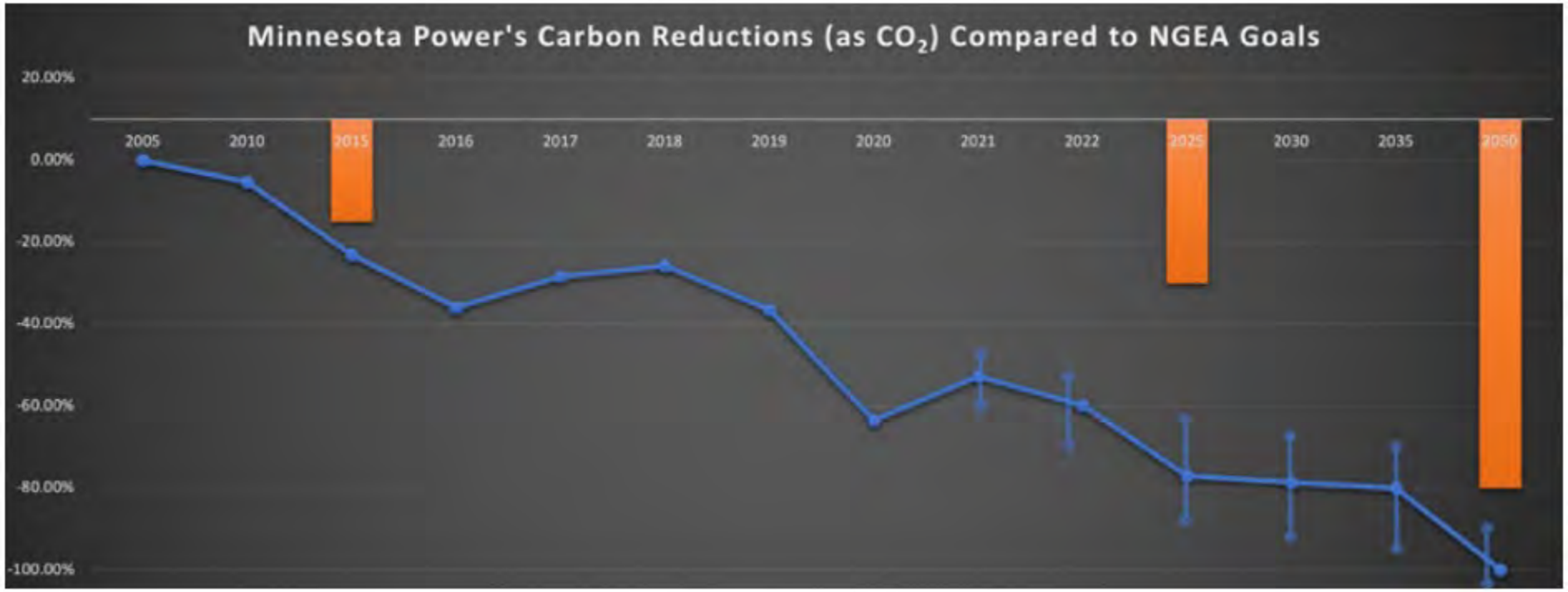
Biochar Research and Opportunities for Further Decarbonization in Mining

March 16, 2022

Kurt Anderson - Director of Environmental & Land Management

WE ARE UNIQUE

Duluth, MN	Headquarters
26,000	Square-miles
145,000	Customers
13%	Residential
67%	Mining and Forestry
15	Minnesota Municipalities
1st	First utility in Minnesota to deliver 50% renewable energy
39%	Reduction in Scope 2 emissions for taconite mines from 2018-2020



Minnesota Power's 100% carbon-free energy vision

Today

Minnesota Power provides over 50% renewable energy, the first utility in Minnesota to achieve that milestone.

By 2030

Add an estimated 400 MW of wind and solar power to reach 70% renewable energy supply.

By 2035

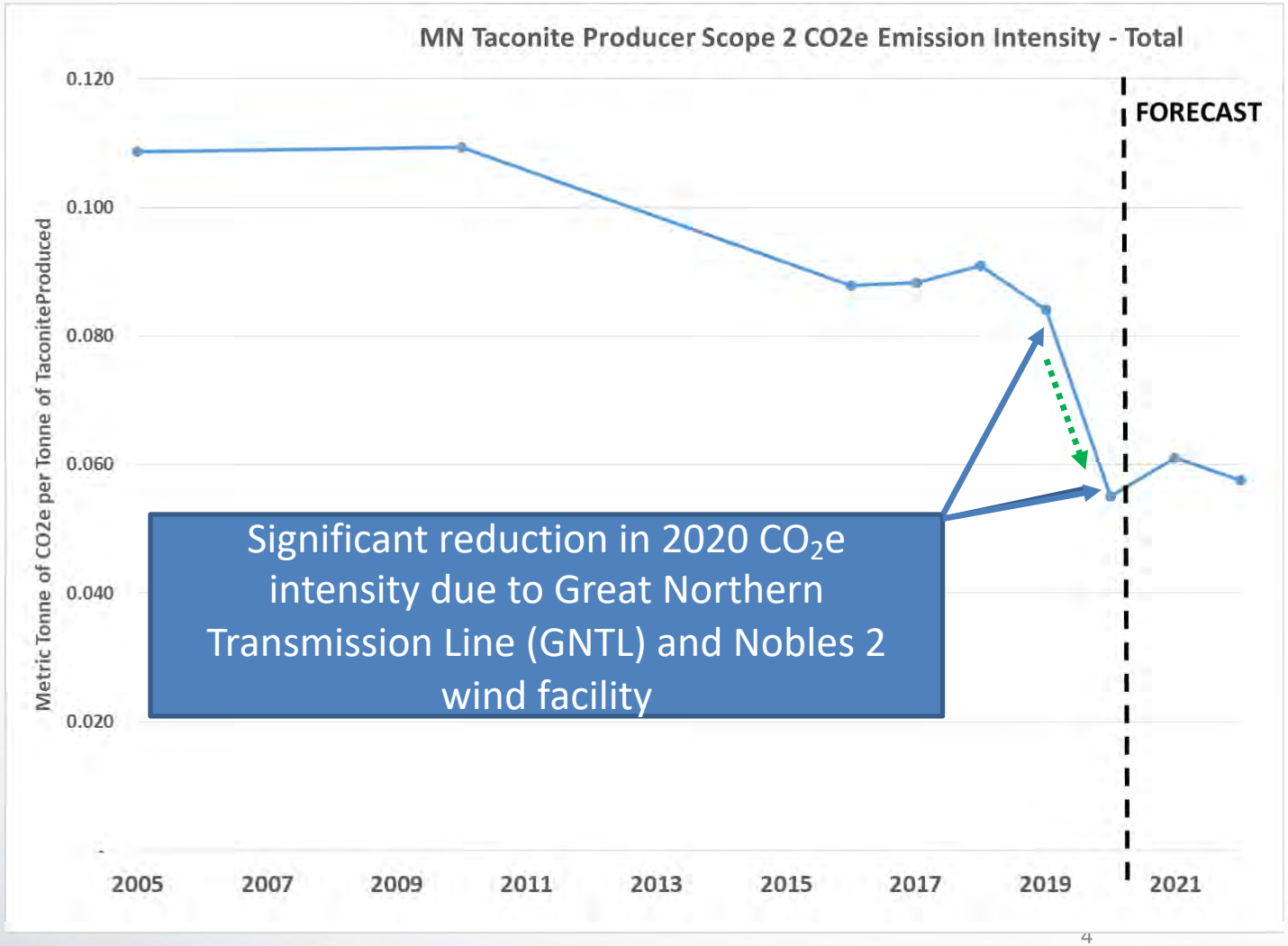
Achieve 80% carbon-free target and a coal-free energy supply by transforming the company's last coal unit.

By 2050

Adopt innovative solutions and use evolving technology to deliver 100% carbon-free energy.

Scope 2 Progress

Minnesota Power's 50% - and increasing – renewable energy mix helps Minnesota's mining companies provide the cleanest metals – resulting in the cleanest steel.



Between 2018 – 2020

- **39% reduction** in Scope 2 CO_2e per ton of taconite produced in MN.
- **~1,100,590 fewer tons** of CO_2e at MN taconite mines based on 2020 production.

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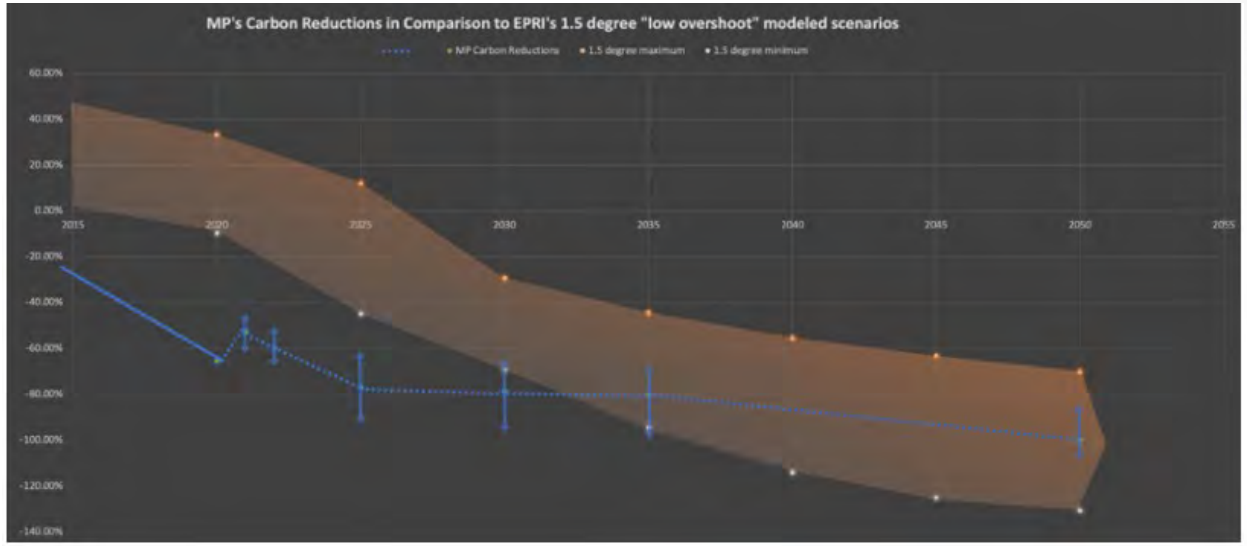
Adding to the Decarbonization Toolbox

- Reducing carbon is shared journey with our customers
  - MP's Scope 1 emissions will continue to decrease
  - We have numerous ways to produce our main product – electrons
  - Our main challenges are to ensure reliability and affordability throughout transition – and keeping it local
- We recognize the same Scope 1 options may not exist for our customers
  - We are committed to developing and providing robust, cost-effective options that benefit **customers, climate, and the communities** we serve
  - Carbon offsets are one such option



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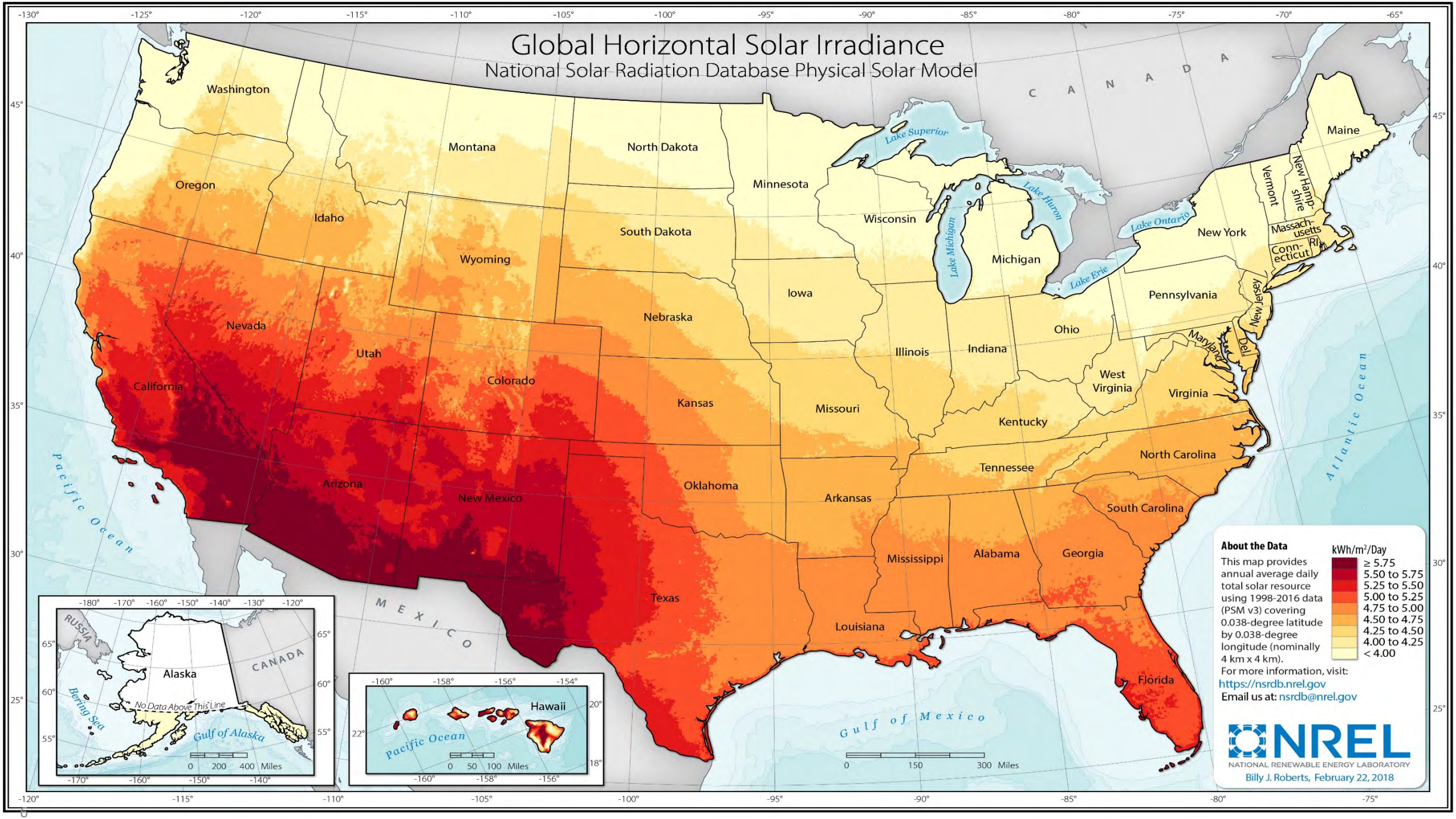
Global Horizontal Solar Irradiance
National Solar Radiation Database Physical Solar Model
Washington
Oregon
California
Nevada
Idaho
Montana
Wyoming
Utah
Arizona
Colorado
New Mexico
North Dakota
South Dakota
Nebraska
Kansas
Oklahoma
Texas
Minnesota
Iowa
Missouri
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Louisiana
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South Carolina
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Virginia
West Virginia
Pennsylvania
New York
Maine
Vermont
New Hampshire
Massachusetts
Connecticut
RI
New Jersey
Del
Maryland
Lake Superior
Lake Michigan
Lake Huron
Lake Erie
Lake Ontario
CANADA
MEXICO
Pacific Ocean
Atlantic Ocean
Gulf of Mexico
Alaska
RUSSIA
CANADA
No Data Above This Line
Bering Sea
Gulf of Alaska
0 200 400 Miles
Hawaii
Pacific Ocean
0 50 100 Miles
0 150 300 Miles
About the Data
This map provides annual average daily total solar resource using 1998-2016 data (PSM v3) covering 0.038-degree latitude by 0.038-degree longitude (nominally 4 km x 4 km).
For more information, visit:
https://nsrdb.nrel.gov
Email us at: nsrdb@nrel.gov
kWh/m²/Day
≥ 5.75
5.50 to 5.75
5.25 to 5.50
5.00 to 5.25
4.75 to 5.00
4.50 to 4.75
4.25 to 4.50
4.00 to 4.25
< 4.00
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Billy J. Roberts, February 22, 2018

Annual Average Wind Speed at 100 m above surface level of North America

from the Wind Toolkit

Wind Speed

(meters/second)

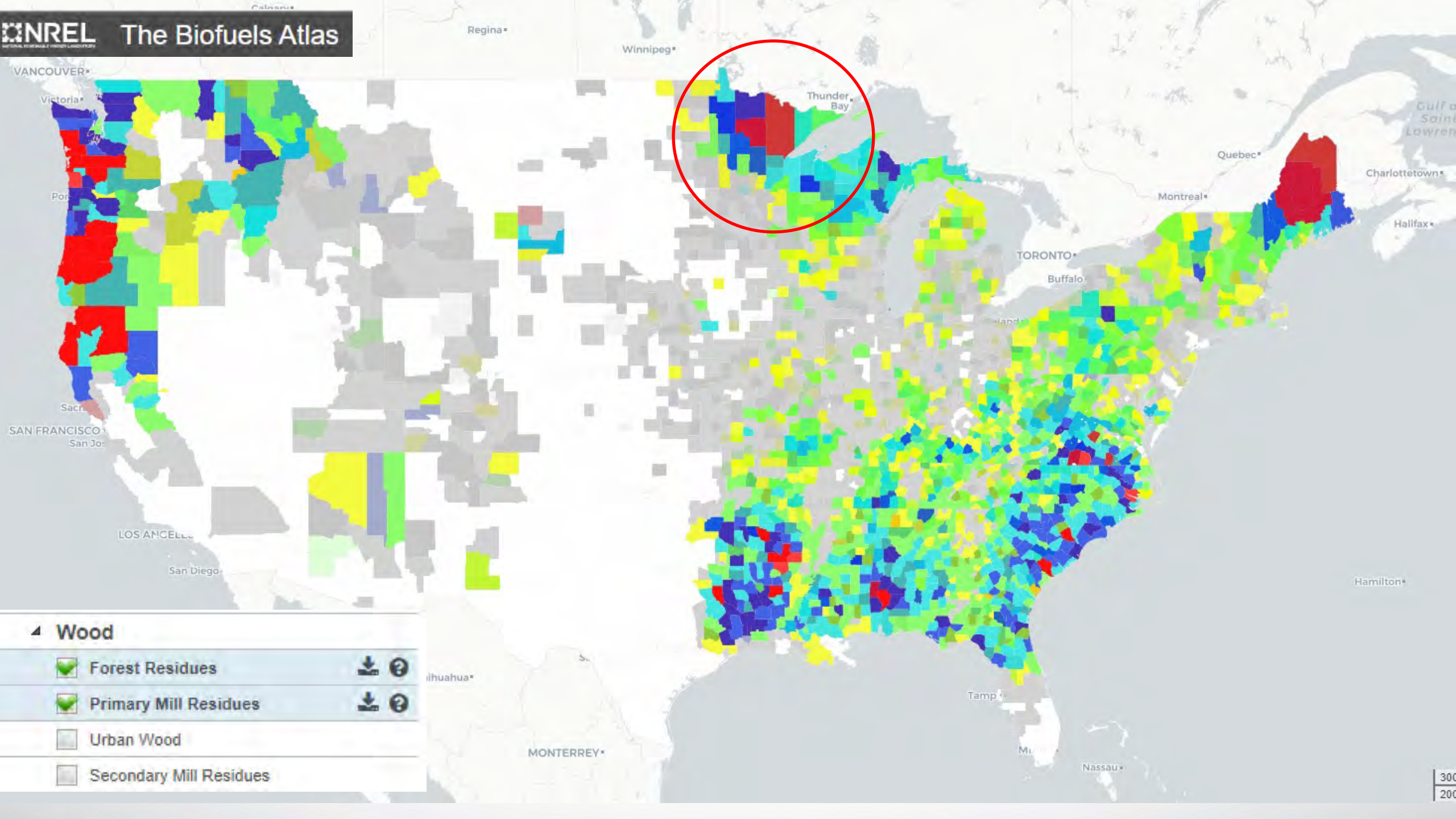
- ≥ 10
- 9.0 to 9.9
- 8.0 to 8.9
- 7.0 to 7.9
- 6.0 to 6.9
- 5.0 to 5.9
- 4.0 to 4.9
- 3.0 to 3.9
- < 3.0

Canada

United States

About the Data

Wind resource data were supplied by the National Renwable Energy Laboratory's Wind Toolkit, originally developed by Vaisala (www.vaisala.com). These data are indicative of the annual average wind speed for the year 2012. Offshore resource is shown to 50 nautical miles.


NREL The Biofuels Atlas
Regina
Winnipeg
VANCOUVER
Victoria
Thunder Bay
Quebec
Charlottetown
Montreal
Halifax
TORONTO
Buffalo
SAN FRANCISCO
LOS ANGELES
San Diego
Hamilton
MONTERREY
Nassau
Wood
Forest Residues
Primary Mill Residues
Urban Wood
Secondary Mill Residues

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Can we leverage the natural carbon capture of Minnesota's forests to reduce carbon in the atmosphere?

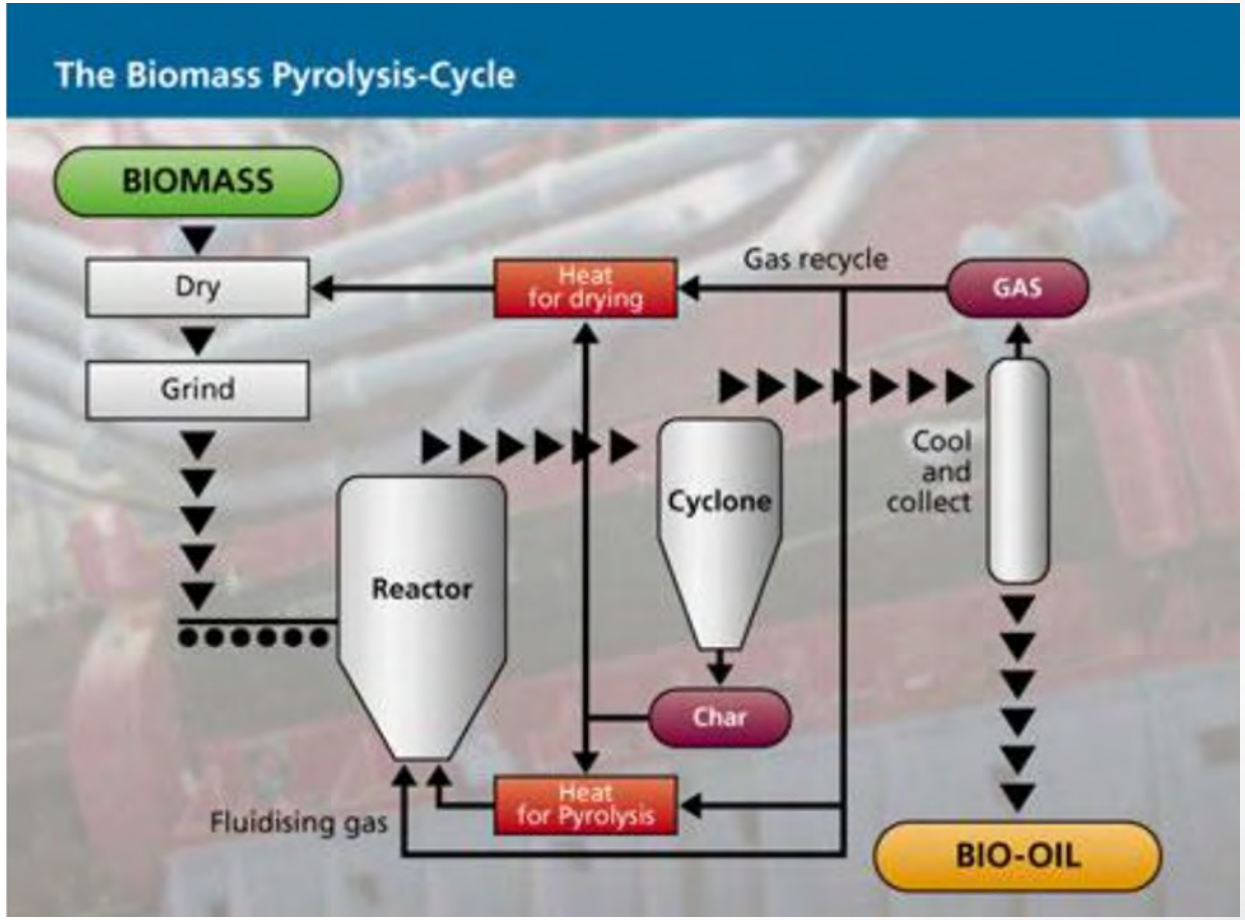
Biochar

- Carbon stabilized from forest biomass
- Biochar used for agricultural amendments, wastewater treatment, etc
  - Crop yield increases can reach 30-40% or more
  - Reduces water needs by up to 40%
  - Retain nutrients, increase soil microbial activity
- Valuable as a carbon offset
  - Stable, high-carbon product with half life of hundreds/thousands of years

Cross sectional profiles 1 meter deep comparing Terra Preta on the left, with nearby Oxisol on the right of the type that is normally found in the Amazon basin. [Glaser, B., Haumaier,

Biochar is the conversion of biomass into charcoal under heat and low/no oxygen (pyrolysis)

- Resulting product has high carbon content and is stable -- if produced correctly
- Not a fuel, but same general process as torrefaction
- Multiple End Uses
  - Agricultural amendment
  - Wastewater and air emission control
  - Syngas/bio-oil byproduct has multiple uses
  - Potential source of metallurgical carbon



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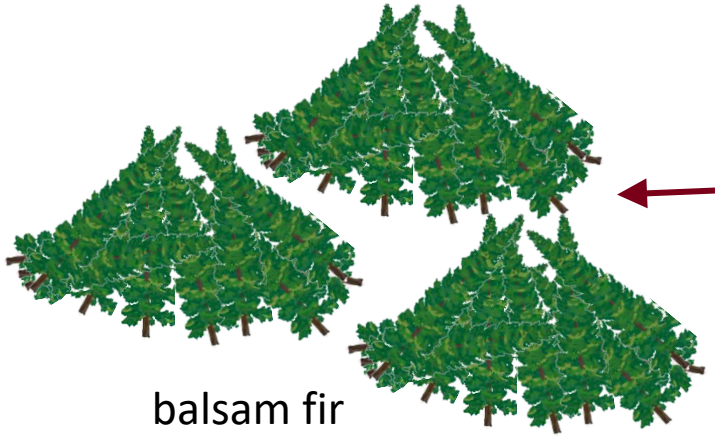
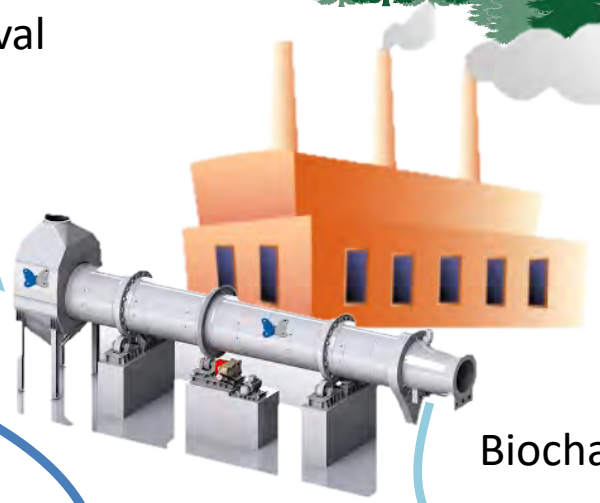
USFS Wood Innovation Program

- Partnership with NRRI to evaluate the potential for using MP infrastructure to create biochar from unmerchantable timber (balsam fir)
  - Primary targets are Hibbard Renewable Energy Center, Boswell Energy Center, and Rapids Energy Center
- Will also evaluate potential for carbon offsets and market analysis
- Includes production of biochar at NRRI's Biomass Conversion Laboratory (BCL) and application in landfill/impoundment cover at MP's Boswell Energy Center

Leveraging MP's location and Assets

Fuel Removal



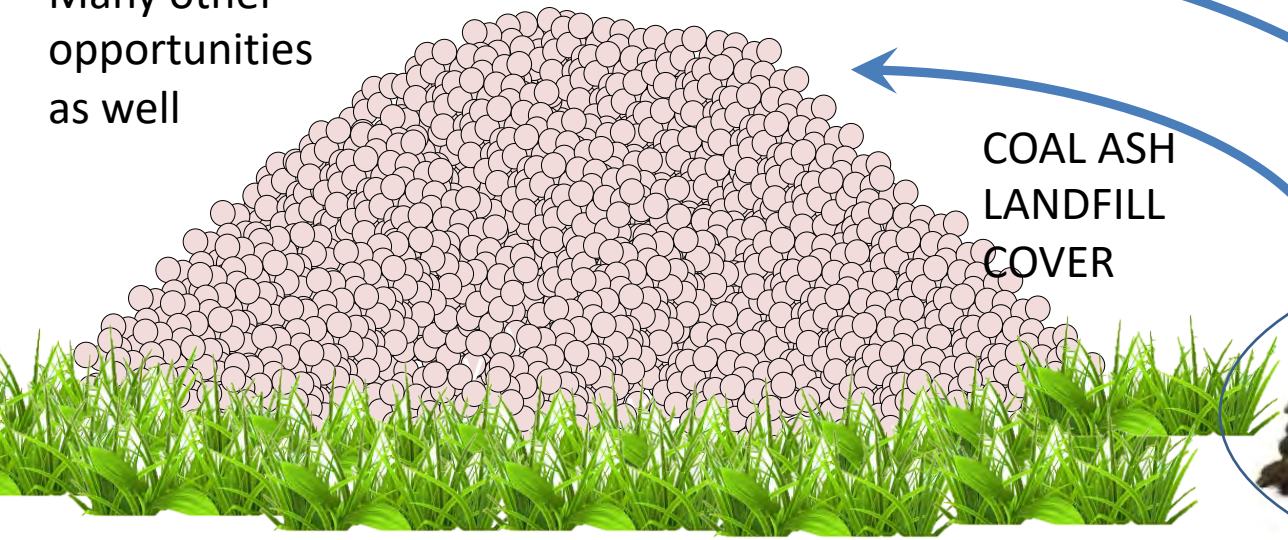


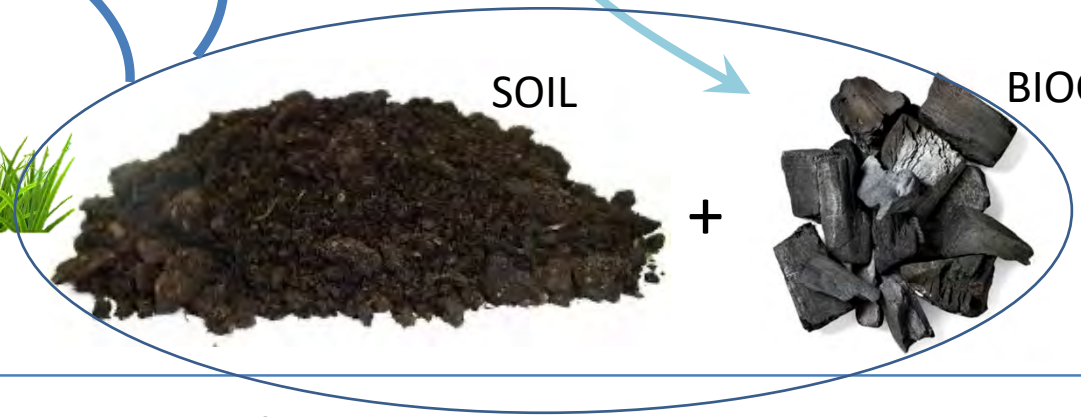
Forest-adjacent Power Plant

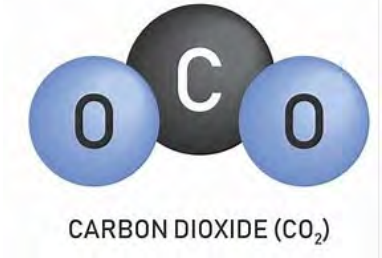
Working in tandem

Biochar kiln

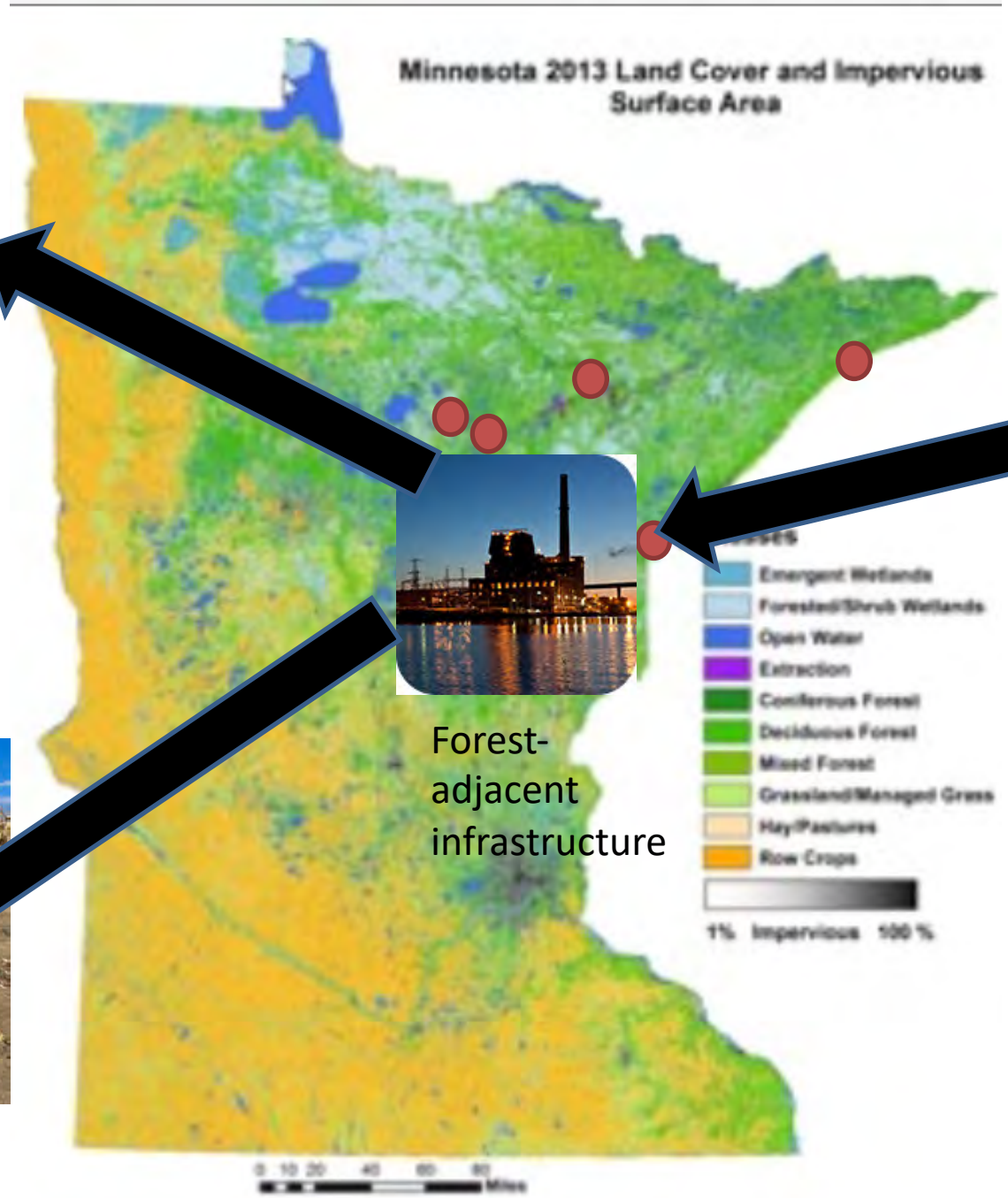
Many other opportunities as well



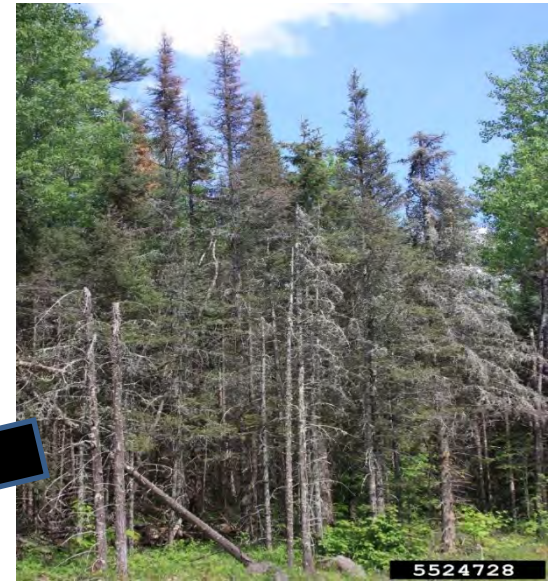




Offsets



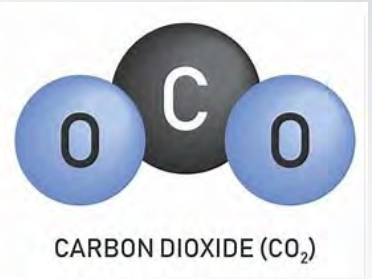
Forest-adjacent infrastructure



Carbon inventory/liability

Carbon sink

Commercial Biochar Production creates Multiple Benefits



- Three value streams possible
  - Each ton of biochar could create ~ 3 tons of CO_2e credits
    - Current biochar credits range from $30-150 or more per ton of CO_2e
    - Depending on production design, could offset hundreds of thousands of tons of CO_2e annually
  - Average application rate of 10 tons/acre – thousands of acres amended annually
    - Improved crop yield (and more photosynthetic carbon capture!)
    - Reduced water usage, especially for sandy soils
    - Improved bulk density for clayey soils
    - Reduced nutrient needs and associated runoff
    - Carbon can also potentially help with contaminant control
    - CAFO applications
  - Reduced wildfire costs and avoided CO_2 emissions


Greenwood Fire 2021

Potential Next Steps

Technical feasibility

Market analysis

Pilots

Letters of intent

Design & Construction

Carbon Offset Certification

COD

minnesota power
AN ALLETE COMPANY

Thank you!

For more information, please contact me at:
kanderson@mnpower.com

https://www.allete.com/Content/Documents/Sustainability/2020/ALE-Sustainability-Report.pdf

Nick Lalena
R&D Projects Technology Manager, Advanced Manufacturing Office

Katharine Greco
Fellow, Advanced Research Projects Agency (ARPA) – U.S. Department of Energy

Rolf Weberg
NRRI Executive Director **&**
Brett Spigarelli
NRRI Metallurgical Engineer

Emerging Research

Department of Energy (DOE)

Recent Research Initiatives on Zero/Low Carbon Steelmaking in Advanced Manufacturing

Nick Lalena

R&D Projects Technology Manager, Advanced Manufacturing Office

U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

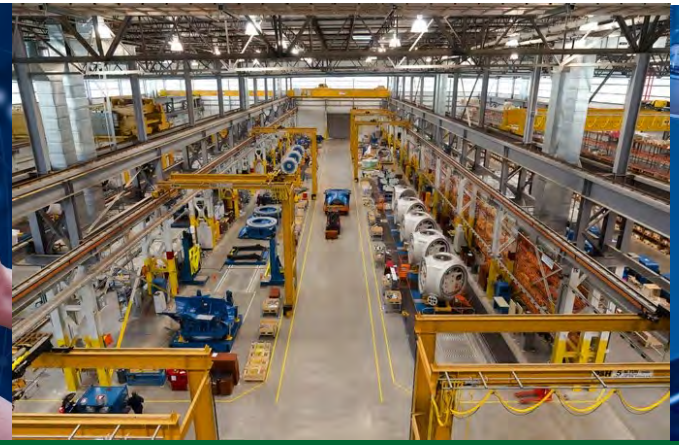
Zero- and Low-Carbon Steelmaking Initiatives at the Advanced Manufacturing Office (AMO)

Presentation to the MN Iron Ore & the Green Economy Climate Forum, March 16, 2022
Dr. J. Nick Lalena, Ph.D.; Technology Manager, R&D Projects
Advanced Manufacturing Office (AMO)

Agenda

- Overview of the Advanced Manufacturing Office (AMO)
- Zero- and Low-Carbon Steelmaking Initiatives and Industrial Decarbonization at AMO
  - Pre-2020
  - 2020-Present
  - 2022 and Beyond
- Q&A






Advanced Manufacturing Office (AMO)

We partner with industry, academia, states, and national laboratories to catalyze R&D and the adoption of advanced manufacturing technologies and practices.

R&D Projects

- Targeted investments for next-generation materials and process technologies that would lead to quantifiable energy and carbon savings

R&D Consortia

- Public-private institutes and hubs that tackle specific technical challenges through major collaborative projects

Technical Partnerships

- Direct technical assistance for the U.S. manufacturers through no-cost tools and trainings, knowledge sharing, and technology validation

BUDGET

$396M

FY21

Guiding Principles for AMO

AMO works to **increase energy and material efficiency in manufacturing,** driving energy productivity, economic growth, and decarbonization.

MANUFACTURING

- Uses roughly 25% of the nation's primary energy
- Accounts for one quarter of the U.S.'s greenhouse gas emissions
- Represents nearly 80% of energy use in energy-intensive sectors
- Generates 11% of the U.S. GDP and 12.6 million jobs
- Incurs $150 billion in energy costs annually

KEY AMO GOALS

- Improve the **productivity, competitiveness, energy efficiency, and security** of U.S. manufacturing
- Reduce the **life cycle energy and resource impacts** of manufactured goods
- Leverage diverse **domestic energy resources and materials** in U.S. manufacturing, while strengthening environmental stewardship
- Transition **DOE-supported innovative technologies** and practices into U.S. manufacturing capabilities
- Strengthen the **U.S. manufacturing workforce**
- Accelerate emerging and transformative technologies needed to **approach net-zero greenhouse gas emissions** in the industrial sector by 2050

Industry Contributes Significantly to CO_2 Emissions

THE U.S. INDUSTRIAL SECTOR

manufacturing | agriculture | mining | construction

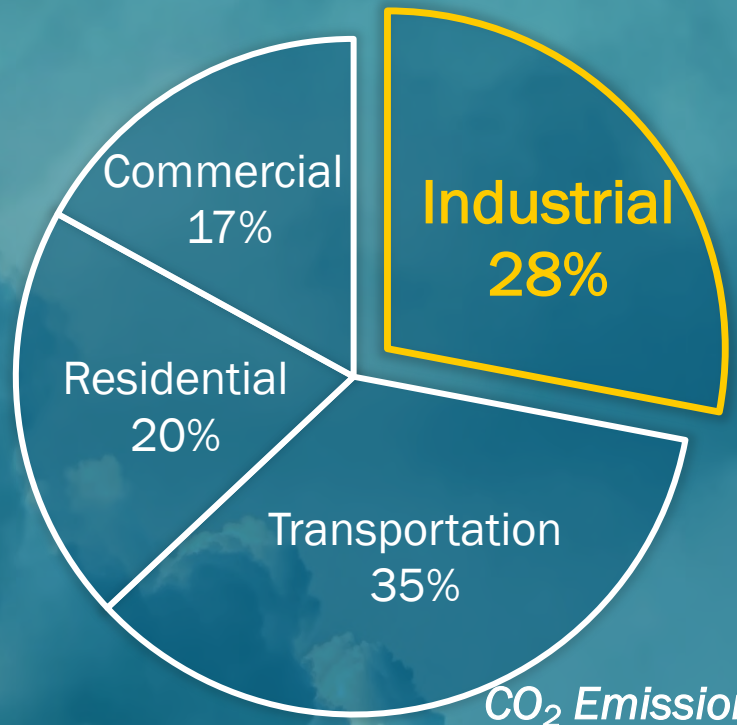
ACCOUNTS FOR

32% of the nation's primary energy use

28% of CO_2 emissions

Anticipated industrial sector energy demand growth of 30% by 2050 may result in a

15% CO_2 emissions increase



CO_2 Emissions By Sector

Technological advances in manufacturing will be critical to enabling decarbonization for other sectors.

Decarbonizing the industrial sector is key to addressing the climate crisis and achieving economy-wide, net-zero emissions by 2050.

EIA, *Annual Energy Outlook 2020 with Projections to 2050.*

Recent Selections

Certain Meritorious Proposals Selected to Fulfill FY21 Direction

AMO FY20 MULTI-TOPIC FOA: $123.6M

- **Efficiency Improvements in Advanced Manufacturing Processes:** $69.4 million for 27 projects
- **Efficiency Improvements in Chemical Manufacturing:** $25 million for eight projects
- **Connected, Flexible, and Efficient Manufacturing Facilities, Products, and Energy Systems:** $29.1 million for 11 projects

BATTERY MANUFACTURING AND THE NATIONAL LABS: ~$14.8M*

- 13 projects selected across six National Laboratories

*Joint with the Vehicle Technologies Office

PLASTICS: $27M*

- 12 projects for advanced plastics recycling technologies and new plastics that are recyclable-by-design
- NREL selected to lead BOTTLE consortium

*Joint with the Bioenergy Technologies Office

WATER SECURITY:

Advanced Water Resource Recovery Systems
FOA: *Selections pending*

Water Resource Recovery Prize: ≤ $1M

- 10 phase-one winners selected
- Phase two now open for phase-one winners

CRITICAL MATERIALS: $50M

- 15 projects for field validation and demonstration, as well as next-generation extraction, separation, and processing technologies

TRANSPORTATION:

- **$15M*:** Two projects for polymer composites for vehicle applications
  - *Joint with the Vehicle Technologies Office
- **$13.8M**** for three electrolyzer manufacturing R&D projects
  $10.4M** for three projects researching advanced carbon fiber for compressed gas storage tanks
  - **Joint with the Hydrogen and Fuel Cell Technologies Office

Stakeholder Engagement Efforts

AMO engages with stakeholders to identify current and emerging gaps, needs, and opportunities, and to disseminate information and encourage uptake for our efforts.

22+ FY20-21 STAKEHOLDER WORKSHOPS

convene industry stakeholders, National Laboratory experts, and academia

TOPICS

- Education & workforce development
- Semiconductor manufacturing
- Water infrastructure & innovation
- Industrial decarbonization
- Thermal processes
- Sustainable chemistry
- Steel

REQUESTS FOR INFORMATION

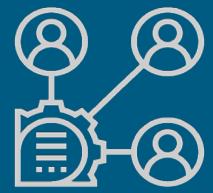
formally solicit input on key interest areas

ONGOING INPUT & INSIGHT

from stakeholder groups and experts whose work aligns with AMO's activities

INTERNATIONAL ENGAGEMENT

through the Clean Energy Ministerial, UNIDO, the Trilateral EU-US-Japan Conference on Critical Materials, and individual MOUs



INTERAGENCY COLLABORATION

through NSTC critical minerals and advanced manufacturing subcommittees, the Federal Consortium for Advanced Batteries, the Water Sub-cabinet, and Manufacturing USA

R&D Projects

$218M | FY21

Targeted, high-impact investments for next-generation materials and process technologies

- Back innovations that would lead to quantifiable energy and carbon savings, from early-stage R&D through validation and verification efforts
- Spread risk through project diversity
- Support early-stage applied research through verification and validation efforts
- Foster industry collaboration with the National Laboratories

R&D Consortia

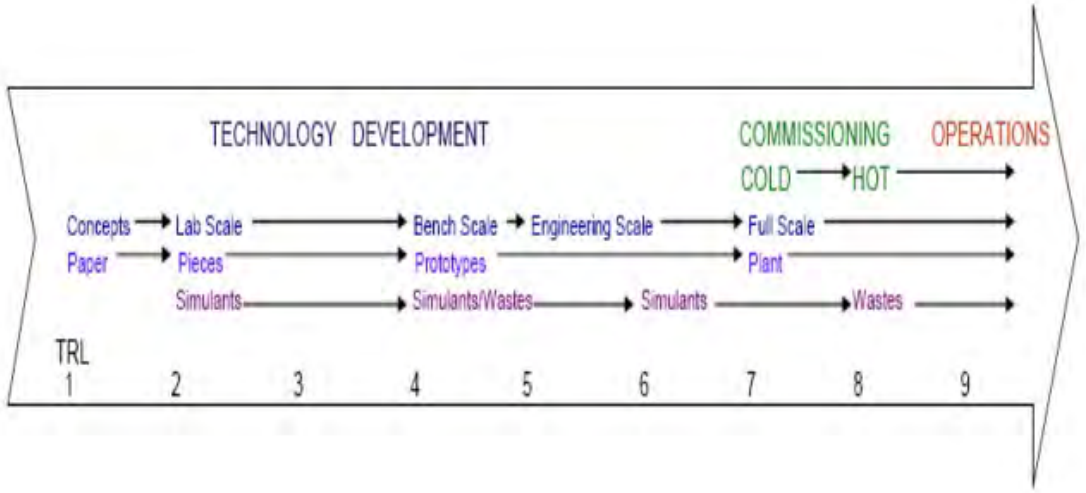
$133M | FY21

Public-private institutes and hubs designed to tackle specific technical challenges

- Secure U.S. manufacturing leadership by executing major collaborative projects around industry's toughest challenges
- Train the U.S. manufacturing workforce in key skills for today's advanced manufacturing jobs

DOE Technology Readiness Levels (TRLs)

System Operations	TRL 9	Actual system operated over the full range of expected mission conditions.
System Commissioning	TRL 8	Actual system completed and qualified through test and demonstration
	TRL 7	Full-scale, similar (prototypical) System demonstrated in relevant environment
Technology Demonstration	TRL 6	Engineering/pilot-scale, similar (prototypical) system validation in relevant environment
Technology Development	TRL 5	Laboratory scale, similar system validation in relevant environment
	TRL 4	Component and/or system validation in laboratory environment
Research to Prove Feasibility	TRL 3	Analytical and experimental critical function and/or characteristic proof of concept
Basic Technology Research	TRL 2	Technology concept and/or application formulated
	TRL 1	Basic principles observed and reported



Technical Partnerships

$45M | FY21

Direct technical assistance for the U.S. manufacturers and workers

- Support U.S. industry in energy efficiency and decarbonization best practices with no-cost tools and trainings, knowledge sharing, technology validation, and workforce development programs

Crosscutting Efforts

AMO Education and Workforce Development Programs

- Programs supporting K-12, Trade Schools and Community Colleges, Undergrad and Post-Grad programs, the Manufacturing Workforce and Innovation Community

Field Validation and Verification Efforts

- Using National Laboratory Capabilities to accelerate industry adoption of next-generation energy-efficient manufacturing technologies

Low-Carbon Iron and Steel Making R&D Projects and Initiatives

- AMO has supported several projects to advance energy efficiency and low-carbon technology in iron and steel through the Office's RD&D portfolio via broad funding opportunity announcements (FOAs) and research conducted through manufacturing institutes:

  - **Process optimization**
    - HPC4 Manufacturing (FY2015)
  - **Energy efficiency improvements**
    - FY2020 Multi-topic FOA
  - **Advanced materials**
    - Next Generation Electric Machines- Enabling Technologies (FY2017)
    - FY2019 Multi-topic FOA
  - **Advanced Processes/Emissions reduction**
    - Advanced Manufacturing Projects for Emerging Research Explorations (FY2018)
    - Innovative Manufacturing Initiative (FY2012)

Pictured: Hot metal charging of a BOF converter

A Novel Flash Ironmaking Process (2012 - 2018)

Technology Summary:

- Could significantly reduce energy consumption by 30–60% and decrease CO_2 emissions by 60–97% compared with blast furnace ironmaking, depending on whether H_2 or C_nH_{2n+2} gas is used.
- In bench reactor, achieved 90-99% reduction of fine powder ore in 2-7 seconds at ~1,200-1,500°C for 2-7 seconds. Process eliminates the need for the briquetting process, as well as particle sticking/fusion.
- AISI (owns the rights to the technology) has developed a commercialization plan and, at the end of the project, was actively seeking funding for construction of a pilot plant.

Project Partners:

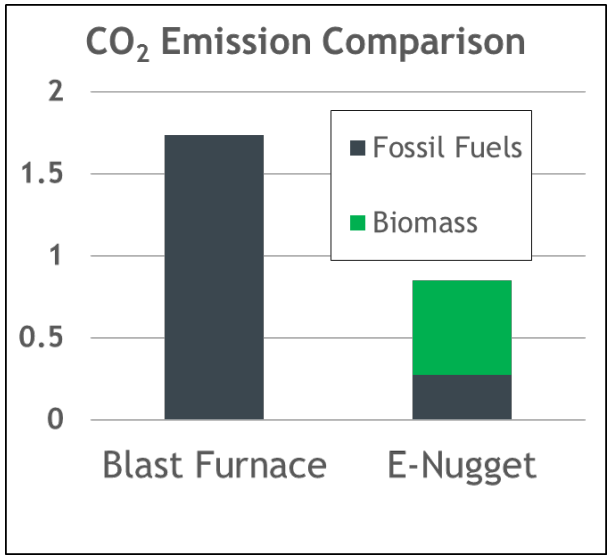
- American Iron and Steel Institute
- University of Utah (Technical lead)
- Berry Metal Company
- ArcelorMittal USA
- The Timken Company
- United States Steel Corporation

The final report is available at: www.osti.gov/scitech: OSTI Identifier: 1485414

HPC4Mfg Pilot: Model the E-Iron Nugget Process (2016 – 2017)

Title: Utilizing HPC to Model the E-Iron Nugget Process
Industry Partner: Carbontec Energy, CIVS Purdue University – Calumet
National Laboratory: Lawrence Livermore National Lab
Award: $300,000

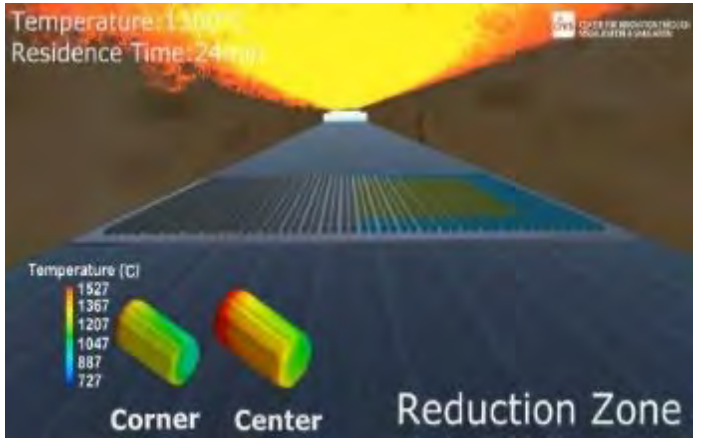
Objective: Better understand new iron smelting process that eliminates the use of coal/coke, scales. The team used large scale CFD simulations to study potential scaled up designs before Carbontec spent money to build a plant. This allowed Carbontec to optimize and prove their designs, greatly reducing the risk of this project moving forward.



Produce high quality iron nuggets utilizing organic biomass as the reductant instead of coke or coal.

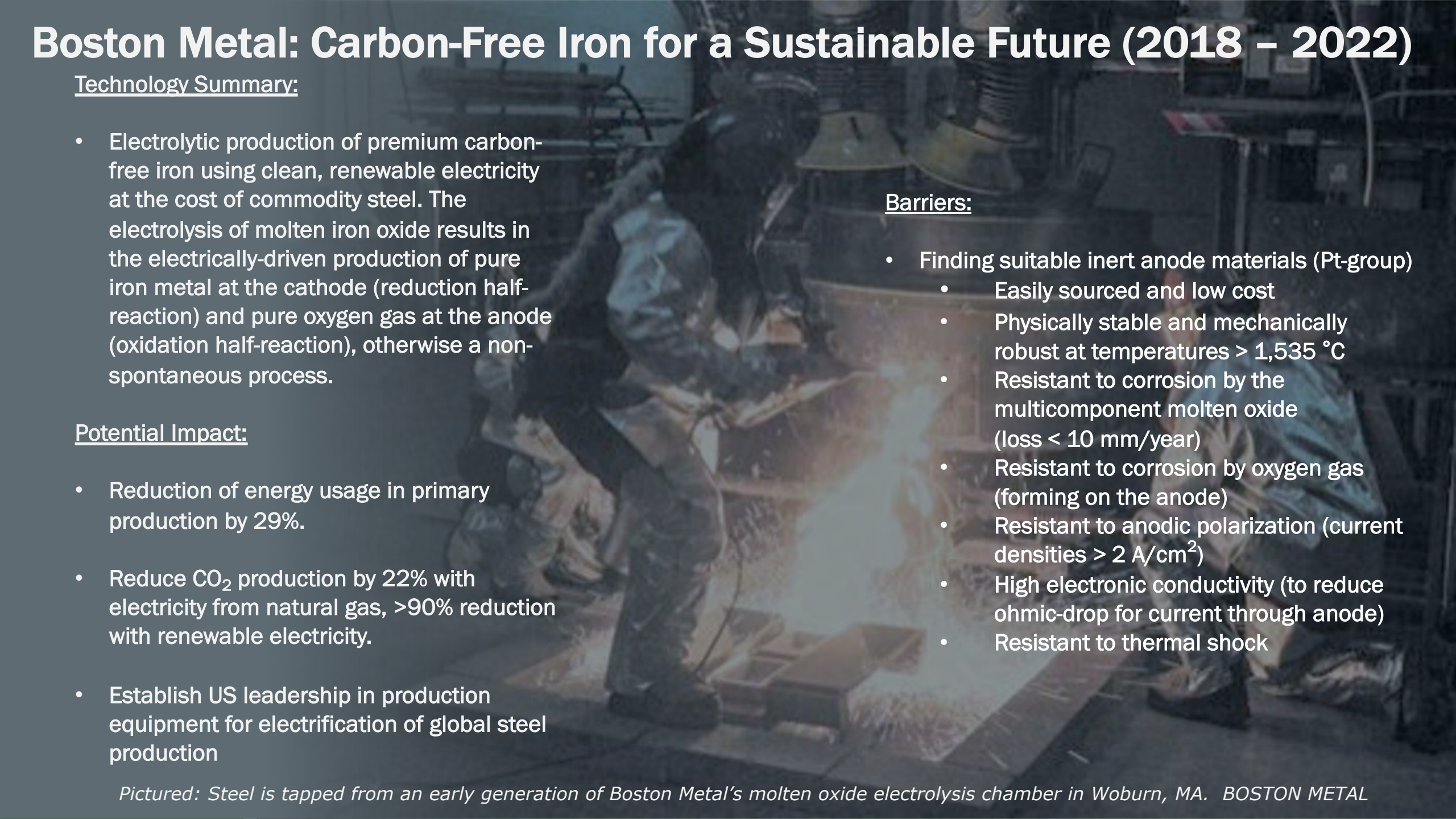
Final project outcome was establishment/validation of a simulation model of the technology for a 100,000 tonne/year plant for converting steel mill waste into pig iron grade iron nuggets.

[Utilizing HPC to Model the E-Iron Nugget Process, Final Report CRADA No. TC02234 (Technical Report) | OSTI.GOV]



Model of Carbontec's E-Nugget process at scale

Boston Metal: Carbon-Free Iron for a Sustainable Future (2018 – 2022)



Technology Summary:

- Electrolytic production of premium carbon-free iron using clean, renewable electricity at the cost of commodity steel. The electrolysis of molten iron oxide results in the electrically-driven production of pure iron metal at the cathode (reduction half-reaction) and pure oxygen gas at the anode (oxidation half-reaction), otherwise a non-spontaneous process.

Potential Impact:

- Reduction of energy usage in primary production by 29%.
- Reduce CO_2 production by 22% with electricity from natural gas, >90% reduction with renewable electricity.
- Establish US leadership in production equipment for electrification of global steel production

Barriers:

- Finding suitable inert anode materials (Pt-group)
  - Easily sourced and low cost
  - Physically stable and mechanically robust at temperatures > 1,535 °C
  - Resistant to corrosion by the multicomponent molten oxide (loss < 10 mm/year)
  - Resistant to corrosion by oxygen gas (forming on the anode)
  - Resistant to anodic polarization (current densities > 2 A/cm^2)
  - High electronic conductivity (to reduce ohmic-drop for current through anode)
  - Resistant to thermal shock

Pictured: Steel is tapped from an early generation of Boston Metal's molten oxide electrolysis chamber in Woburn, MA. BOSTON METAL

Recent Activities: FY20 Multi-topic FOA Selections

$123.6 million awarded with an additional $44.7 million in cost share

46 projects selected

23 states represented

Efficiency Improvements in Advanced Manufacturing Processes (Iron & Steel, Drying, Aerostructures, Wind blades, CMCs)
$69.4 million for 27 projects ($20.8 million for seven I&S projects)

Efficiency Improvements in Chemical Manufacturing (R&D, Dynamic Catalyst Science w/Data Analytics)
$25 million for 8 projects

Connected, Flexible, and Efficient Manufacturing Facilities, Products, and Energy Systems (Integrating CCU into Industrial Processes, CHP in a DE system w/Renewable –fueled Generating Station
$29.1 million for 11 projects

FY20 Multi-topic FOA Awards: Innovation in Iron and Steelmaking Processes

Lead Organization	Partners	Project Title		DOE Funding
Purdue University Northwest - Steel Manufacturing Simulation and Visualization Consortium	Cleveland-Cliffs, Oak Ridge National Laboratory, Praxair Inc. a Linde Company, Purdue University, U.S. Steel	**Integrated Virtual Blast Furnace for Real-time Energy Efficiency Improvement**	Hammond, IN	$7,048,766
Missouri University of Science and Technology	Praxair Inc. a Linde Group, Big River Steel, Commercial Metals Company, Gerdau North America, Nucor Steel, CIX Inc., Colorado School of Mines	**Intelligent Dynamic EAF Advisory System (IDEAS) for Improving EAF Operating Efficiency**	Rolla, MO	$5,227,988
Colorado School of Mines	National Renewable Energy Laboratory, Sandia National Laboratories	**Maximizing Scrap Recycling by Designing Cu Tolerant Steel Compositions**	Golden, CO	$2,238,996
Natural Resources Research Institute, University of Minnesota Duluth	Nucor Steel, ArcelorMittal	**Enhancement of Iron Ore Pellet Chemistry to Allow More Efficient Natural Gas Based Direct Reduced Iron Production and Subsequent Conversion of the Metalized Product to Gangue Free Metallic Nodules and Pig Iron**	Duluth, MN	$2,112,619

Builds on an earlier HPC4Mfg project with LLNL and PNW. Will Model H_2 and NG injections to improve energy efficiency and reduce emissions of blast furnaces

Builds on work from an ongoing FY19MT-FOA project with in-line sensors. Targeting 30 – 100 lb. CO_2/TLS reduction in GHG emissions

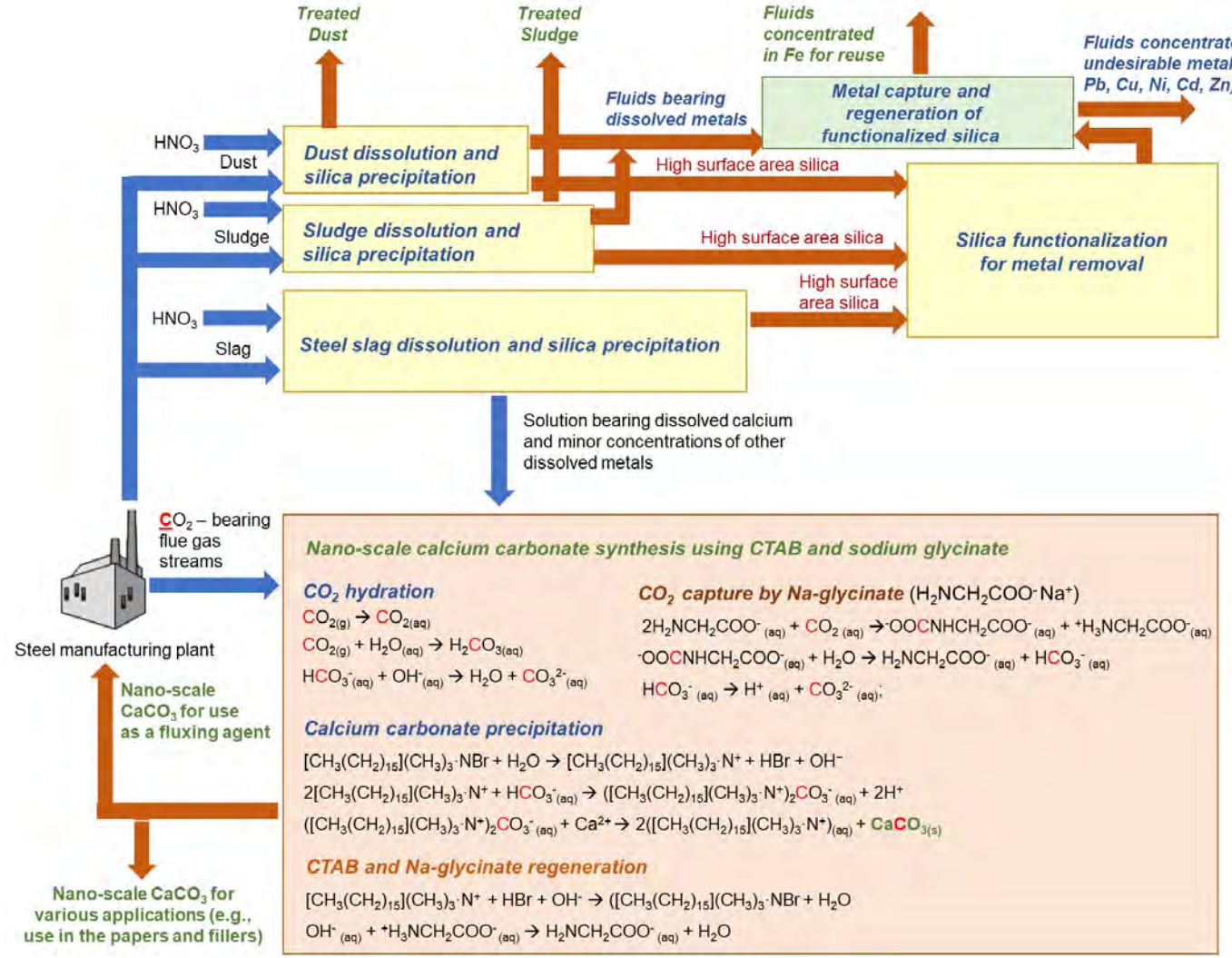
FY20 Multi-topic FOA Awards: Innovation in Iron and Steelmaking Processes

Lead Organization	Partners	Project Title	Location	DOE Funding
Antora Energy Inc.	none	**High-efficiency solid-state waste heat recovery for iron and steelmaking**	Golden, CO	$2,000,000
Cornell University	Reaction Engineering International	**Integrated Reuse and Co-Utilization of Slag, Sludge and Dust With Inherent Heavy Metal Capture and Nanoscale Calcium Carbonate Production as an Enhanced Fluxing Agent in Steel Plants (INSIGHT)**	Ithaca, NY	$1,226,921
Oak Ridge National Laboratory	United States Steel Corporation, Allied Mineral Products Inc., Reno Refractories Inc., American Metallurgical Services Company, LLC, Minerals Manufacturing Corporation, National Energy Technology Laboratory, University of Alabama at Birmingham	**Use of Novel Refractory Design and Installation Techniques for Improved Energy Efficiency in Iron and Steel and Other Energy Intensive Industries**	Oak Ridge, TN	$1,000,000

Use integrated CO_2 capture/hydration with regenerable solvents and surfactants to precipitate nano-scale calcium carbonate from aqueous phases for use as a fluxing agent in iron and steel making

INSIGHT Aims and Approach

- Co-utilize slag, sludge and dust to produce nano-scale $CaCO_3$, recover iron oxide, and remove heavy metals
  - Use integrated CO_2 capture/hydration with regenerable solvents and surfactants to precipitate nano-scale calcium carbonate from aqueous phases for use as a fluxing agent in iron and steel making
  - Use pH swings to produce high-purity silica and iron oxide (for reuse in steelmaking)
  - Functionalize silica particles for effective separation of undesired metals



Approved for release

Alternative Fuel Injection

Some encouraging results that has garnered interest from the industrial partners.

- **Issues:**
  - Feasibility of use of injected fuels for improved energy efficiency & reduced CO_2 emissions
  - Direct injection of H_2 in the raceway desired to decrease furnace CO_2 emissions
  - Furnace instability with H_2 injection due to significant quenching effects on flame temp.
- **Potential Solutions:**
  - Increased H_2 injection rates, and/or temperatures
  - Mixing H_2 with other substances (NG, pulverized coal, etc.)
    - Reduces coke consumption with NG or PCI
  - May require increased O_2 through tuyeres
- **Research:**
  - Use CFD to determine impacts of injection on flame temp, coke rate, and cohesive zone
  - Endeavor to optimize multi-parameter operating conditions to use with pure H_2 injection to achieve significant CO_2 emissions reduction

Approved for release

Intelligent Dynamic EAF Advisory System (IDEAS) for Improving EAF Operating Efficiency

Missouri S&T Materials Science and Engineering

ASU

Traditional EAF Control

-Delayed Feedback Loop to Operator (up to 2-3 days)
-Response dependent on operator skill and motivation

Residuals checked post-production with chem analysis

Post-production slag samples taken (infrequently) to check basicity and FeO%

Temperature/Oxygen probe sampled at the end of the process

Liquid steel height checked by eye and used to adjust scrap weight/account for yield changes

Advisory System Real-Time Data Inputs

- Electricity Input
- Burners/Oxygen Lances
- Raw Materials Additions
- Measured Heat Losses
- Offgas flow rate

Future EAF Control

Real-time process feedback using:
- Enhanced sensor networks
- Digital twin production models
- Dynamic models coverage of full heat cycle
- Recommendations to operator for out-of-bound conditions and corrective actions

Enhanced raw materials tracking via image analysis. Slag chemistry optimization-higher material recovery, flame steering, maximized carbon utilization, and higher energy efficiency

Novel sensors (fiber optics) for precise, real-time temperature and EAF weight monitoring of:
- Water-cooled components
- Refractory condition
- EMI-immune replacement for load cells/strain gauges
- Real-time slag chemistry analysis

CIX, Inc. Continuous Improvement Experts

NUCOR

Linde

GERDAU

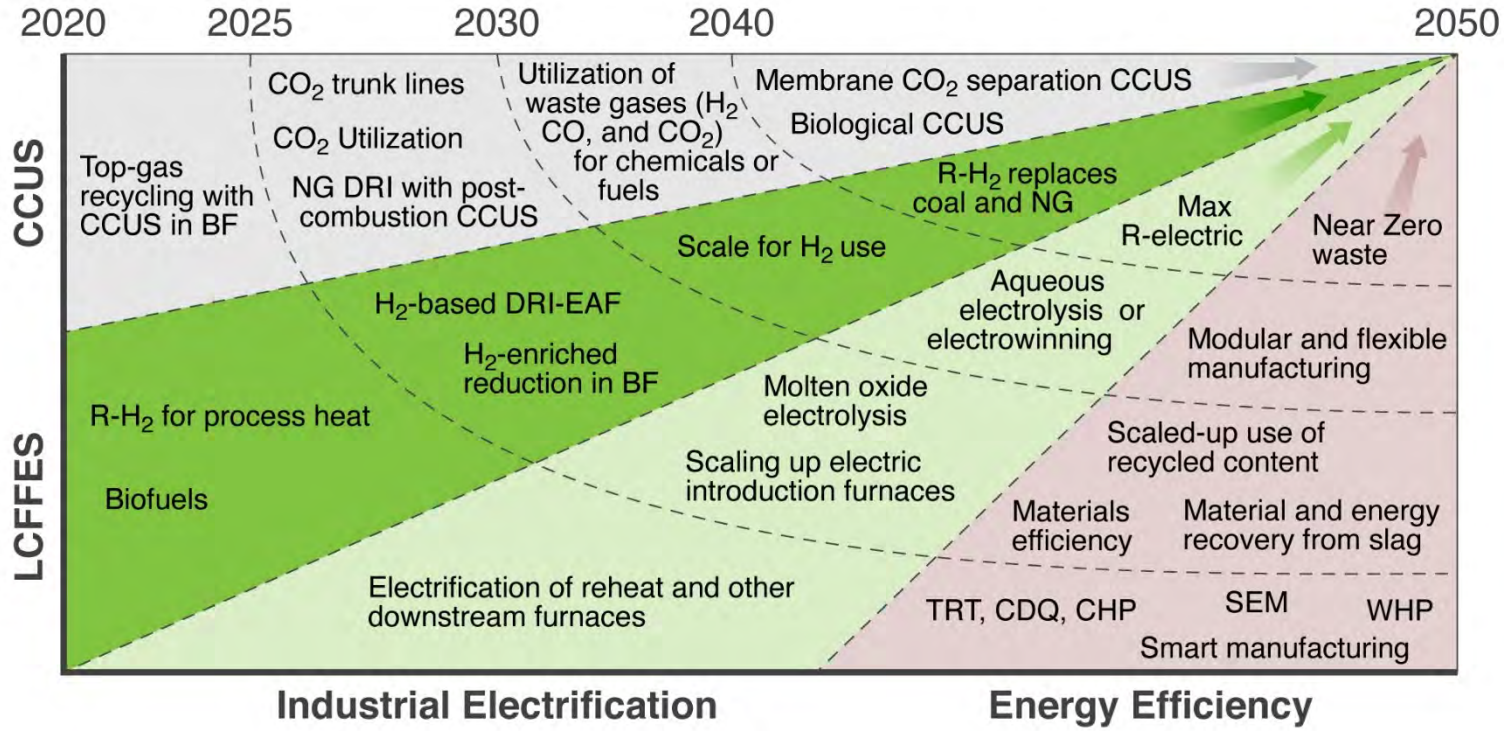
PSMRC Kent D. Peaslee Steel Manufacturing Research Center

BRS Big River Steel, a U. S. Steel company

Objective/Goal	Metric	Minimum	Stretch	Estimated Annual Benefit at Min	Typical Industry Baseline
Reduced energy consumption	kWh/TLS	20	60	$ 88,200,000	300-500 kWh/TLS
Decreased C Consumption	lb./TLS	3	15	$ 14,175,000	15-60 lb./TLS
Electrode Savings	lb./TLS	0.1	0.5	$ 31,500,000	0.9-6.0 lb./TLS
Reduced Flux Consumption	lb./TLS	5	10	$ 23,625,000	60-150 lb./TLS
Increased Fe Yield	%	1	5	$ 252,000,000	87%-94%
Decreased operating cost	$/TLS	$2/ton	$10/ton		
Increased productivity	TLS/year	10%	30%		
Decreased slag volume		5%	10%		
Reduced EAF dust generation	lb./TLS	2	4	63,000 tons/y	10-40 lb./TLS
Reduced GHG	Lb. CO_2/TLS	30	100	945,000 tons/y	Raw Mat'l Dependent

Pending Approval for release

Where to from here?

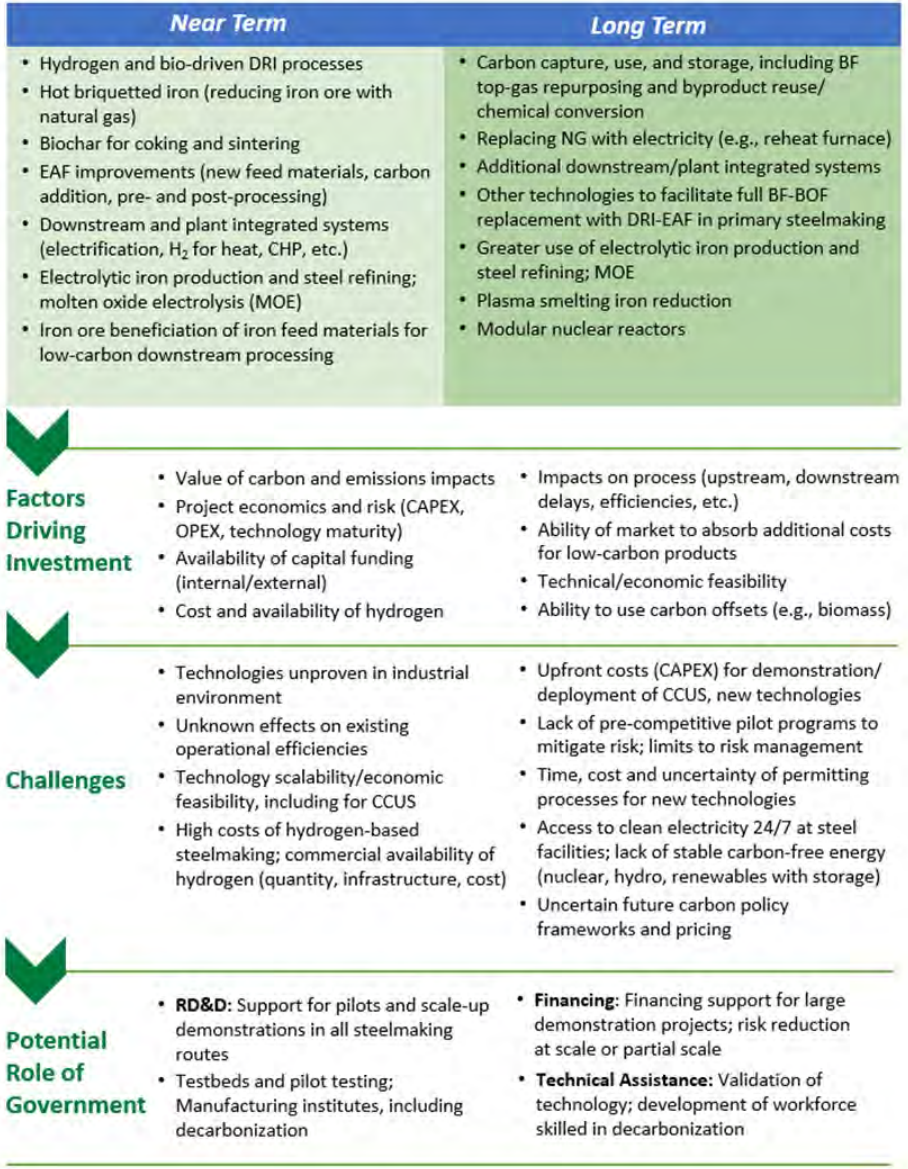


LANDSCAPE OF RD&D ADVANCEMENT OPPORTUNITIES BY DECADE AND DECARBONIZATION PILLAR FOR THE U.S. STEEL INDUSTRY NOTED BY ATTENDEES AT THE ROADMAP VIRTUAL SESSIONS. FURTHER DEFINITIONS ARE AVAILABLE IN THE GLOSSARY. ACRONYMS ARE DEFINED IN THE ACRONYMS LIST AT TOP OF THE DOCUMENT. SOURCE: THIS WORK.

The U.S. Department of Energy's Advanced Manufacturing Office held the Industrial Decarbonization Roundtable: Iron and Steel on December 8, 2021. The roundtable brought together executive leaders from a diversity of companies in the industry to gather perspectives on opportunities and challenges, both near and long term, for decarbonization of iron and steel processes.

DE-FOA-0002687 RFI on Industrial Decarbonization Priorities released on January 27, 2022.

2021 Industrial Decarbonization Roundtable: Iron and Steel



	Near Term	Long Term
	• Hydrogen and bio-driven DRI processes • Hot briquetted iron (reducing iron ore with natural gas) • Biochar for coking and sintering • EAF improvements (new feed materials, carbon addition, pre- and post-processing) • Downstream and plant integrated systems (electrification, H_2 for heat, CHP, etc.) • Electrolytic iron production and steel refining; molten oxide electrolysis (MOE) • Iron ore beneficiation of iron feed materials for low-carbon downstream processing	• Carbon capture, use, and storage, including BF top-gas repurposing and byproduct reuse/ chemical conversion • Replacing NG with electricity (e.g., reheat furnace) • Additional downstream/plant integrated systems • Other technologies to facilitate full BF-BOF replacement with DRI-EAF in primary steelmaking • Greater use of electrolytic iron production and steel refining; MOE • Plasma smelting iron reduction • Modular nuclear reactors
Factors Driving Investment	• Value of carbon and emissions impacts • Project economics and risk (CAPEX, OPEX, technology maturity) • Availability of capital funding (internal/external) • Cost and availability of hydrogen	• Impacts on process (upstream, downstream delays, efficiencies, etc.) • Ability of market to absorb additional costs for low-carbon products • Technical/economic feasibility • Ability to use carbon offsets (e.g., biomass)
Challenges	• Technologies unproven in industrial environment • Unknown effects on existing operational efficiencies • Technology scalability/economic feasibility, including for CCUS • High costs of hydrogen-based steelmaking; commercial availability of hydrogen (quantity, infrastructure, cost)	• Upfront costs (CAPEX) for demonstration/ deployment of CCUS, new technologies • Lack of pre-competitive pilot programs to mitigate risk; limits to risk management • Time, cost and uncertainty of permitting processes for new technologies • Access to clean electricity 24/7 at steel facilities; lack of stable carbon-free energy (nuclear, hydro, renewables with storage) • Uncertain future carbon policy frameworks and pricing
Potential Role of Government	• **RD&D:** Support for pilots and scale-up demonstrations in all steelmaking routes • Testbeds and pilot testing; Manufacturing institutes, including decarbonization	• **Financing**: Financing support for large demonstration projects; risk reduction at scale or partial scale • **Technical Assistance:** Validation of technology; development of workforce skilled in decarbonization

Thank you

For additional information
and to subscribe for updates:

energy.gov/eere/amo

Department of Energy (DOE)

The Technology Whitespace for Deep Decarbonization of Steel Production

Katharine Greco

Fellow, Advanced Research Projects Agency (ARPA) – U.S. Department of Energy

The Technology Whitespace for Deep Decarbonization of Steel Production

Katharine Greco, PhD
ARPA-E Fellow

MN Iron & The Green Economy

March 16th, 2020

Dr. Jen Shafer
Program Director

Dr. Christina Chang
Fellow (alumni)

ARPA-E Mission

Goal 1: To enhance the economic and energy security of the United States through the development of energy technologies that—

Goal 2: To ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies.

arpa·e
CHANGING WHAT'S POSSIBLE

ARPA-E Impact Indicators

Since 2009 ARPA-E has provided **$2.93 billion** in R&D funding to more than **1,270 projects**

183 projects have attracted more than **$7.6 billion** in private-sector follow-on funding

109 companies formed by **ARPA-E projects**

266 projects have **partnered with other government agencies** for further development

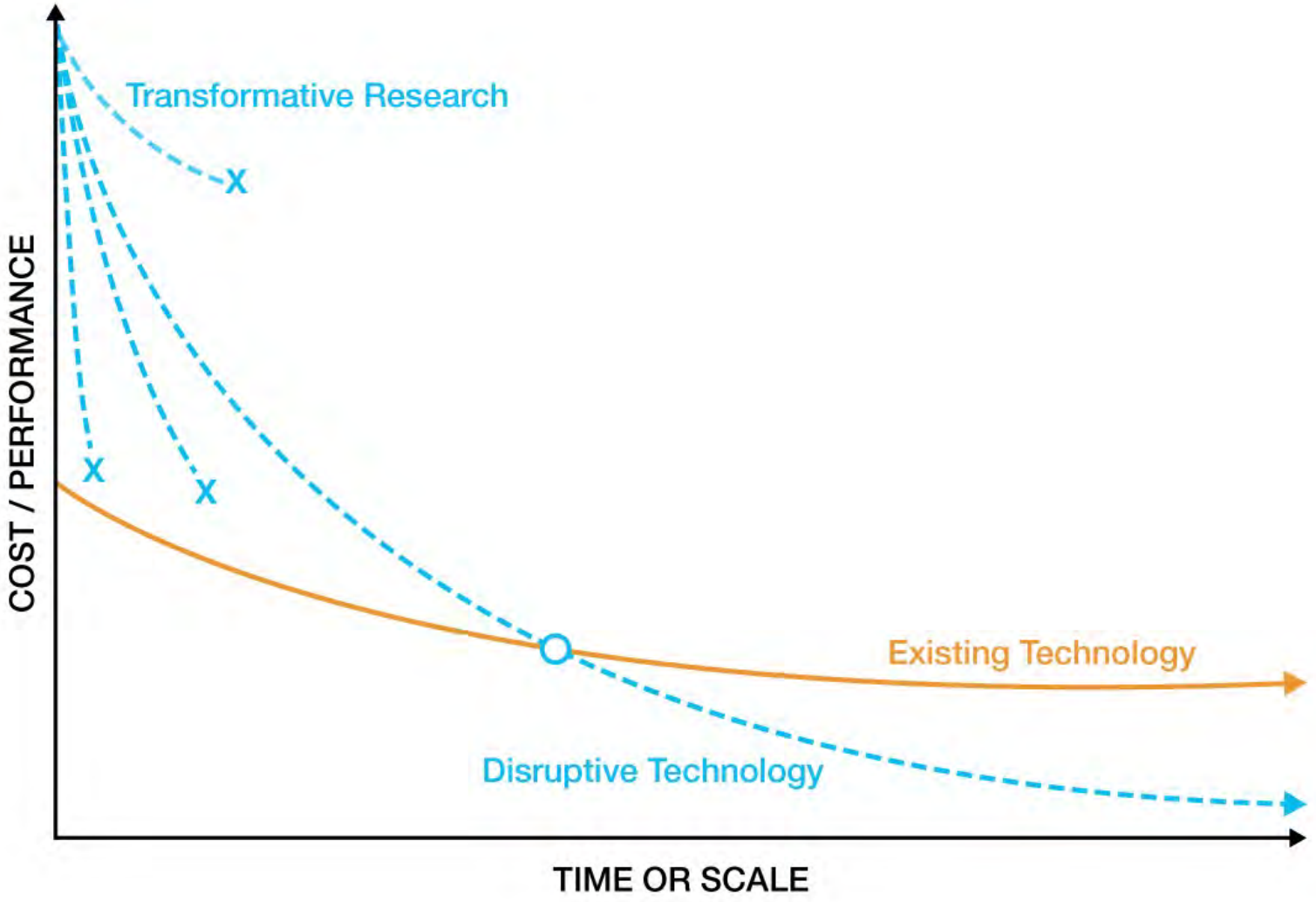
4,871 peer-reviewed **journal articles** from ARPA-E projects

789 patents issued by U.S. Patent and Trademark Office

253 licenses reported from ARPA-E projects

17 exits market valuations worth **$19.4 billion** from mergers, acquisitions, and IPOs

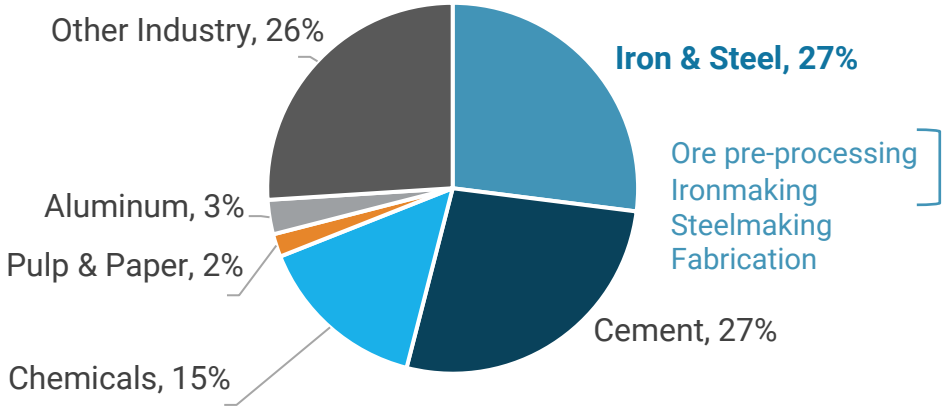
Creating New Learning Curves



arpa·e
CHANGING WHAT'S POSSIBLE

Green ironmaking will be essential to get to net-zero

Global Industrial Emissions (~10 Gt CO_2e)



Ore pre-processing
Ironmaking
Steelmaking
Fabrication

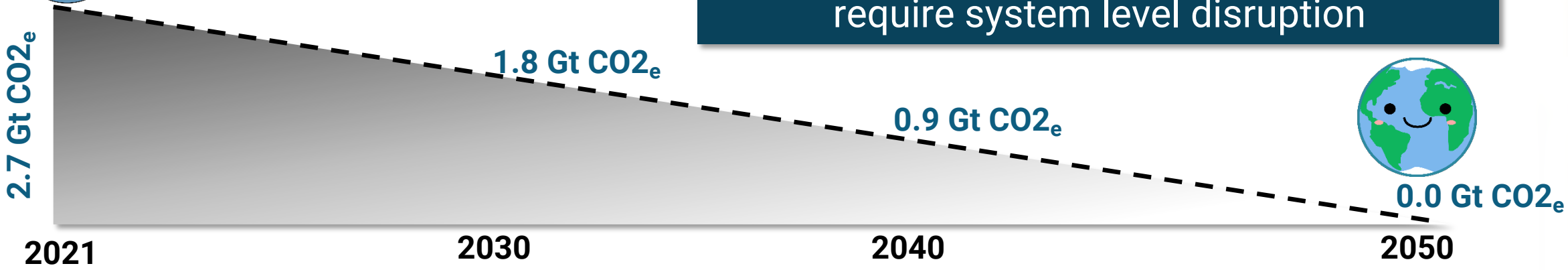
Ironmaking Globally:

Produced in 2019: 1.4 Gt Fe
3% of world energy (16 quads)
5.5% of world CO_2e (2.7 Gt CO_2e)

Ironmaking in the USA:

Produced in 2019: 26 Mt Fe
0.4% of US energy (0.4 quads)
~1% of US CO_2e (59 Mt CO_2e)

Cost competitive, zero emission iron will require alternative technologies and may require system level disruption



US iron & steel industry process map

Annual US steel demand (138 Mt steel) is 8% of global demand (1800 Mt = 1.8 Gt steel)

US annual **steel demand** ~ 138 Mt

Domestic steel production		Imports (semifinished + in goods)
89 Mt steel	268 Mt CO_2 (4% of US) 2+ quads (2% of US)	**43 Mt steel** 95 Mt CO_2 0.8+ quads

268 Mt CO_2e — Current Emissions

126 Mt CO_2e — **With 100% Renewable Grid**

Ironmaking

Steelmaking

Coal — 12 Mt CO_2e, 0.04 quads — Coking — Coke

Ore concentrate — 3 Mt CO_2e, 0.04 quads — Agglomeration — Sinter; Pellets

Beneficiation

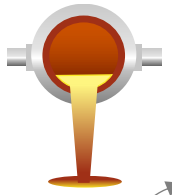
Extraction

Mines

"Mining" 28 Mt CO_2e, 10

$CO + H_2$ from CH_4

40 Mt CO_2e, 0.34 quads — Blast Furnace Reduction (27 Mt Fe) — liquid iron



75% / 25%

~4 Mt CO_2e, 0.02 quads — Basic Oxygen Furnace Steelmaking (35 Mt steel)

~3 Mt CO_2e — Direct Reduction (2 Mt Fe) — direct reduced iron (solid)

1-10%

22 ~~44~~ Mt CO_2e, 0.1 quads — Electric Arc Furnace Steelmaking (54 Mt steel)

90-99%

scrap (61 Mt steel)

molten Steel (89 Mt)

0.02 quads — casting

15 Mt CO_2e, 0.3 quads — rolling steps

mill products

26 ~~120~~ Mt CO_2e, 1 quad — fabrication steps

steel products

15% landfill

~85% recycled

Emissions in 10^6 tonnes CO_2e (Mt CO_2e)
Production vol in 10^6 tonnes metal (Mt)
Values if grid were 100% renewable

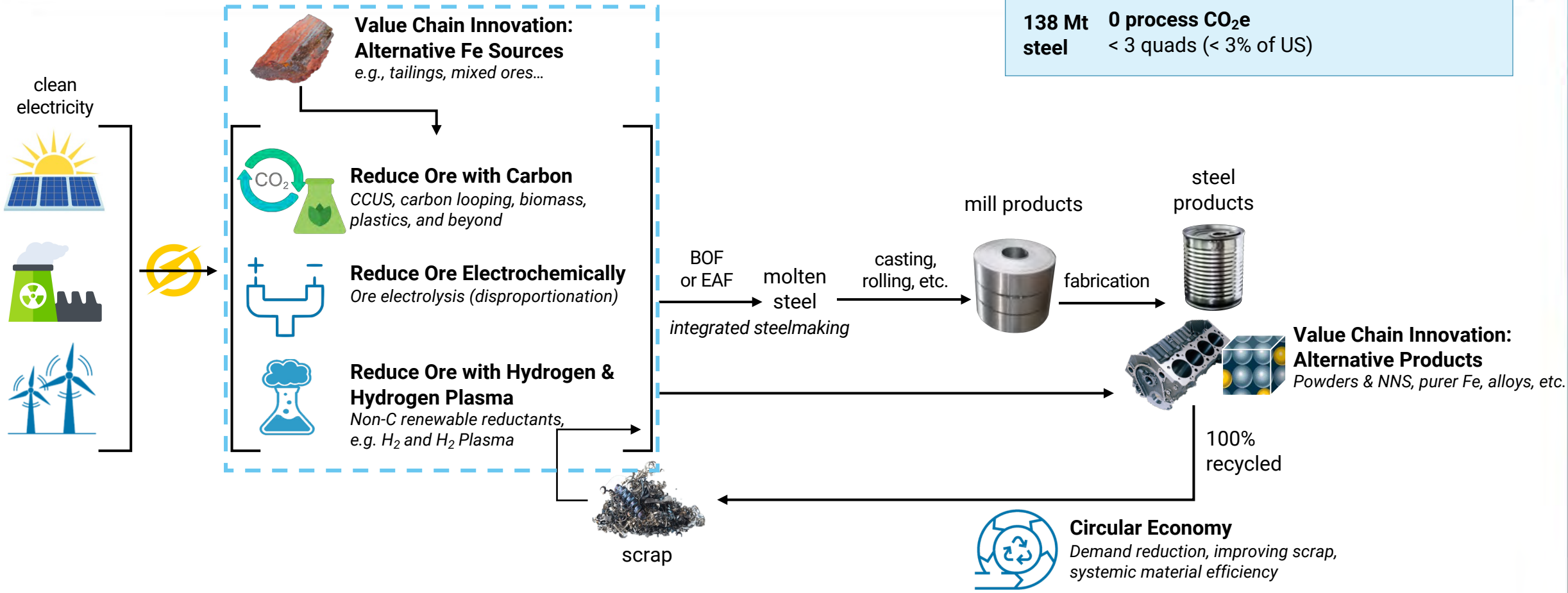
arpa·e CHANGING WHAT'S POSSIBLE

Reimagined steel industry process map

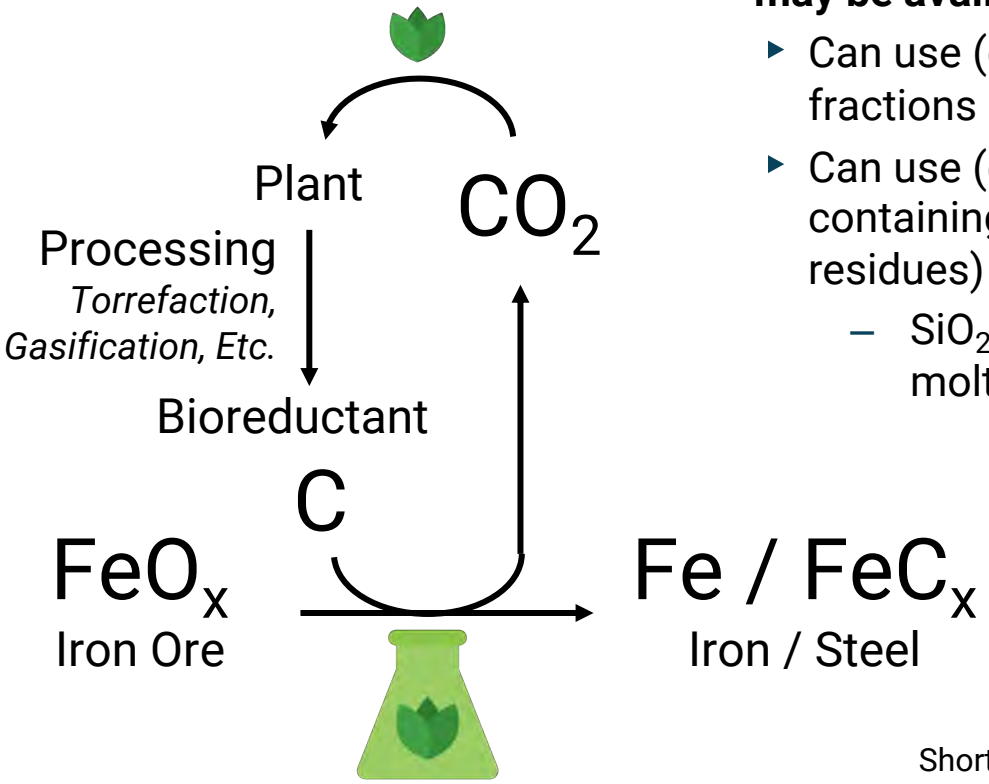
US annual **steel demand** ~ 138 Mt

Domestic steel production

138 Mt steel	**0 process CO_2e** < 3 quads (< 3% of US)



Reducing ore with biomass could be drop-in replacement



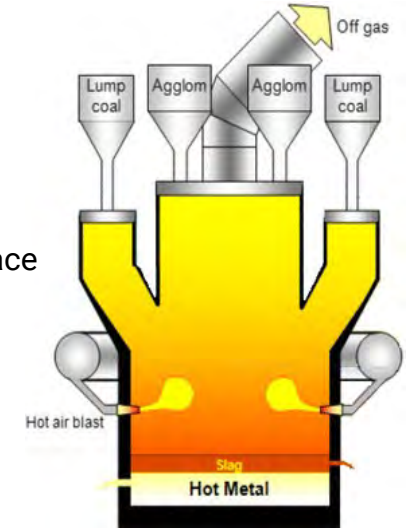
Cheap, appropriate bio-feedstocks may be available

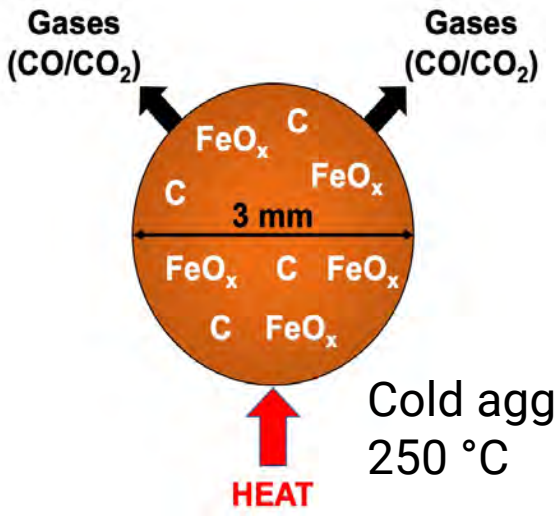
- Can use (cheaper) solid or gas fractions
- Can use (cheaper) 2nd gen ash-containing residues (e.g. forest residues)
  - SiO_2/Al_2O_3 is desirable in molten ironmaking!

Component	Ash
Standing trees	2%
Logging residue	2%
Logging residue chips	2%
Delimbed logs	1.4%
Dried pine blend	1.75%

"Autoreducing" agglomerates ("solid fuels")

Short mini furnace

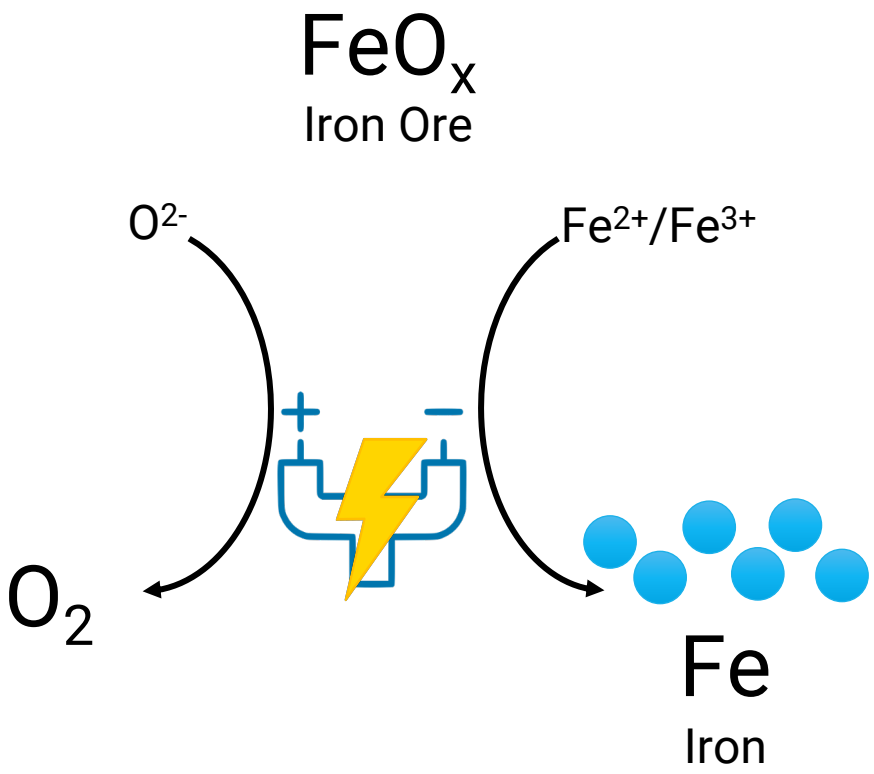




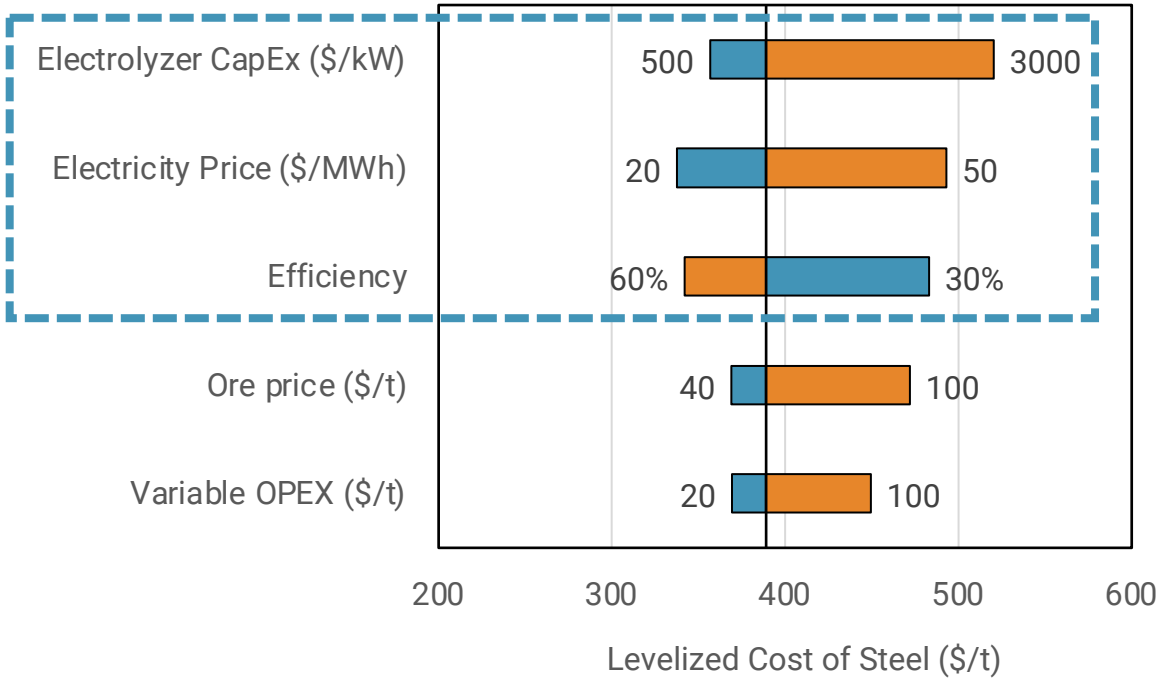
Cold agglomeration
250 °C

Hartley et al. - WOODY FEEDSTOCKS STATE OF TECHNOLOGY REPORT, INL 2019
Contrucci, Mourao, Takano, D'Abreu, Allanore, Sustainable Industrial Processing Summit (2015)

Reducing ore electrochemically can utilize cheap electricity

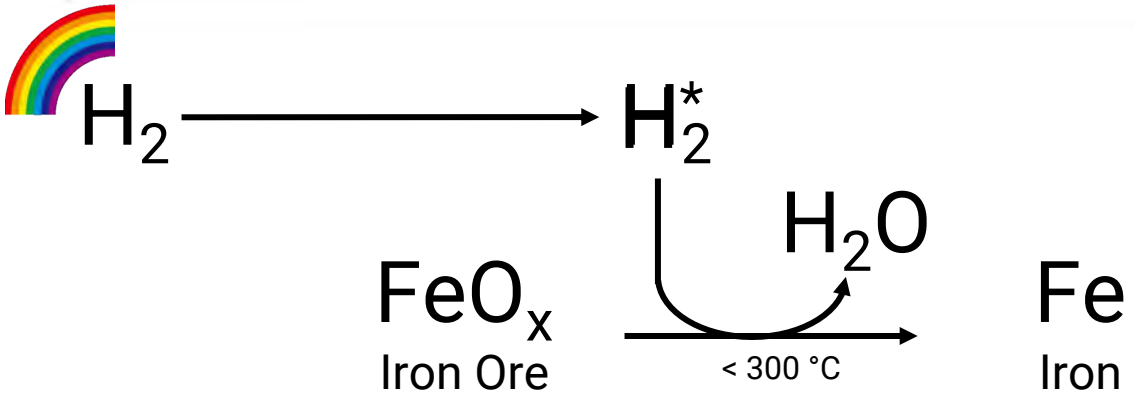


can run intermittently when e^- cheapest



TEA credit: Dr. Ian Robinson

Reducing ore with H plasma can increase throughput



Technical challenges:

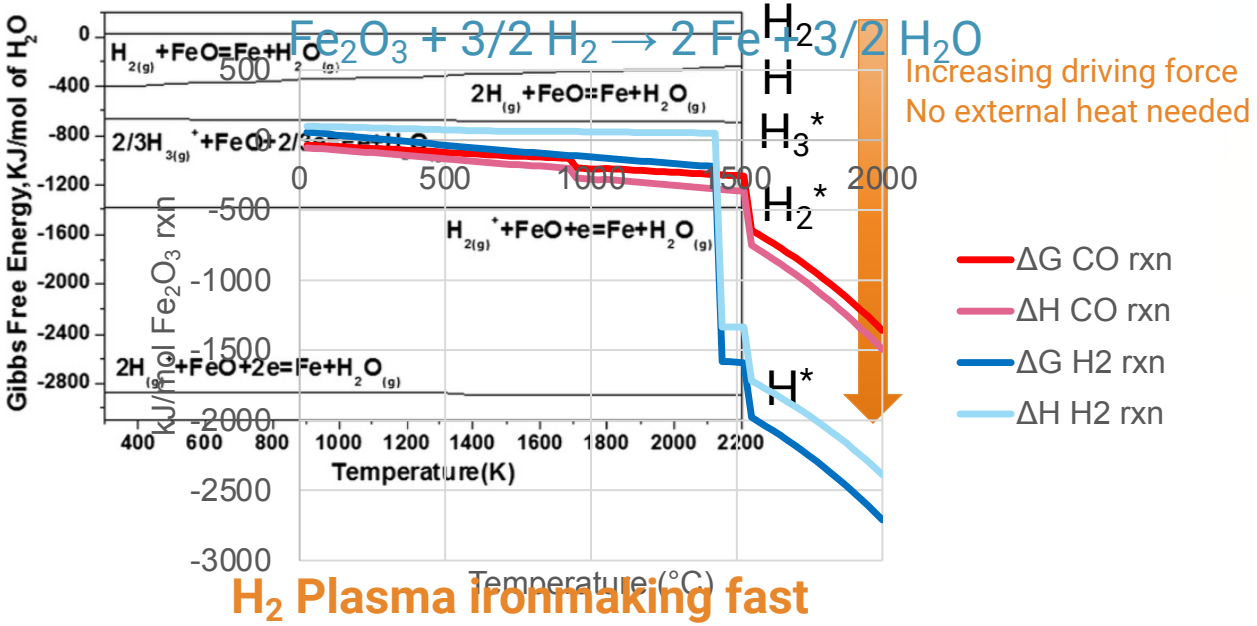
- Only small fraction of plasma volume utilized, thus low conversion, high E cost per Fe produced
- Thermalization losses not recovered or re-integrated

Kinetic benefit:
Faster throughput

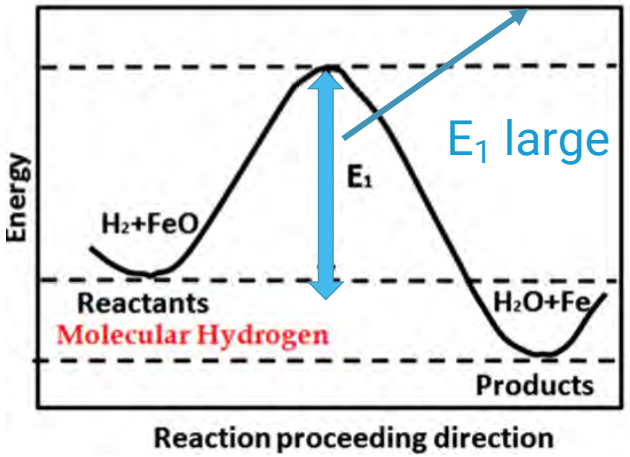
Thermodynamic benefit

$Fe_2O_3 + 3\,CO \rightarrow 2\,Fe + 3\,CO_2$

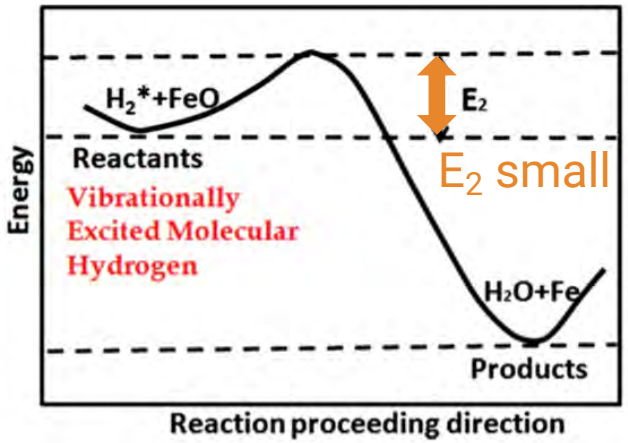
$Fe_2O_3 + 3/2\,H_2 \rightarrow 2\,Fe + 3/2\,H_2O$

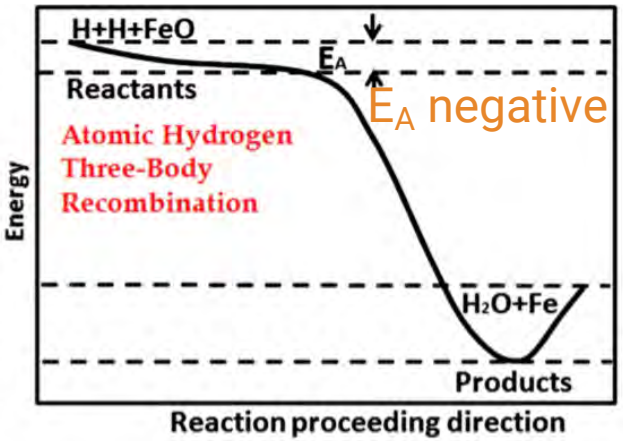


H_2 ironmaking slow



H_2 Plasma ironmaking fast





Value chain innovation: utilize abundant domestic Fe sources

Hematite
Fe_2O_3

~60% Fe

Hematite/REE Co-deposit

~60% Fe

Taconite
Fe_3O_4/Fe_2O_3

~20-30% Fe

Waste Products
(Red Mud)

~30-90% Fe

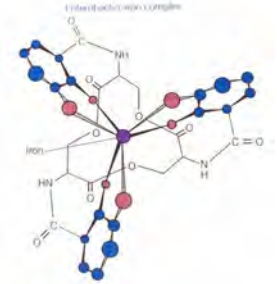
Tailings

~30-60% Fe

Imported

Domestic

Use chelating agents to increase rate of dissolution



Siderophores + functional mimics

Avoid dissolution via catalytic siderophores

Ex) methemoglobin reductase
($Fe^{3+} \rightarrow Fe^{2+}$)

Would remove beneficiation, pelletization and sintering

$$Al^{3+} + 3e^- \rightarrow Al^0 \quad E^0 = -1.66V$$

$$Ti^{3+} + e^- \rightarrow Ti^0 \quad E^0 = -1.37V$$

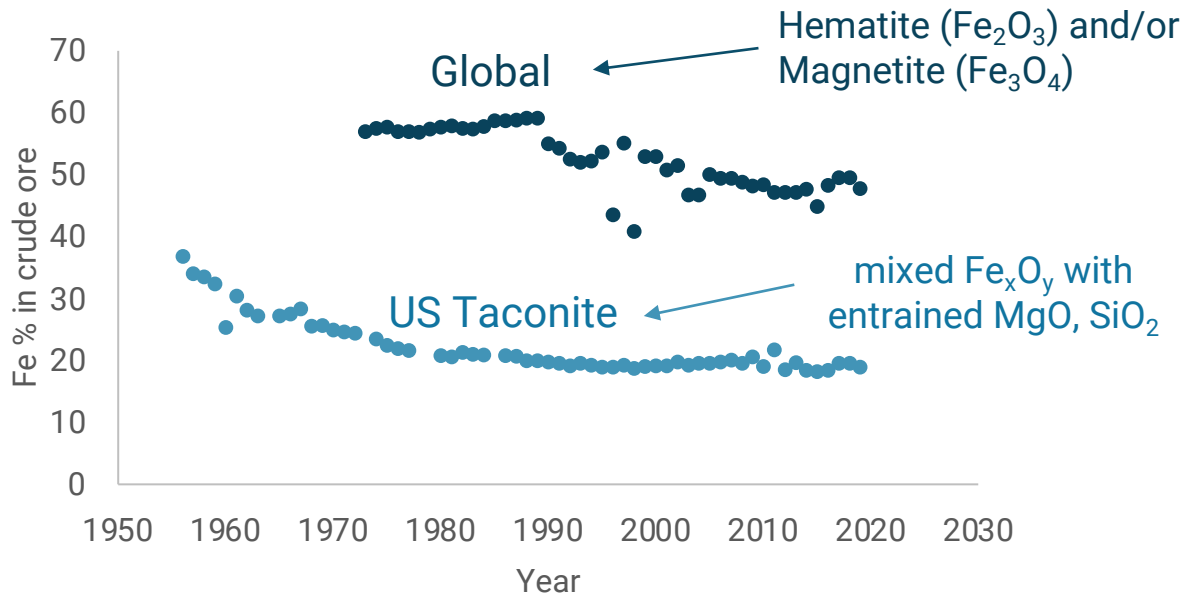
$$Fe^{2+} + 2e^- \rightarrow Fe^0 \quad E^0 = -0.44V$$

$$Fe^{3+} + 3e^- \rightarrow Fe^0 \quad E^0 = -0.036V$$

$$Cu^{2+} + 2e^- \rightarrow Cu^0 \quad E^0 = 0.34V$$

$$Cu^{+} + e^- \rightarrow Cu^0 \quad E^0 = 0.52V$$

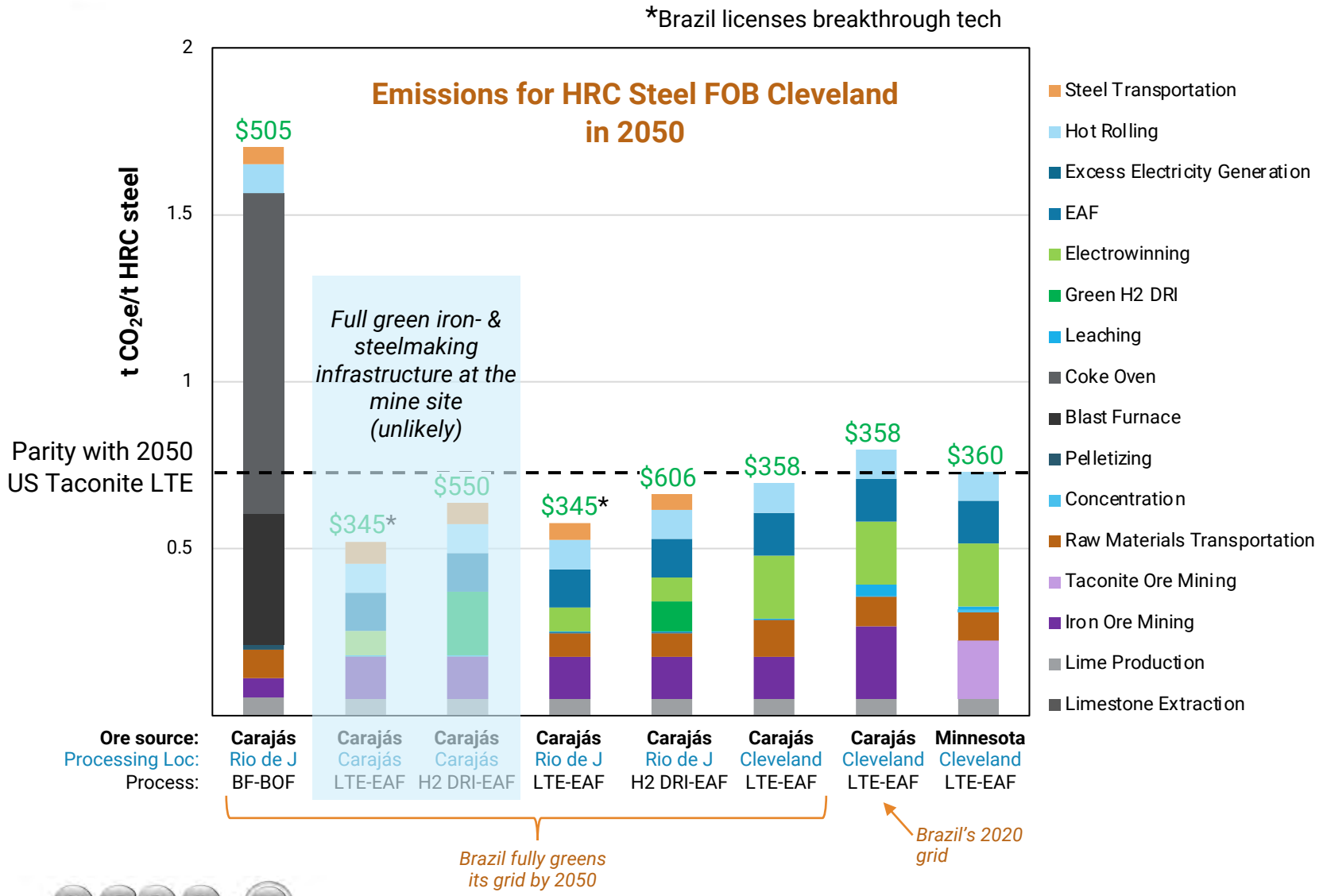
U.S. vs Global iron ore resources



Country	Fe% (crude ore)	Fe% (pellets)	Composition	Value ($/t)
Brazil	52	63.7	Hematite	127.32
Canada	38	60.2	Hematite	134.77
USA	19	63.5	Taconite	87.12

U.S. ore is low grade (low Fe%) compared to global average

Taconite is cost- and emissions- competitive with green imports



Key Takeaway #1:
Domestic low-T electrolysis of taconite can hit very **low costs** and **low emissions**

Key Takeaway #2:
Disruptive tech can ensure U.S. resources **remain competitive**

LCA credit: Dr. Daniel Garcia

https://arpa-e.energy.gov

katharine.greco@hq.doe.gov

Natural Resources Research Institute (NRRI): Iron Ore & Minerals of the Future

Rolf Weberg

NRRI Executive Director **&**

Brett Spigarelli

NRRI Metallurgical Engineer

Natural Resources Research Institute

University of Minnesota Duluth

Driven to Discover

Discover the Economy of the Future

Minnesota Iron Ore and the Green Economy

Virtual Forum Presentation | March 16, 2022

Presentation Overview

Natural Resources Research Institute
University of Minnesota Duluth
Driven to Discover

- **Introduction to NRRI**
- **Minnesota Iron -** *Challenges of Today*
- **Research Opportunities for MN -** *Iron Ore and the Green Economy*
- **Steelmaking Potential -** *What's Next*

NRRI Introduction

Natural Resources Research Institute
University of Minnesota Duluth
Driven to Discover

NRRI CHARTER: To foster the economic development of Minnesota's natural resources in an environmentally sound manner to promote private sector employment.

-Minnesota State Legislature, 1983

NRRI MISSION:

Deliver integrated research solutions

that value our resources, environment and economy for a sustainable and resilient future.

NRRI VISION:

Discover the Economy of the Future

What is the Economy of the Future?

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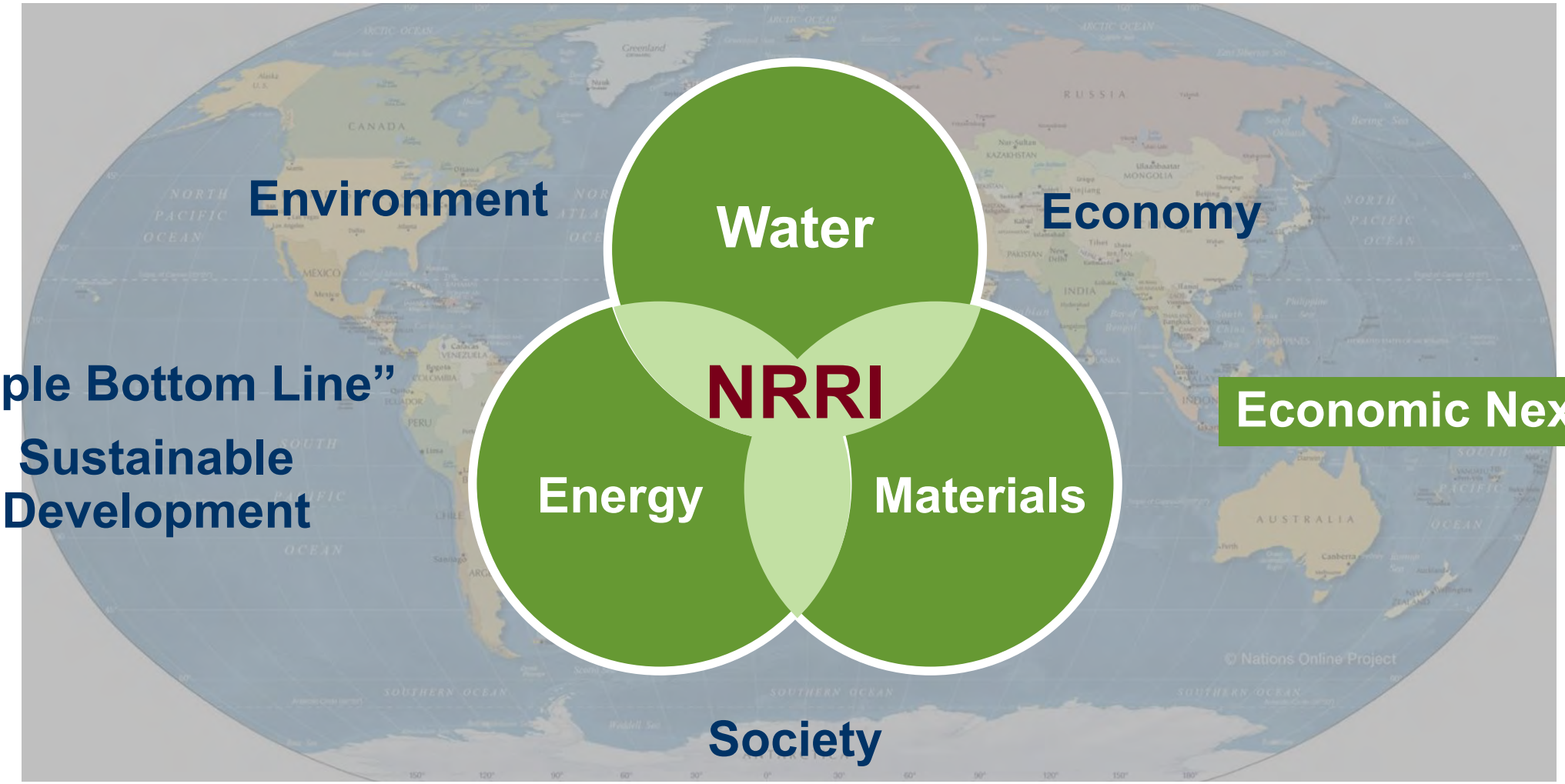

NRRI Facilities

Natural Resources Research Institute
University of Minnesota Duluth
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NRRI DULUTH

19 research labs and pilot areas for land & water ecosystem studies, wildlife, forestry, forest products, minerals, materials development & testing, and process development.

NRRI COLERAINE

15 building, 27-acre industrial laboratory site focused on minerals characterization, minerals processing, metallurgy, biomass processing, energy and materials research.

NRRI Innovation Goals:

Good Decisions for the Economy of the Future

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- ✓ Understand Our Resources
- ✓ Diversify the Product Portfolio
- ✓ Convert Waste to Value Opportunity
- ✓ Embrace Life Cycle Thinking

NRRI IMPACTS – *Strategic Initiatives*

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Ecosystem Resilience

- Understand ecosystem structures and interactions in the face of land use & climate change
- Detect and assess ecosystem disturbances
- Deliver strategies & technologies to mitigate impacts to land and water ecosystems

Future Forest Industries

- Model forest composition & function vs. harvest scenarios and climate change
- Develop hybrid plant species for biomass, biofuels and bioplastics
- Develop partnerships in engineered forest product opportunities
- Convert biomass into energy and value-add carbon products

Iron/Minerals of the Future

- Characterize remaining ore reserves & develop beneficiation strategies
- Reduce energy, water, effluent and environmental impacts of mineral activities
- Decarbonization of iron, steel, other metals and related products

Minnesota Iron – Today's Challenges

Today's challenges include:

1. Decarbonization of the industry
2. Energy and water conservation
3. Changing nature of MN iron ore
4. Broader product portfolio

Ore Characterization

Iron Ore Processing

Ironmaking

Steelmaking

NRRI is working on all aspects of Iron and Steel Production

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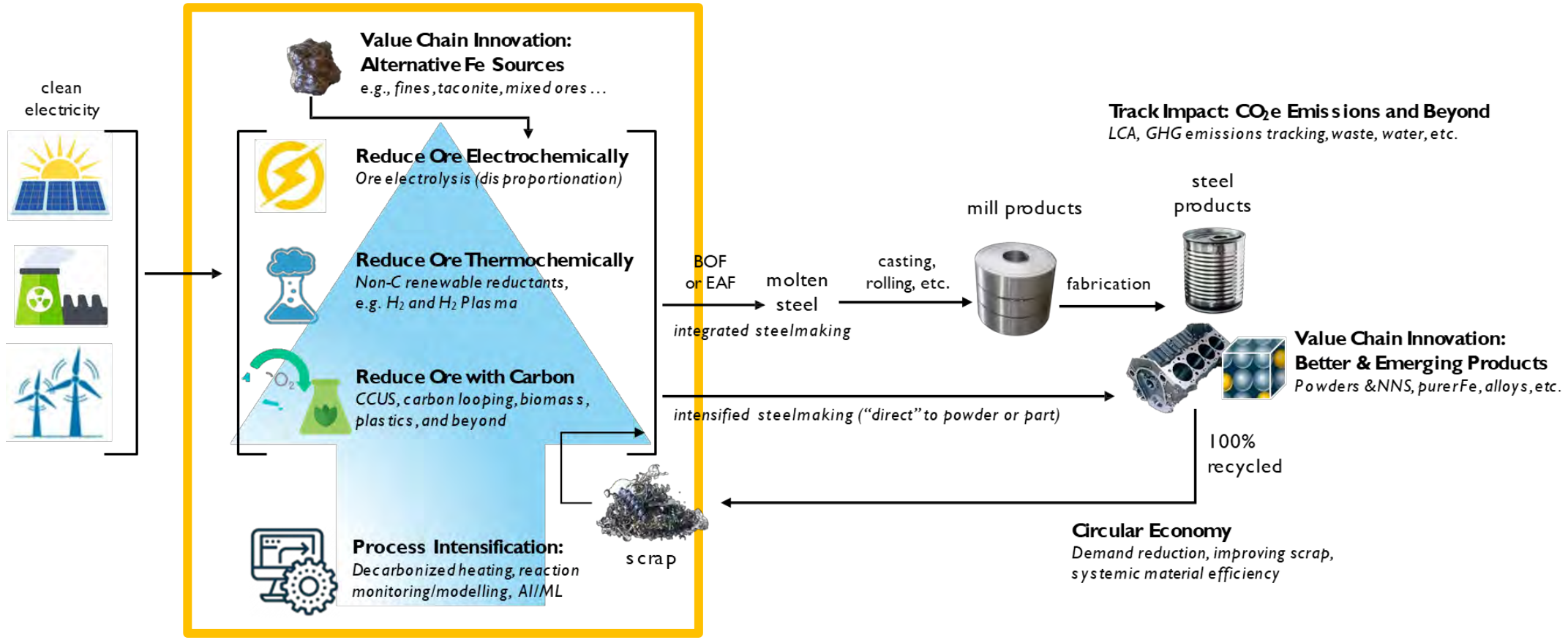
Decarbonization of the Industry



- Steel production accounts for roughly 8% of global CO_2 emissions
  - 3.5% of US CO_2 emissions
- Minnesota will need to drive value chain innovation to stay competitive

C. M. Chang, "The Technology Whitespace for Deep Decarbonization of Steel Production," in *ARPA-E Zero Emissions Iron and Steelmaking Workshop*, 2021.

Energy and Water Conservation

Challenges

- Reduced energy consumption
- Reduced water usage
- Impact Management
  - Sulfate
  - Mercury
  - Other contaminates
- Social license to operate

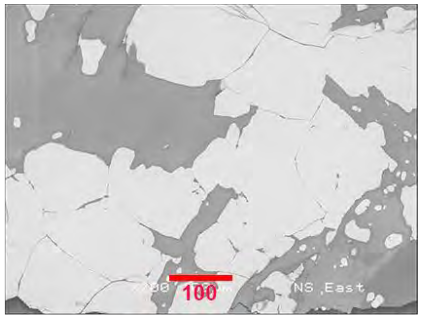
Changing Nature of Minnesota Ore

Changing iron ore quality

- More complex
- Finer liberating

New pellet processing additives

- Binders and coatings
- Flux materials
- Chemical reagents

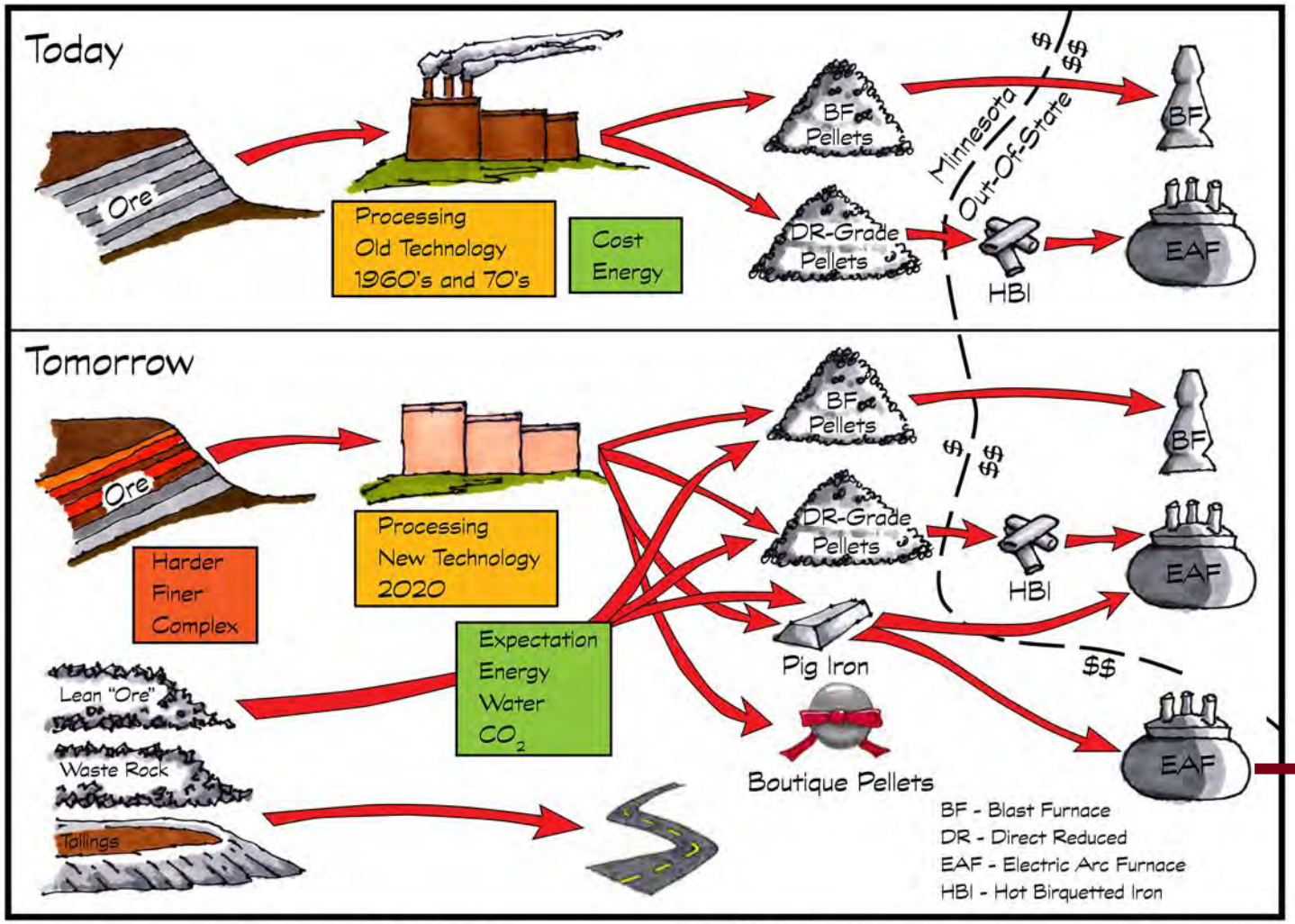


Magnetite grains are up to 144 µm

Magnetite grains with a liberation size of 45 µm

Magnetite grains with a liberation size < 25 µm

Broader Product Portfolio



Research Map, Version 1.2, R. Johnson, April 15, 2020

Research Opportunities for Minnesota Iron Ore and the Green Economy

Ore Characterization

Iron Ore Processing

Ironmaking

Steelmaking

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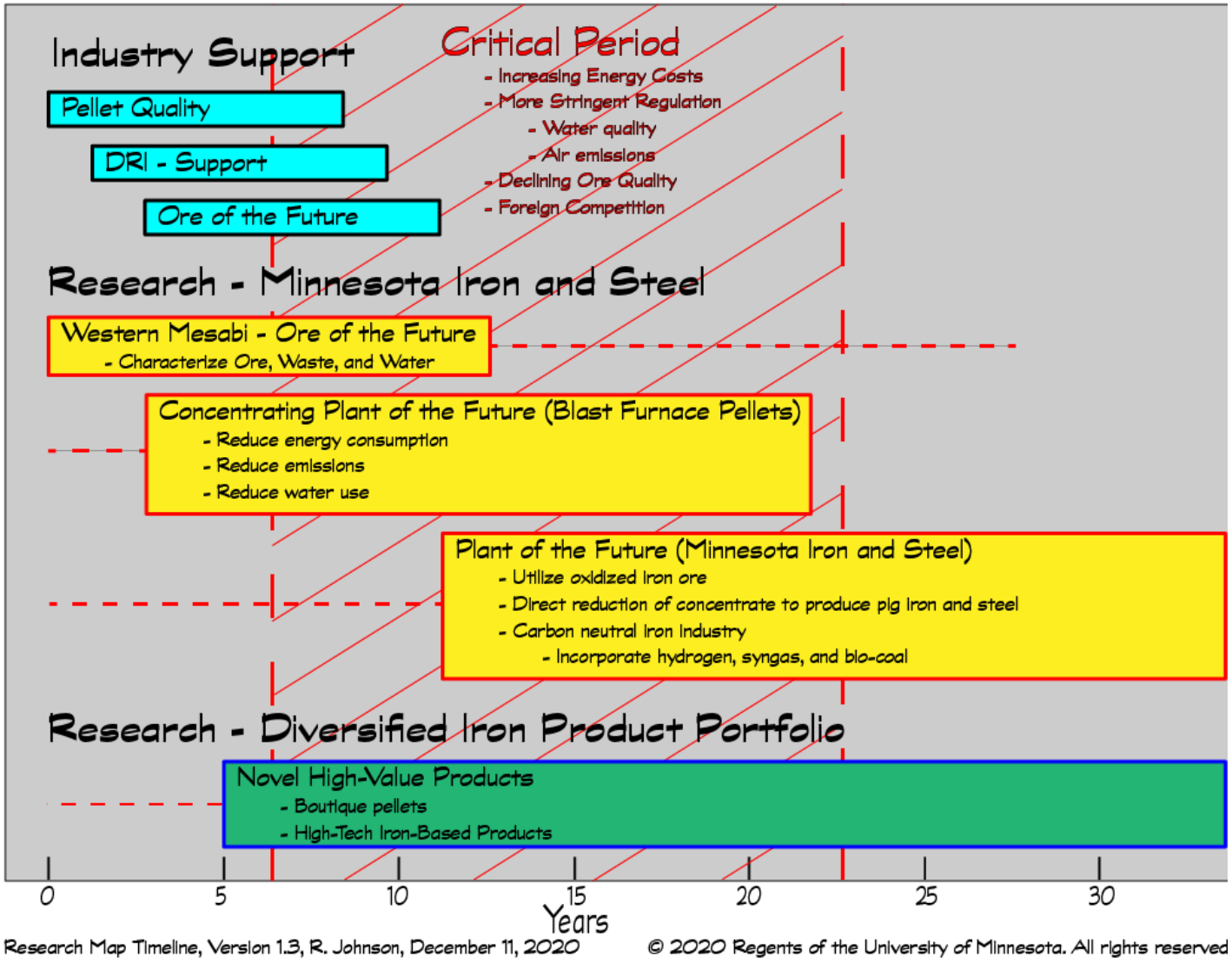
Emerging Research Pipeline



Incumbent Industry Support

- Ore Characterization
- Comminution
- Mineral Processing
- Agglomeration
- Induration/Pyrometallurgy
- Pellet Quality



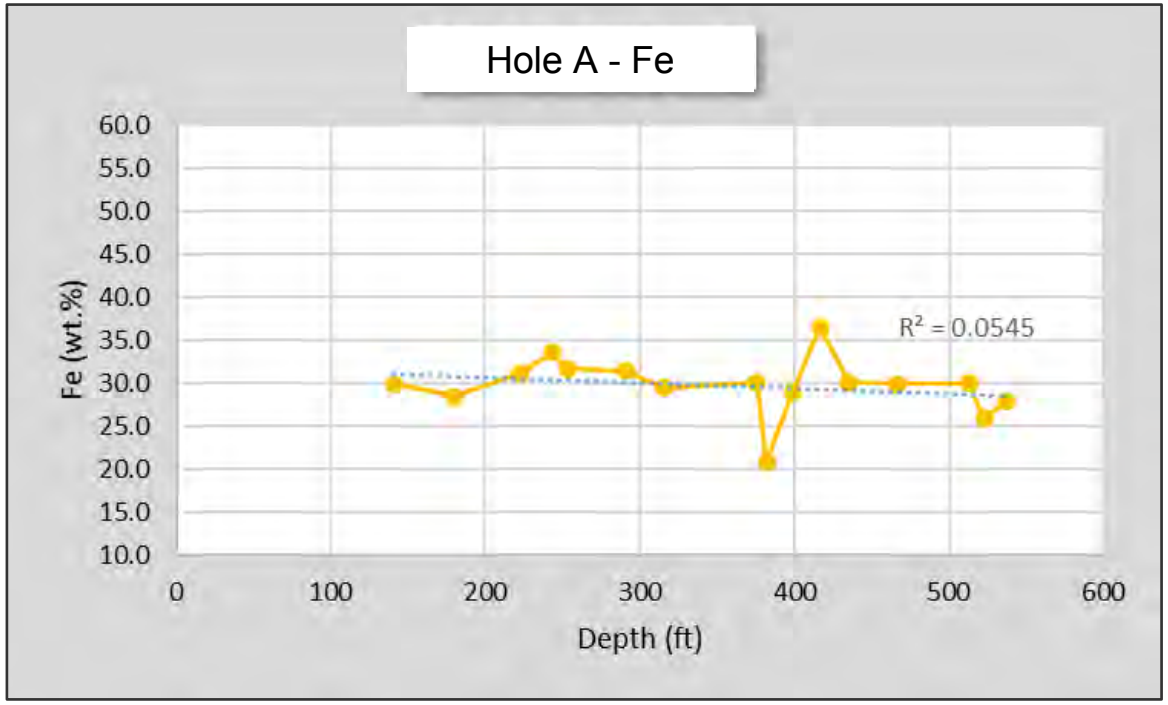


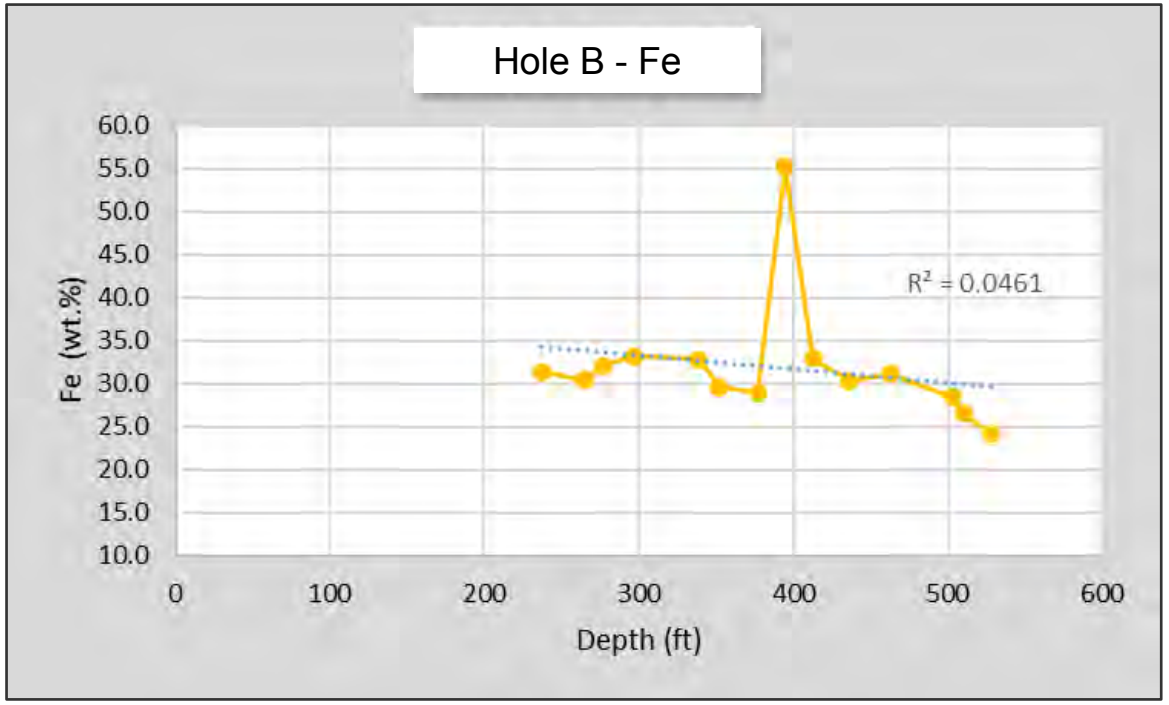
Characterization of Alternative Iron Resources

- **Project**
  - LCCMR – Western Mesabi Iron Resources of the Future
  - Budget: $275,000

- **Objectives**
  - Completed characterization of the partially and highly oxidized iron formation that occurs throughout the western end of the Mesabi Iron Range
  - Conducted a comprehensive geologic, mineralogic (process and environmental), geometallurgical, and metallurgical characterization

Characterization of Alternative Iron Resources



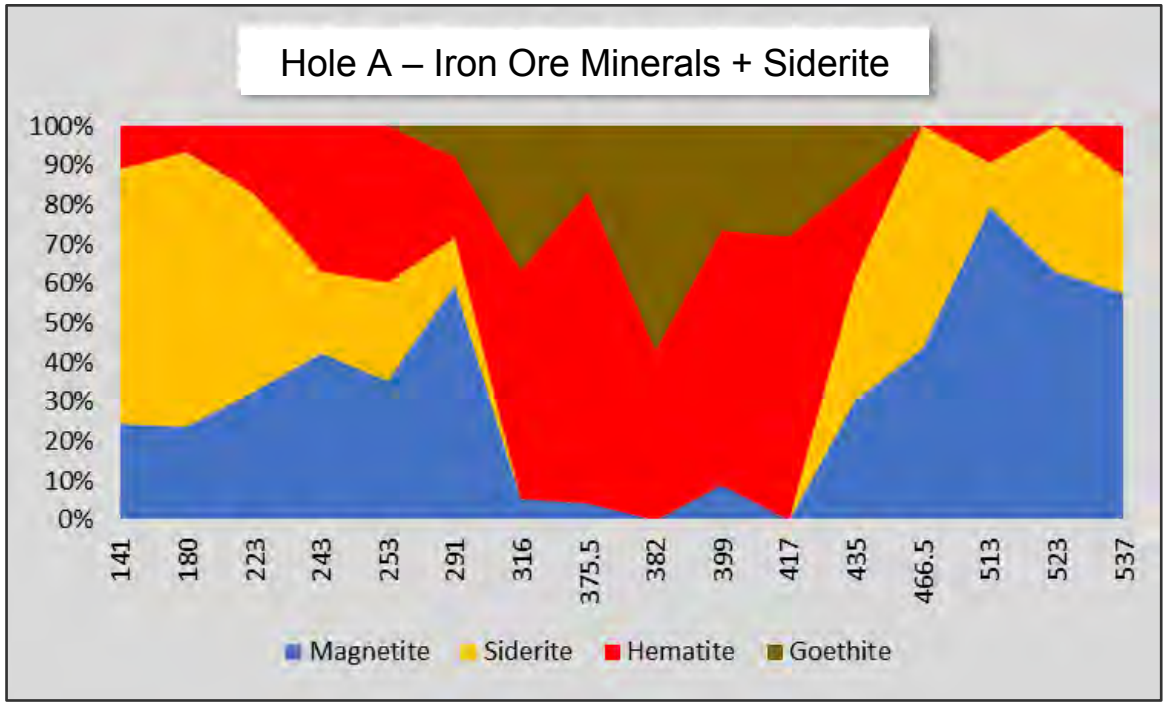


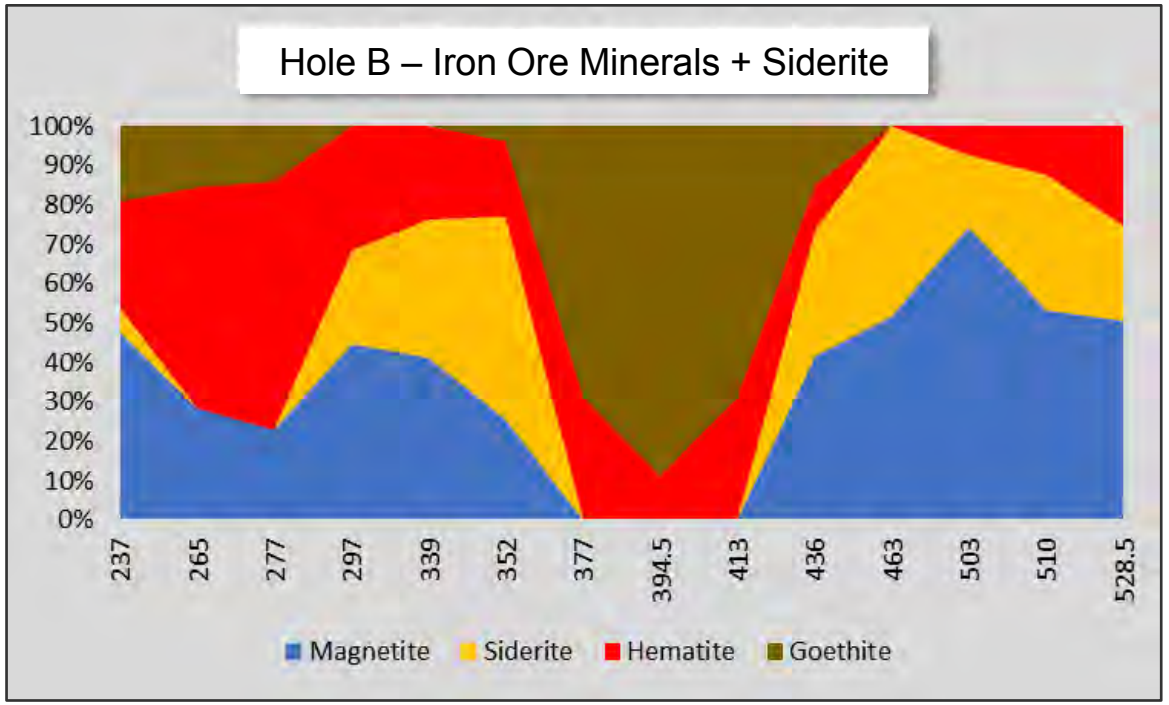
Average = 29.7 wt.%

Average = 32.0 wt.%

Average = 30.2 wt.% (less 55.25 wt.%)

Characterization of Alternative Iron Resources





Magnetite = Fe_3O_4 **Siderite = $FeCO_3$** **Hematite = Fe_2O_3** **Geothite = FeO(OH)**

Processing of Alternative Iron Resources

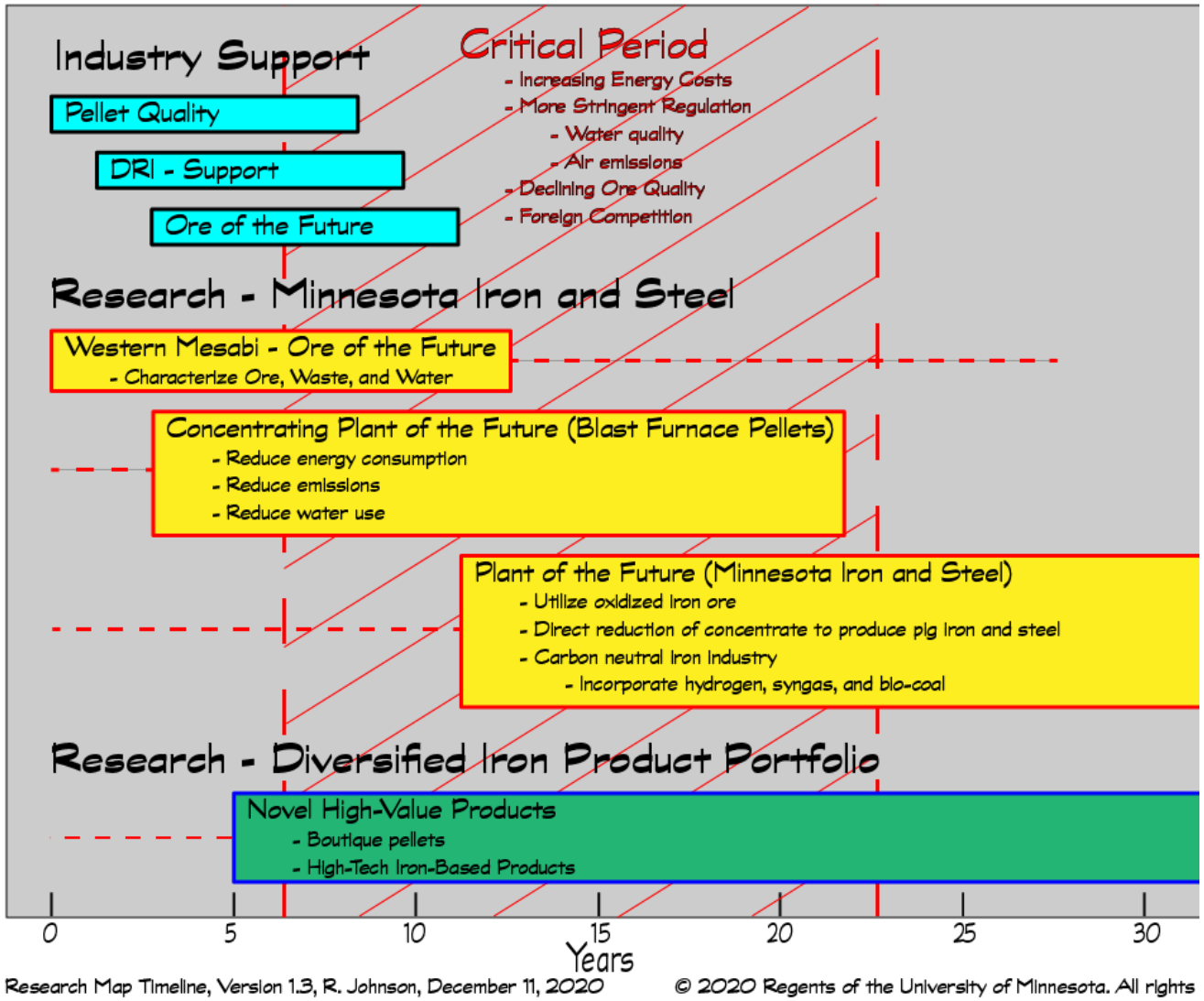
Project

- LCCMR – Minerals and Water: Next Generation Technologies and New Iron Products
- Budget: $450,000

Objectives

- Build characterization database
- Develop and demonstrate process options for alternative iron resources
  - Processing reagents
  - Unique concentrates
  - Water quality management
- Hydrogen reduction of concentrates to iron products

Emerging Research Pipeline



Critical Period

- Reduce energy and water consumption
- Reduce emissions
- Improve water, energy, and resource efficiencies
- Basic data in collaboration with industry

Future Focus

- Develop a high-tech, high-value iron industry
- Diversify the iron product portfolio
- Participating in a robust iron-based industry
- Accessing lean ore and waste resources

DRI Simulator

Project: DOE AMO – Enhanced Pellet Chemistry

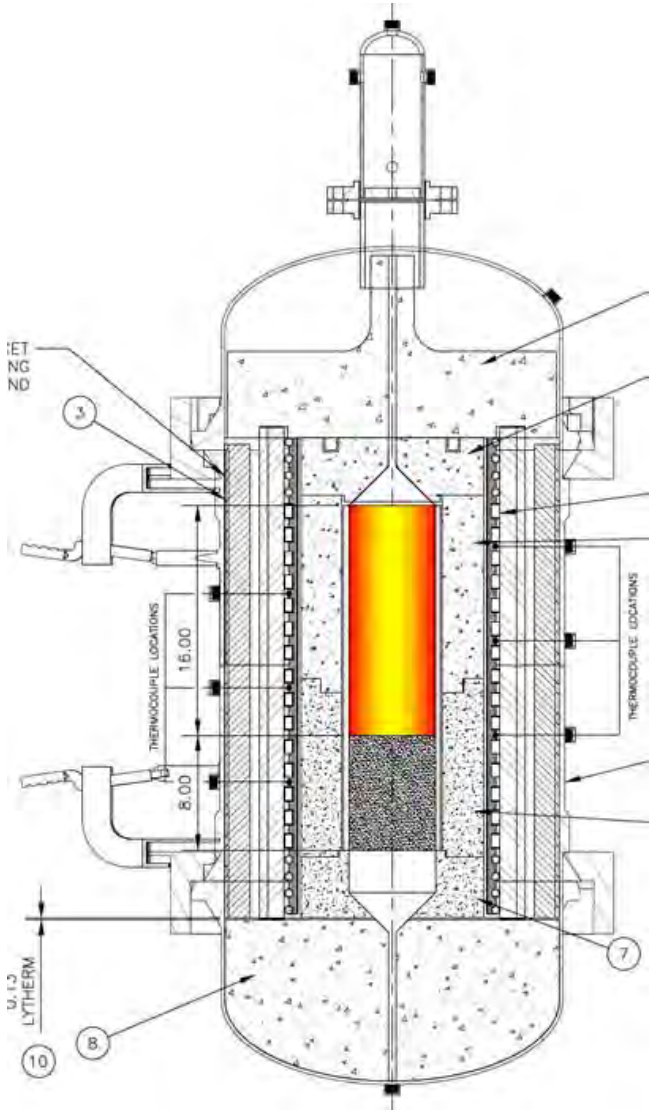
- **Duration:** 2021-2025
- **Federal Funding:** $2,100,000
- **State/NRRI Funding:** $1,600,000

Concept

- Globally unique simulation of the entire shaft furnace direct reduction process in one reaction vessel

Impact to Minnesota

- Reduce risk associated with evaluating feedstocks for the shaft furnace reduction process
- Expanding the iron product portfolio



Alternative Ironmaking

Project: DOE AMO – Enhanced Pellet Chemistry

- **Duration:** 2021-2025
- **Federal Funding:** $2,100,000
- **State/NRRI Funding:** $1,600,000

Concept

Improve the high temperature properties of DRI feed to:

- ✓ Allow higher temperatures in reduction
- ✓ Enhance removal of gangue
- ✓ Produce granulated pig iron nodules

Impact to Minnesota

Expanded iron product portfolio with reductions in energy and carbon

Novel Non-Steel Iron-Based Products

Technical engagement since 2018 for iron-air battery component development

High capacity, long duration, power plant sized energy storage

GRE/Form Energy 1.5 MW pilot in 2023

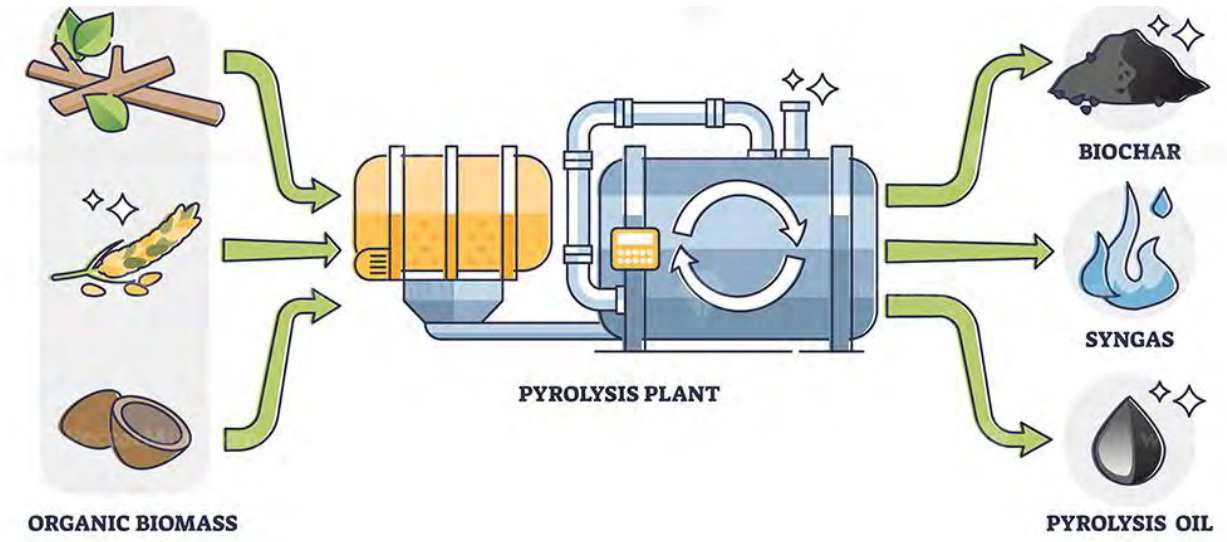
Biocarbon Applications

Coal and coke substitute for BF, EAF

- Physical properties
- Composition

Syngas generation

Biomass → H_2 + CO



https://vectormine.com/item/biochar-syngas-and-oil-production-by-pyrolysis-plant-from-organic-biomass/ Accessed March 15, 2022

Green Hydrogen

NRRI submitting input to DOE ARPA-E Hydrogen Hub RFI's

Minnesota has unique resources for green hydrogen generation

- DC power, clean water $H_2O \xrightarrow{e^-} H_2 + ½\ O_2$
- Iron ore

Natural Gas Reduction

$Fe_2O_3 + 3CO = 2Fe^o + 3CO_2$ (Exothermic)

$Fe_2O_3 + 3H_2 = 2Fe^o + 3H_2O$ (Endothermic)

Hydrogen Reduction

$Fe_2O_3 + 3H_2 = 2Fe^o + 3H_2O$ (Endothermic)

Hybrit. Available at: http://www.hybritdevelopment.com/%0A. (Accessed: 1st September 2020)

Steelmaking Potential

What's Next

Ore Characterization

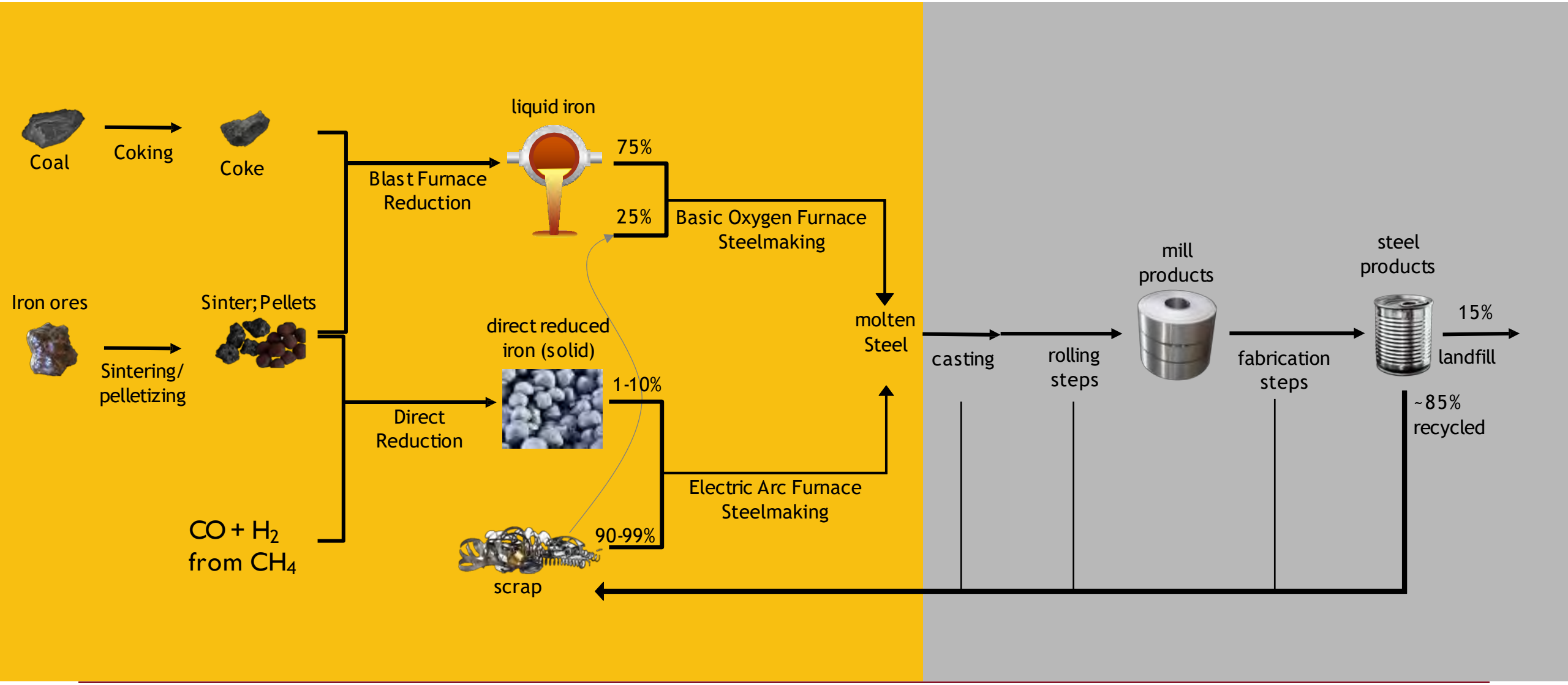
Iron Ore Processing

Ironmaking

Steelmaking

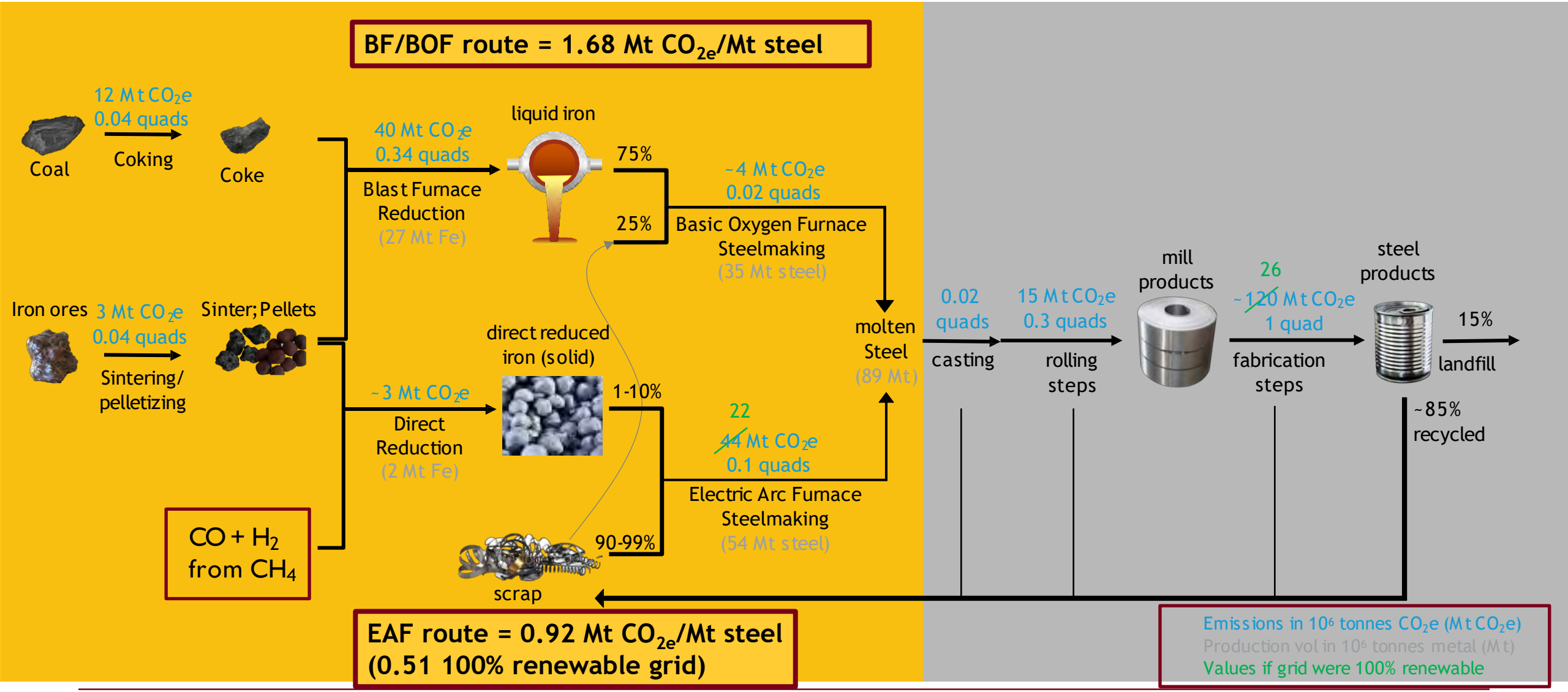
Natural Resources Research Institute
University of Minnesota Duluth
Driven to Discover

Potential for Steelmaking – What's Next



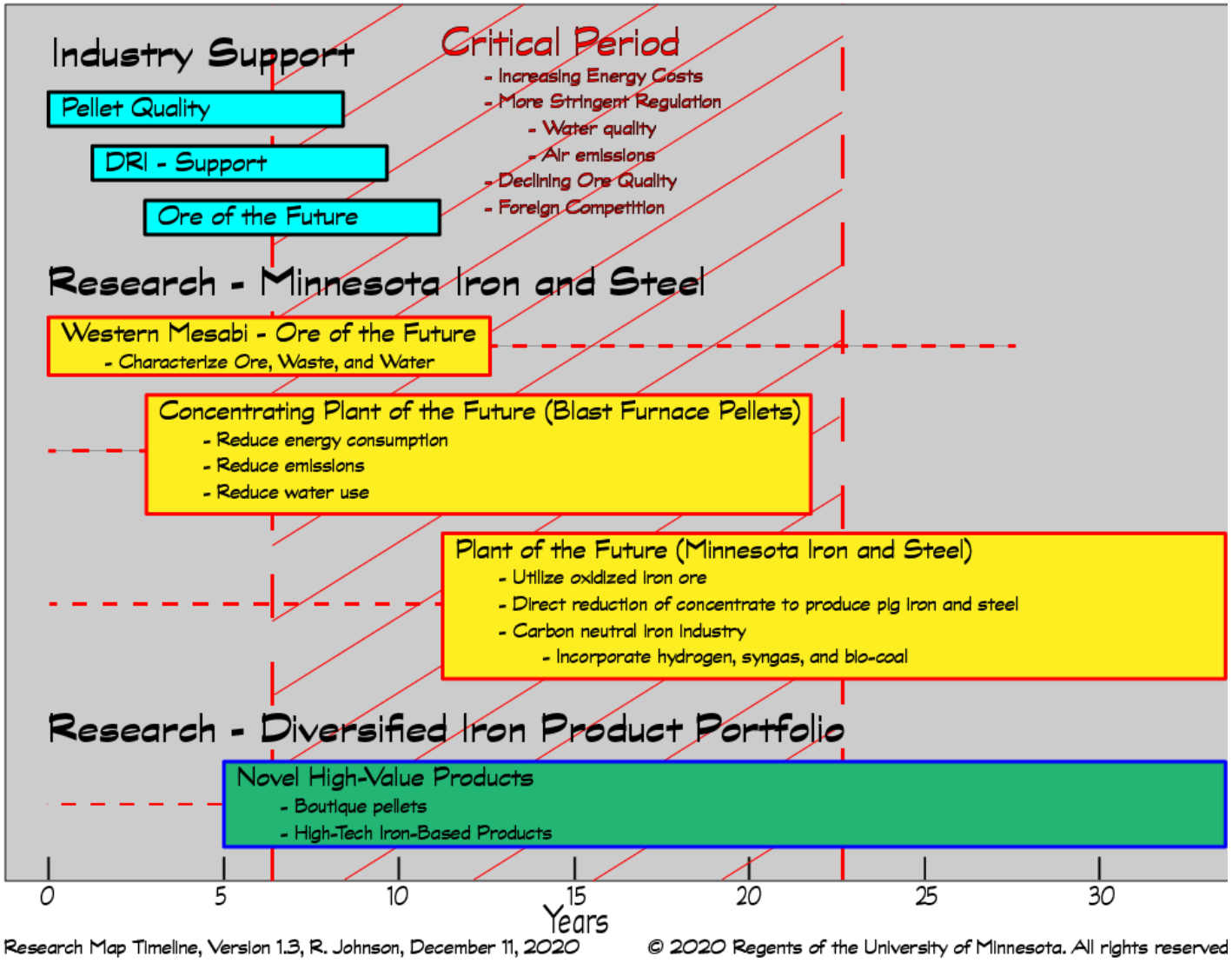
C. M. Chang, "The Technology Whitespace for Deep Decarbonization of Steel Production," in *ARPA-E Zero Emissions Iron and Steelmaking Workshop*, 2021.

Potential for Steelmaking – What's Next



C. M. Chang, "The Technology Whitespace for Deep Decarbonization of Steel Production," in *ARPA-E Zero Emissions Iron and Steelmaking Workshop*, 2021.

Looking Forward



Thank You

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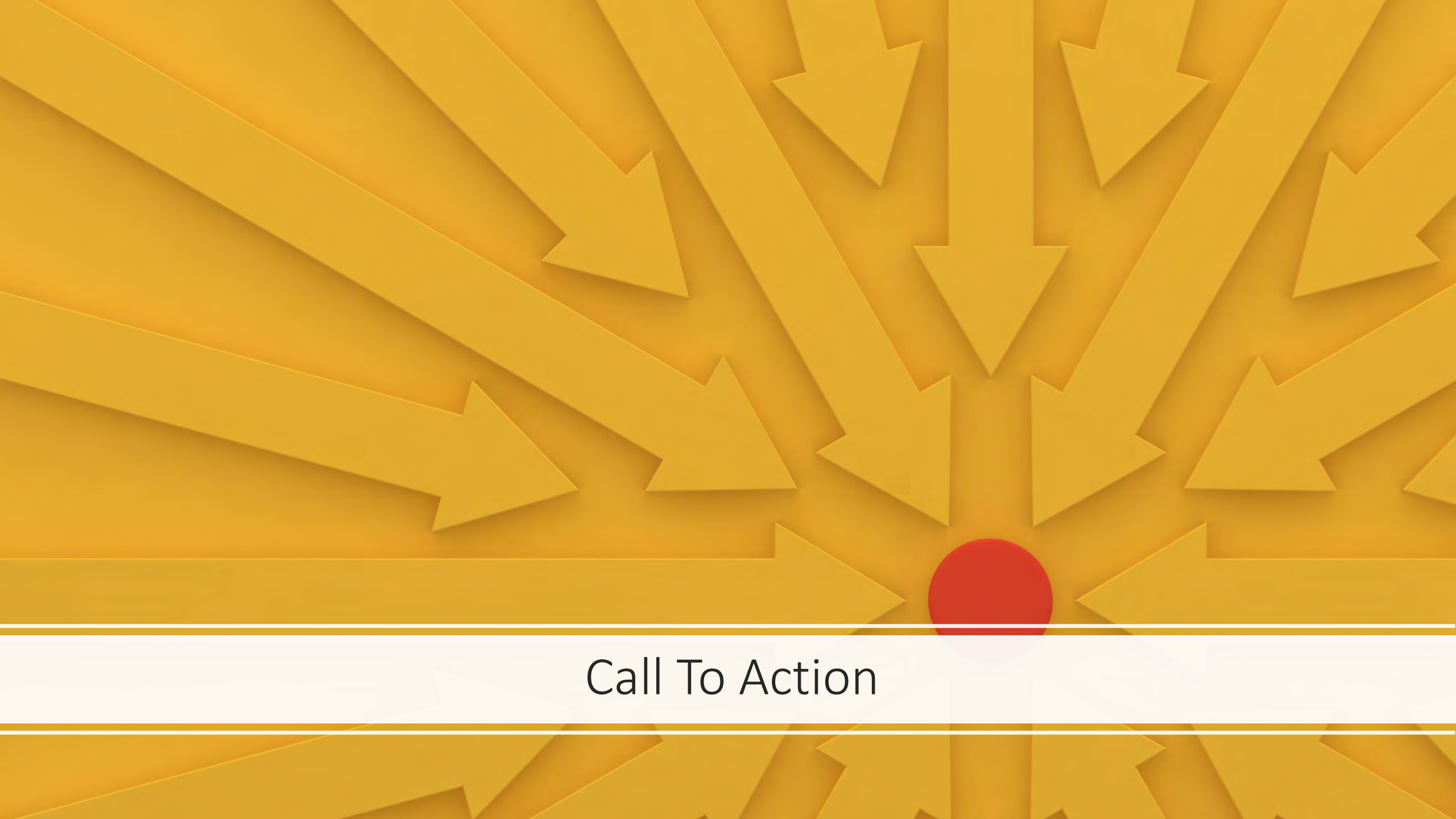
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