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

AMMTO & IEDO JOINT PEER REVIEW

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Washington, D.C.

Iron and Steel Programmatic Summary

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Nexight support for IEDO

Steel 101

Iron Ore
Coal
Limestone
→ 80% of input
Molten Pig Iron
Blast Furnace
~5% carbon →

20% of input is Scrap Steel →

Oxygen →

Basic Oxygen Furnace (BOF)
Integrated Mill

16-18 GJ/tonne steel

2450 kg CO_2/tonne steel

Iron Ore, Coal
Reducing Gases
Fuel
→ 20-25% solid pig iron
30% Direct Reduced Iron →

25-75% Scrap Steel →

Electricity, Gas, carbon, oxygen →

Electric Arc Furnace (EAF)
Mini Mill

8-9 GJ/tonne steel

1040 kg CO_2/tonne steel

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Minimum theoretical
~8 GJ/tonne steel

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Reducing Gases
Fuel

20-25% solid pig iron
30% Direct Reduced Iron

25-75% Scrap Steel

Electricity, Gas, carbon, oxygen

Electric Arc Furnace (EAF)
Mini Mill

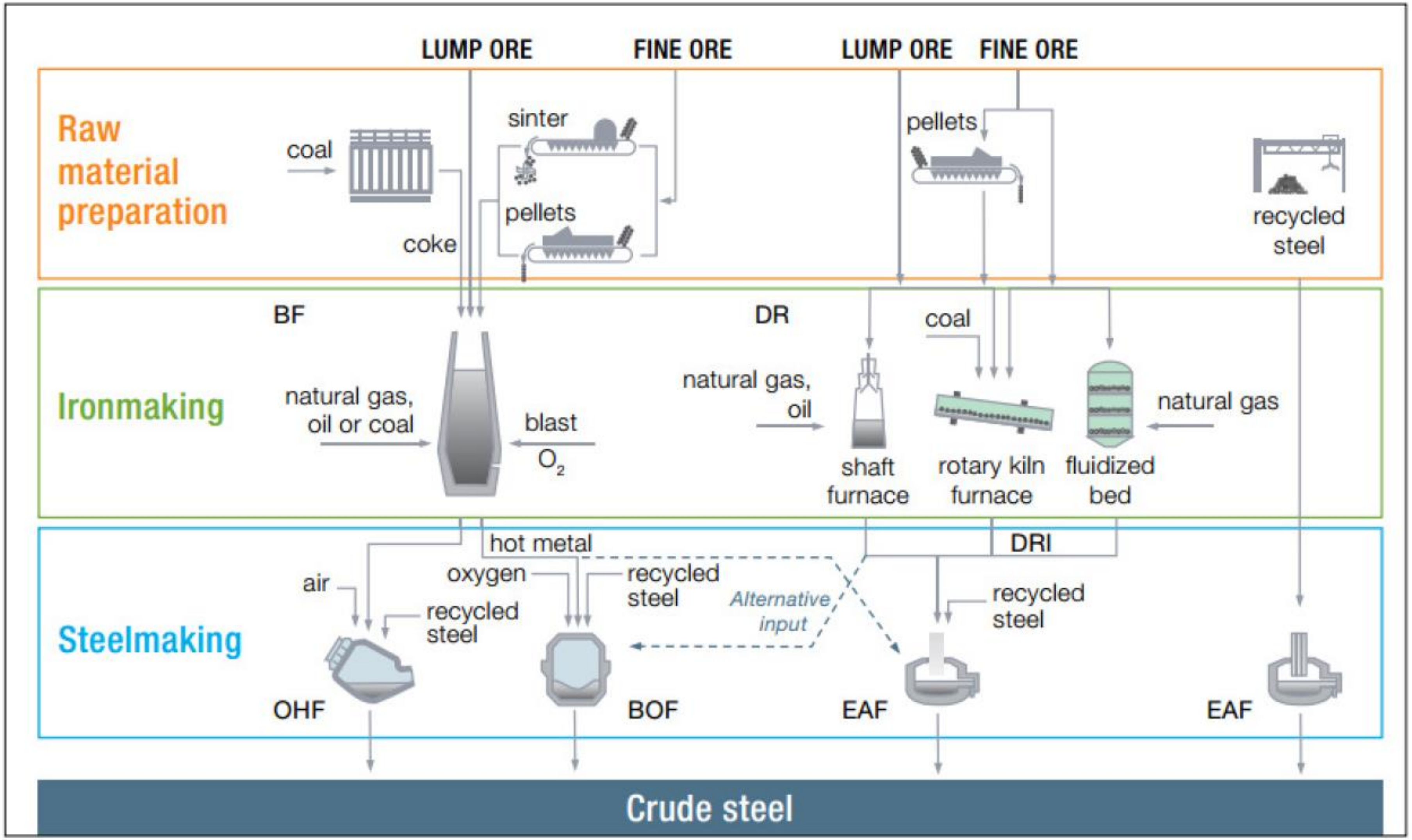
8-9 GJ/tonne steel

1040 kg CO_2/tonne steel

Minimum theoretical
~1 GJ/tonne scrap
~6 GJ/tonne scrap/DRI

Steel 101

90% of the energy is consumed prior to casting



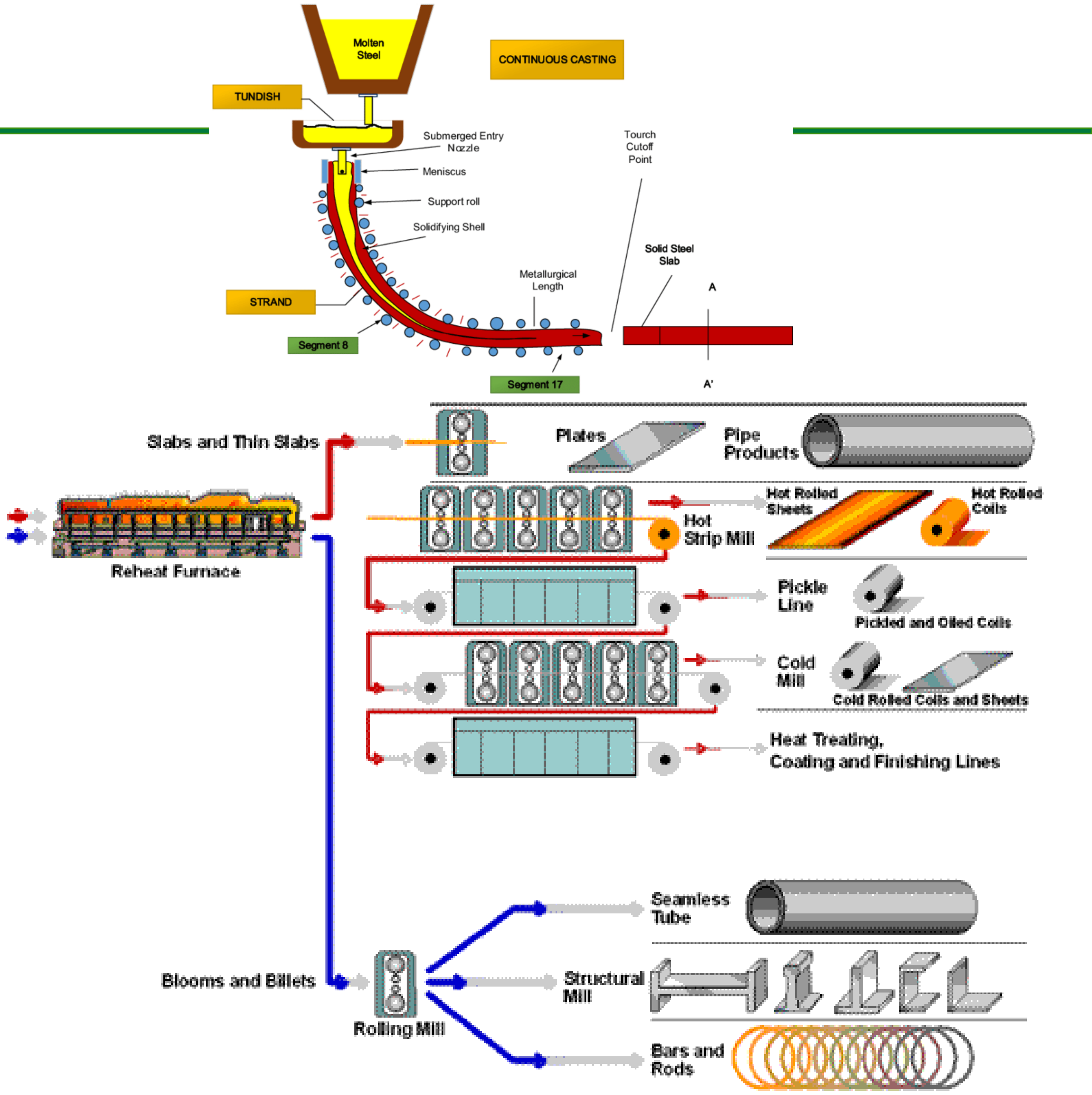
Source: World Steel Association

Most of the decarbonization opportunities are in the Iron and Steelmaking process

Steel 101

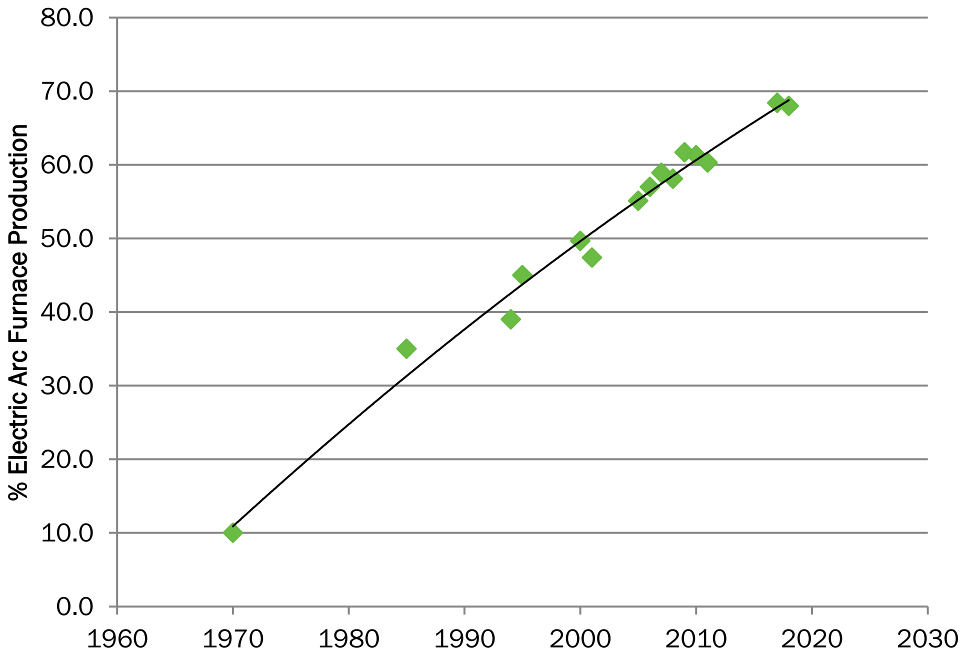
Forming and Finishing operations

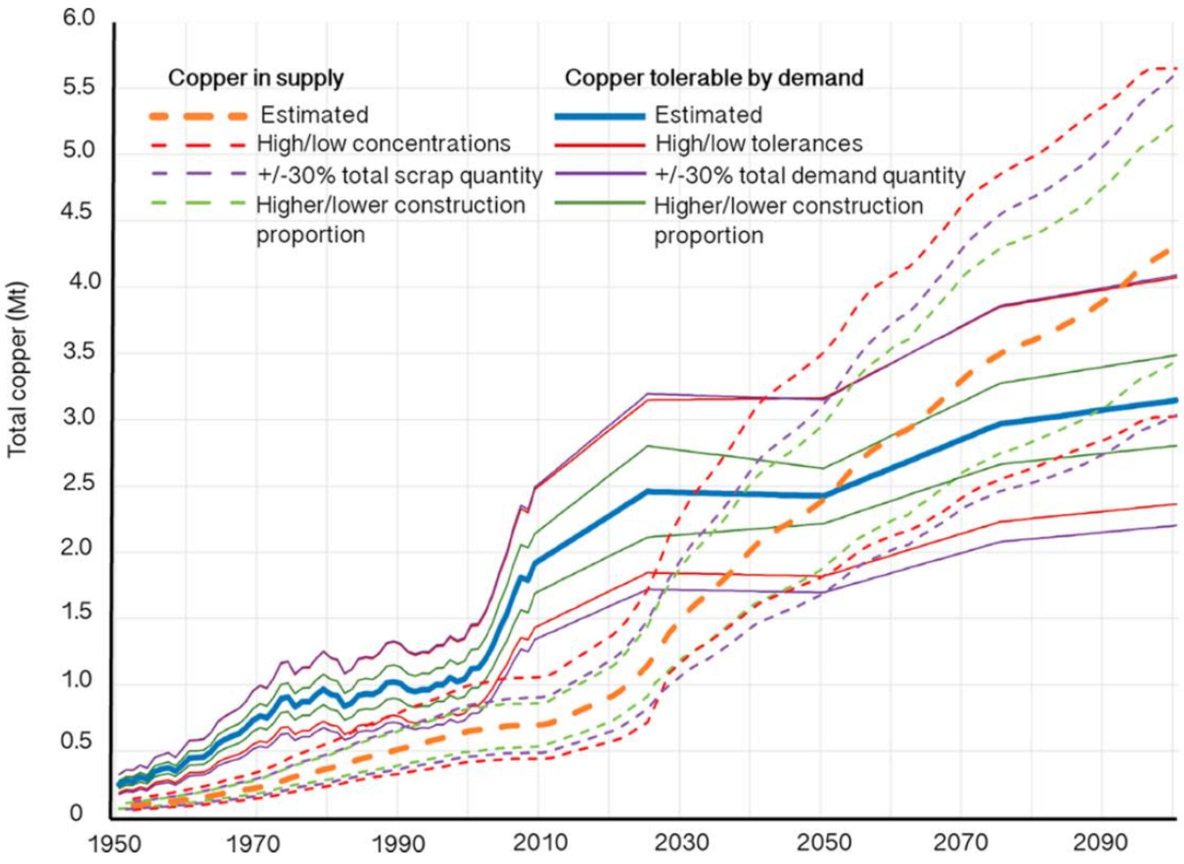
- Hot rolling, cold rolling, annealing, pickling, and other heat treatments, slitting, coating, etc.
- Hot rolling reheat furnace opportunity: most energy intensive operation once the steel is solid



The consequence of recycling: copper contamination

Fraction of US electric arc furnace steel production vs. time





Decades of increased use of recycled steel.
Copper is trapped in the steel recycle stream.
Exceeds tolerances for demanding applications

Copper in scrap is diluted with clean Ore-Based Metallics

Domestic Industry Overview

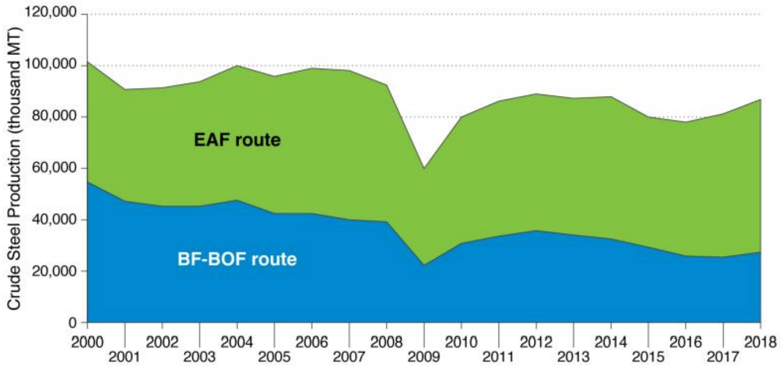
Market and Industry Landscape

- The value of products from the industry was $137 billion in 2018[1].
- Iron and steel producers are primarily concentrated in the Midwest.
- Nationwide, there are 19 blast furnaces operated by 2 companies and 152 electric arc furnaces operated by 49 companies[2].
- Lifetime of industry assets (BF, EAF) ~50 years.
- Share of U.S. steel produced from EAFs increased from 46% in 2000 to ~70% in 2019[3].
- Iron/steel sector is expected to grow by approximately 11% by 2050[4].

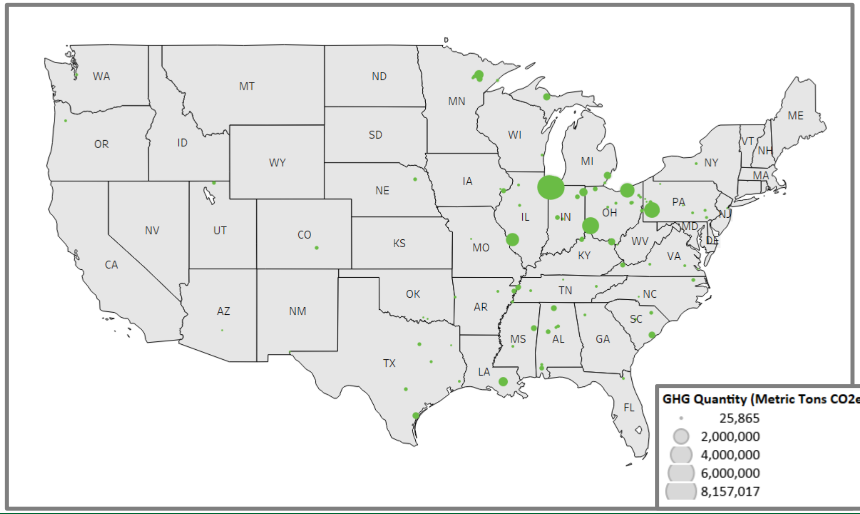
Key Stakeholders

- Trade associations – AISI, SMA (public policy); AIST (technology)
- Companies – Cleveland Cliffs, Nucor, U. S. Steel, ArcelorMittal, SSAB, Gerdau, Steel Dynamics, Commercial Metals Company
- Industry has increased planned investment in decarbonization and emphasized importance in public/private investment to achieve decarbonization objectives.

Domestic crude steel production between 2000-2018[3]



Iron and Steel Facility Locations and Emissions



[1]Iron and Steel Statistics and Information, Tuck, 2019.
[2]2022 AIST Directory, AIST, 2022.
[3]World Steel Association, 2020.
[4]AEO Table 21, EIA, 2021.

Long History of Steel-DOE Partnerships

Industries of the Future

1995

Steel Vision and Roadmap

- Measure temp. of galvanneal steel
- Dilute oxygen combustion
- Cokeless ironmaking
- Hot oxygen injection into BF
- Extend pot hardware life in continuous hot dipping Automatic high-temp steel inspection system
- Improving system life of BOF and EAF hoods, roofs, & vents

2010

Technology Roadmap Research Program for the Steel Industry

Final report summarizing the collaborative 10-year R&D efforts of the steel industry and DOE.

$5.5M cost share for Mesabi iron nugget pilot plant Minnesota

2015

Steel Industry Roundtable: R&D Needs

Topics:

- Big Data
- Smart Manufacturing
- Alt. Feedstocks (Bio-derived carbon)
- EAFs
- Predictive Modeling, Simulation, & Visualization

2019

Steel Industry Roundtable: Emerging Technologies

Topics:

- Low-emission steelmaking
- Sustainable integrated steel plants
- New and recycled materials
- Sensors and high-performance computing
- Advanced technologies for measuring performance

2021 and Beyond

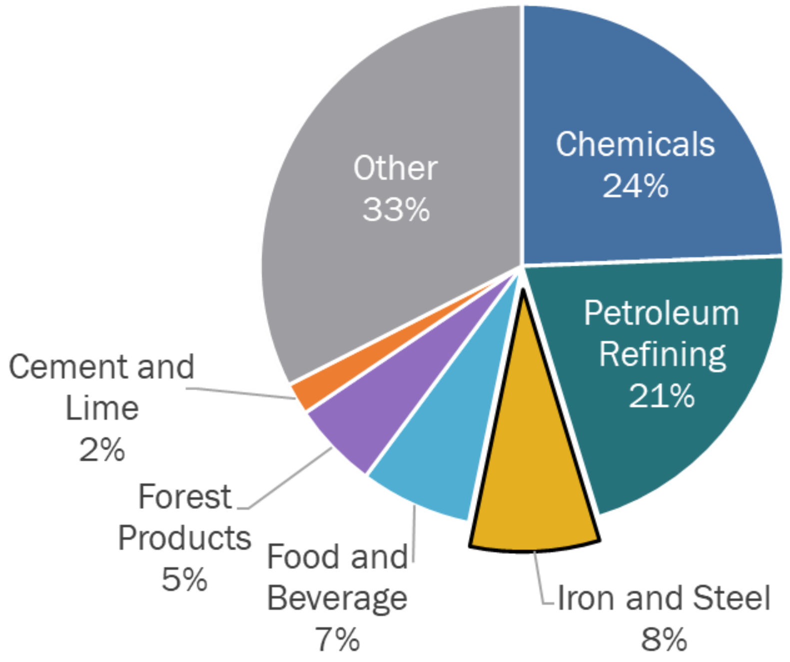
Industrial Decarbonization Roundtables

Focus on Sustainability, Decarbonization, Energy Efficiency

Energy and Emissions of the Iron and Steel Sector

Iron and steel is the third largest emitter of energy-related CO_2 in the domestic manufacturing sector.

Share of Energy-related CO_2 Emissions for the Iron and Steel sector
Total: 1124 MMT CO_2



Global CO_2 emissions: 37 Gt/year
Global steelmaking CO_2: 11% of global
Chinese steelmaking CO_2: 7% of global
US steelmaking CO_2: 0.3% of global

[1]Manufacturing Energy and Carbon Footprints, DOE AMO, 202

Current Portfolio

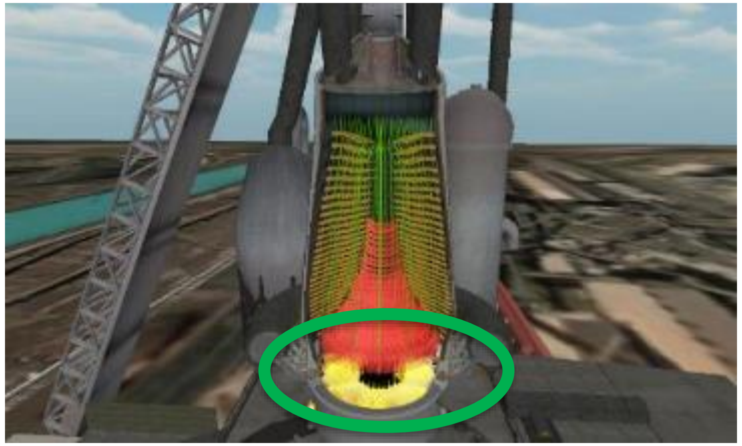
Lead Organization	Goals/Targets	Project Title	DOE Funding
Purdue University Northwest - Steel Manufacturing Simulation and Visualization Consortium	Reduce BF energy consumption by 4.5% (454 kBtu/nthm - $8.3M/yr)	Integrated Virtual Blast Furnace for Real-time Energy Efficiency Improvement	$7,048,766
Missouri University of Science and Technology	• Reduced energy Consumption by 20-60 kWh/TLS • **Reduced GHG by 20-30 Lb. CO2/TLS**	Intelligent Dynamic EAF Advisory System (IDEAS) for Improving EAF Operating Efficiency	$5,227,988
Colorado School of Mines	80% energy savings for Interstitial Free steels	Maximizing Scrap Recycling by Designing Cu Tolerant Steel Compositions	$2,238,996
Natural Resources Research Institute, University of Minnesota Duluth	Improved EAF energy efficiency by 33.3%	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	$2,112,619

Current Portfolio

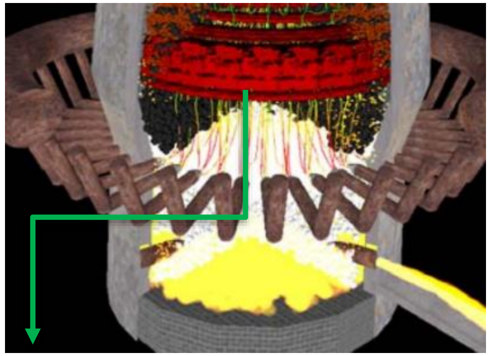
Lead Organization	Goals/Targets	Project Title	DOE Funding
Antora Energy Inc.	Heat-to-electric conversion 40%	High-efficiency solid-state waste heat recovery for iron and steelmaking	$2,000,000
Cornell University	• 90% pure CaCO3 • Remove undesired metal constituents in flue dust and sludge with a separation efficiency of ≥ 90% • Recover > 85% iron oxide from sludge and dust,	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)	$1,226,921
Oak Ridge National Laboratory	• 2% near-term energy savings • 10% long-term energy savings	Use of Novel Refractory Design and Installation Techniques for Improved Energy Efficiency in Iron and Steel and Other Energy Intensive Industries	$1,000,000

Integrated Virtual Blast Furnace for Real-time Energy Efficiency Improvement

Project Lead: Purdue University Northwest
Project Partners: Cleveland-Cliffs, Linde, Oak Ridge National Laboratory, U. S. Steel
Timeline: 06/14/2021 – 03/31/2025



Technology: Determined the software architecture needed for complex gas flow, combustion, and chemical reactions in order to scale Purdue's current simulation to the entire blast furnace. The team took advantage of LLNL's supercomputers and modeling expertise to modify the software so the blast furnace simulations can be run in days or hours instead of weeks or months.



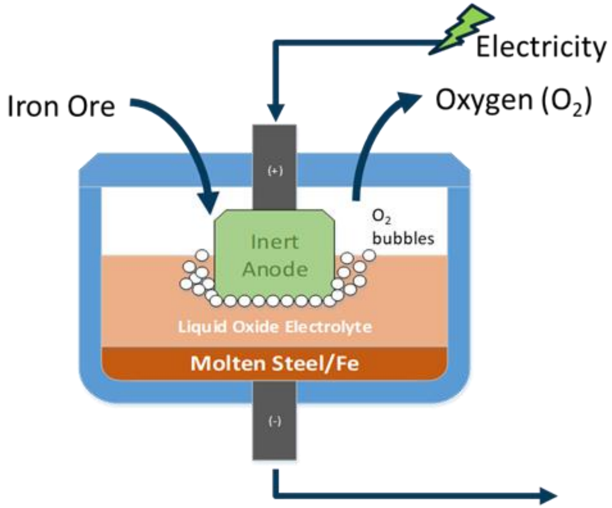
CFD results of the blast furnace based on the improved code combined with the CIVS training simulator

In this case study, LLNL, Purdue University Northwest, and steel-industry stakeholders use their high-performance computing (HPC) modeling, simulation and visualization capabilities to optimize blast furnaces in order to reduce emissions and energy use.

Carbon-Free Iron for a Sustainable Future

Partners: Boston Metal

Technology Summary: Electrolytic production of premium carbon-free iron using clean, renewable electricity at the cost of commodity steel. This technology will use the existing supply chain and distributions channels to reduce the cost of emerging alloys such as 3rd generation advanced high-strength steels.

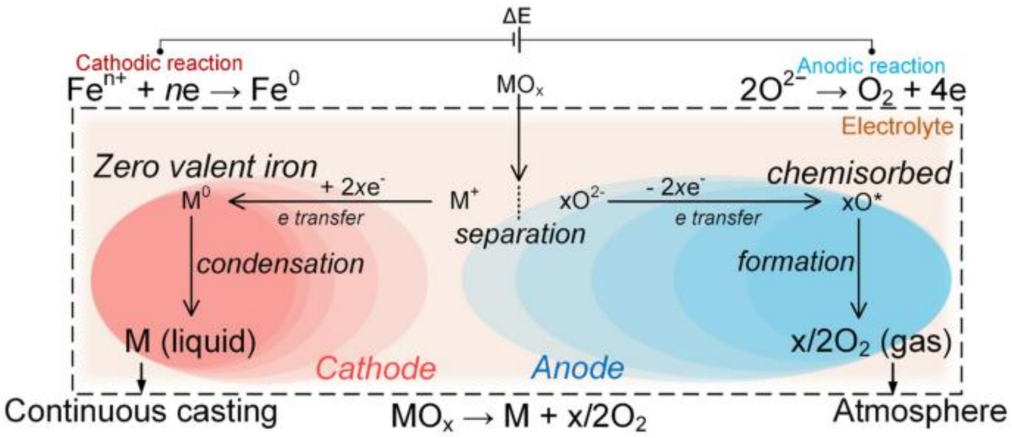


Impact:

- Reduction of energy usage in primary production by 29%.
- Reduce CO2 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

Challenges:

- Inert Anode technology used in the electrolysis process needs to be scaled from laboratory to industrial size
- Achieving high production efficiencies to maintain commodity prices and speed adoption



Key Takeaways

Iron and Steel Portfolio

- IEDO (and formerly AMO): engaged with industry / academic stakeholders
- Fully-aligned with congressional directives on funding allocation ($5M in FY22)
- Funding opportunities are crafted with a technical understanding of steelmaking technologies
- Projects are selected
  - Relevant
  - Impactful
  - With consideration of industry priorities and needs

Iron and Steel Programmatic Summary

Acknowledgements:

Mike Sortwell and Kenta Shimizu at Energetics

Leadership: Isaac Chan and Paul Majsztrik at the PM level, and Nick Lalena and Keith Jamison at the TM level