



Hydrogen-Electric Reduction Smelting For Green Iron & Steel Production

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Hydrogen-Electric Reduction Smelting (HERS™) for Green Iron & Steel Production

Project Overview

Project Goals:

- Demonstrate a path to low-cost green steel production from low-grade ores through detailed technoeconomic modeling
- Benchtop scale demonstration of the key innovative aspects of Hertha's technology
- Concept pilot demonstration of technology (>>100 kg/d rate)

Project Timeline

- Phase 1: Jan 1, 2024 to Dec 31, 2024 (10%)
- Phase 2: Jan 1, 2025 to Dec 31, 2025

Budget

- Total Budget: \$2,064,241
- FY'24: \$1,061,558 (DOE: \$849,058; HM: \$212,500)
 - Funds Spent: DOE:\$0; HM: \$62,500
- FY'25: \$1,002,683 (DOE: \$802,183; HM: \$200,500)

Partners

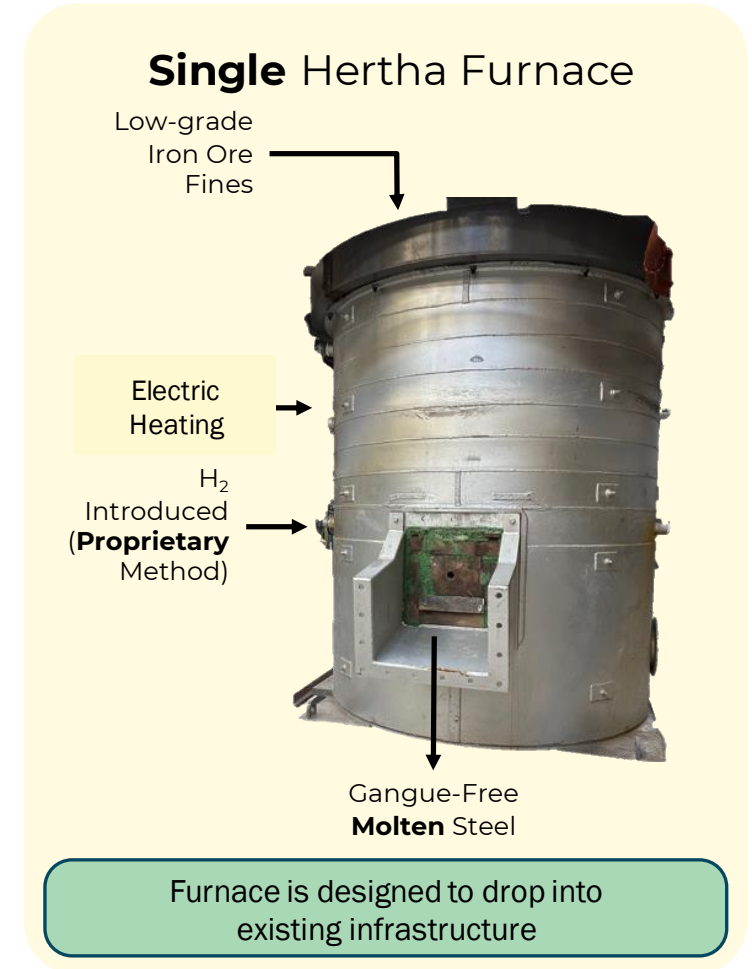
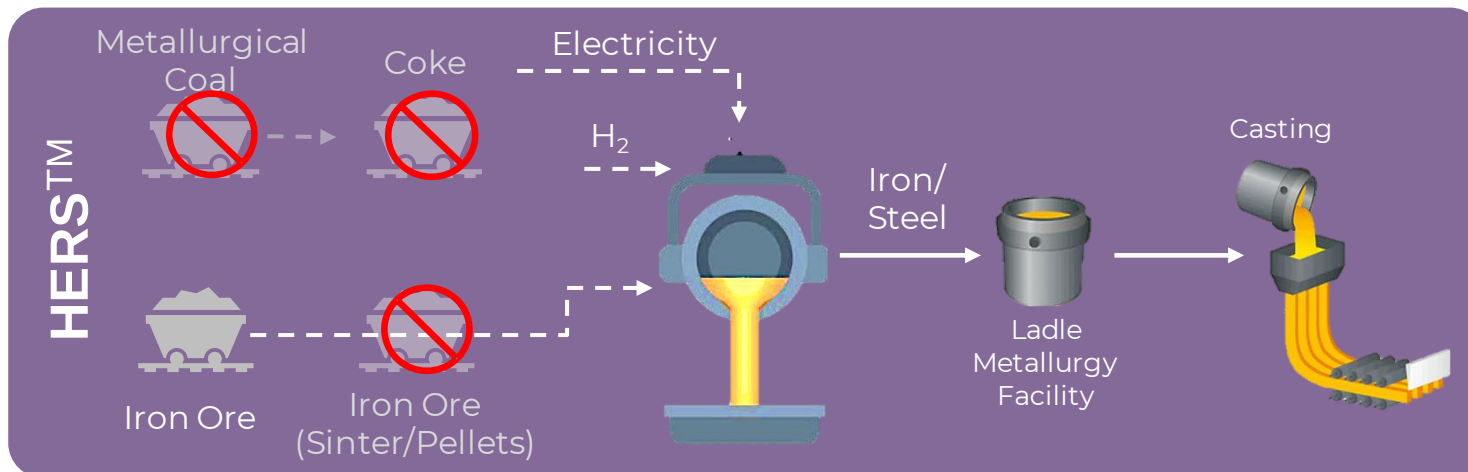
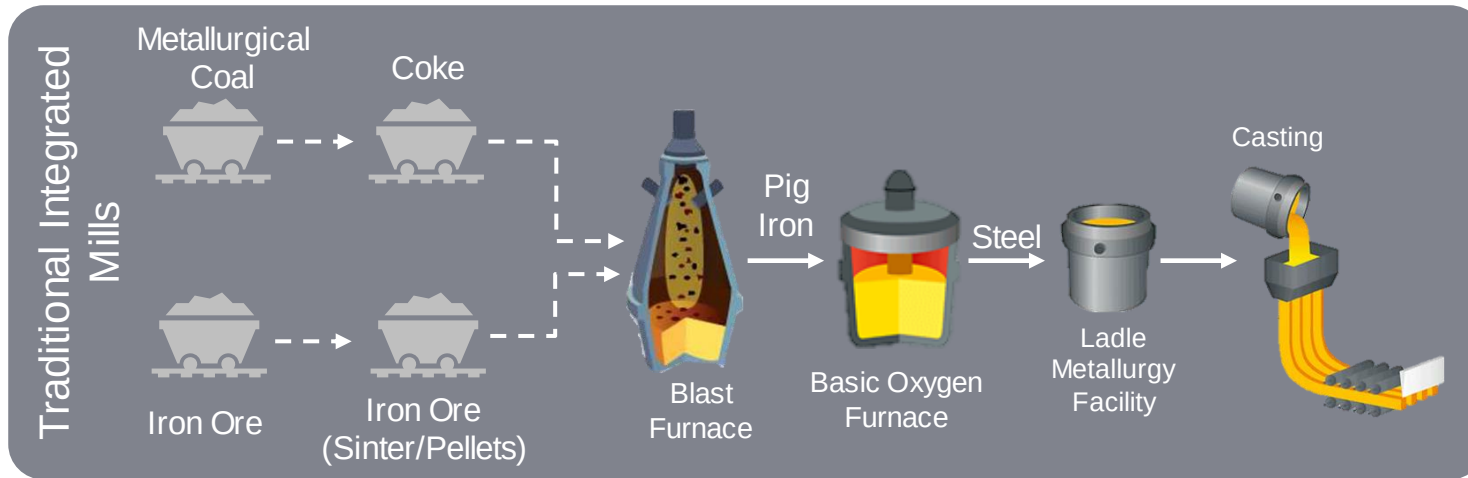
- None

Barriers

- Slag bath containment
- Iron oxide reduction rates
- Scaling to >>100 kg/d production rates of iron

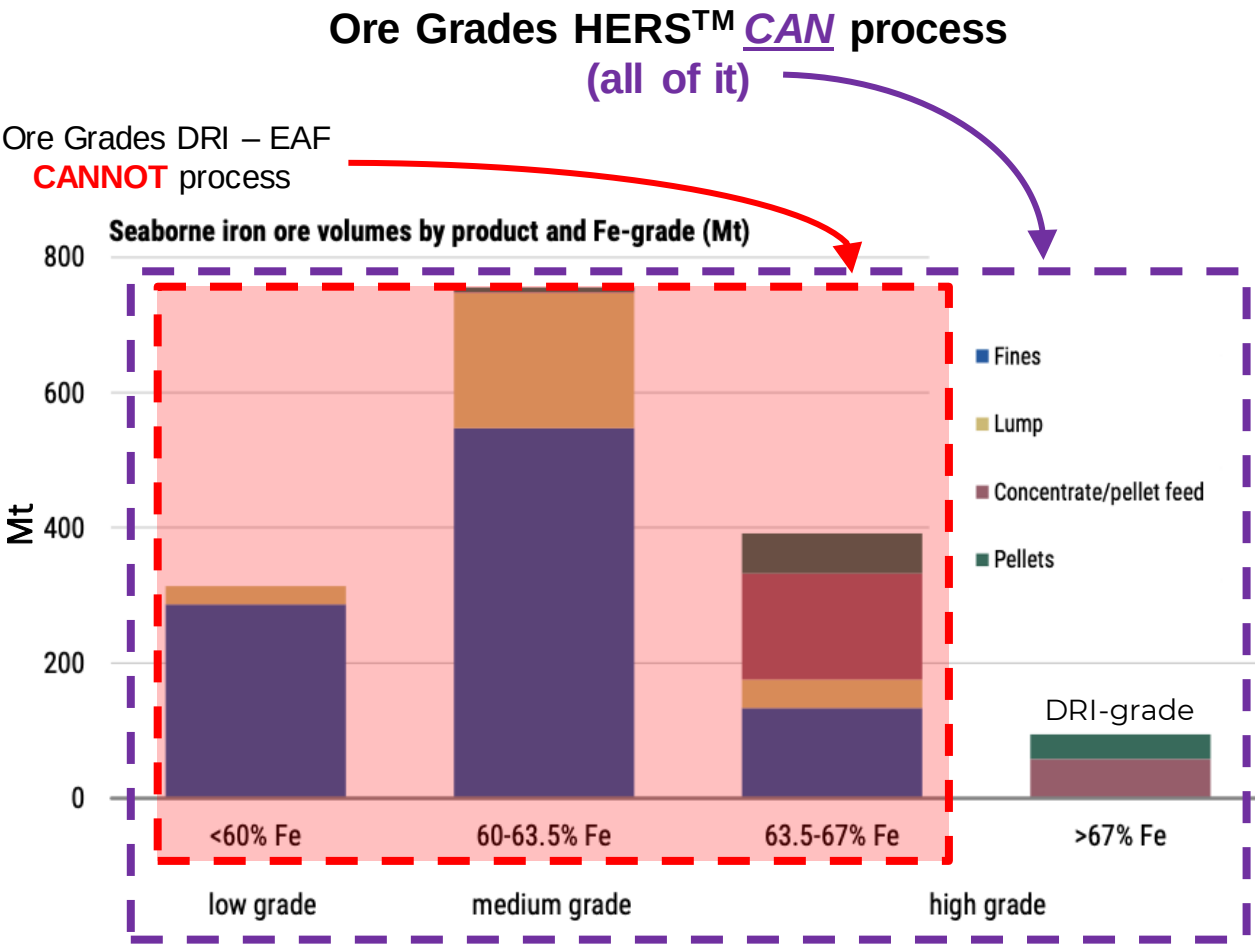
Hydrogen Electric Reduction Smelting (HERS™)

Green steel production to save humanity



DRI is good, HERS™ is Better!

Using lower grade ores provides a strategic cost advantage and secures long-term profitability



Premium to 62% Fe index (US\$/t)

		2018-2022	2026	2030+
Class 1	DR agglomerate (68% Fe)	74	~78	~95
Class 1	BF agglomerate (65% Fe)	66	~68	~75
Class 1	Premium Fines (65% Fe)	18	~20	~22
Class 2	Low-grade fines (58% Fe)	-27	~ -30	~ -30

Decreasing Cost

Increasing Availability

Iron ore data figures adapted from Morgan Stanley Research, Wood Mackenzie

Relevance to DOE Goals

Meeting or exceeding all targets

DOE Objective (Target)	Hertha Target
Reduce CO ₂ emissions by $\geq 40\%$ (stretch goal: 100%)	Reduce CO ₂ emissions per ton of steel produced by 95%
Reduce energy consumption by $\geq 15\%$ (Stretch goal: 30%)	Reduce electrical energy intensity to 1.3 MWhr per ton of crude steel (56% reduction)
Increase throughput by $\geq 15\%$ (Stretch goal: 30%)	Increase overall throughput by 15% by eliminating production steps
Production cost $\geq$ current production (Stretch goal: 30% reduction)	Achieve cost parity with current coal-based crude steel production

Approach

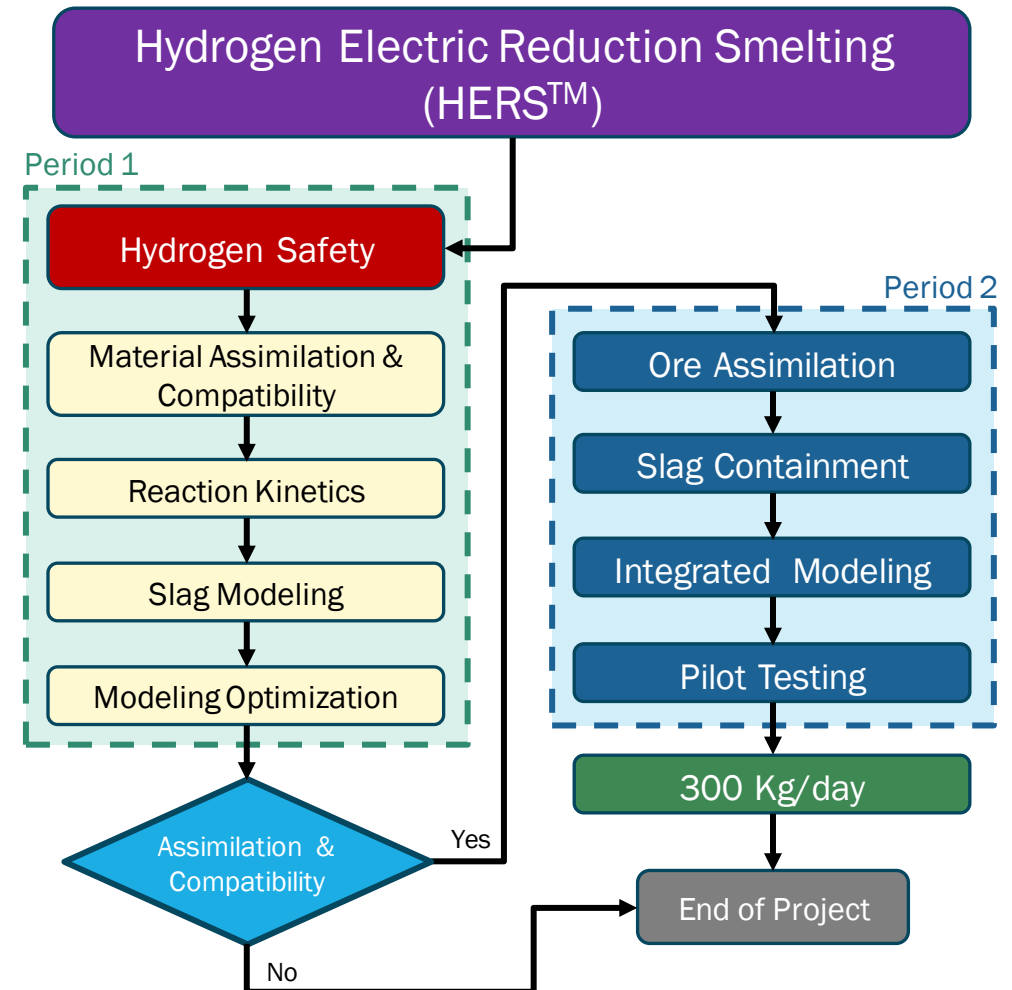
Two phases over two years

Phase 1: Laboratory Work

- Develop hydrogen safety plan
- Demonstrate refractory-slag compatibility
- Establish reaction kinetics for hydrogen reduction of iron oxide
- Demonstrate ore assimilation rates
- Develop predictive models

Phase 2: Pilot Scale

- Confirm refractory dissolution and ore assimilation rates in pilot furnace
- Verify ore assimilation rates in pilot furnace
- Validate reaction kinetics
- Establish optimal production rates in pilot furnace



Safety Planning and Culture

Building on team's industrial experience

A hydrogen safety plan reviewed by the HSP is required for this project

- This plan is undergoing a final internal review and will be submitted to the HSP by April 1.

Incorporating best safety practices and lessons learned

- Task based safety program, built with input from all team members so that “everyone goes home everyday in the same condition that they arrived at work”
- Safety program incorporates the best practices and lessons learned from industry.
 - Team members have extensive experience in industries including steel, hydrogen production, and oil and gas
 - Daily toolbox talks in each area
 - Monthly safety meetings with entire team covering incidents and lessons learned throughout the month

Established safety culture

- Each team member has the right (and responsibility) to stop “unsafe” work
- All team members have input in developing the SJP for tasks.
- All employees have access to all safety documents at any time (i.e. SJPs, SDSs, etc).

Achievements and Progress - Overview

Lab set up and achievements

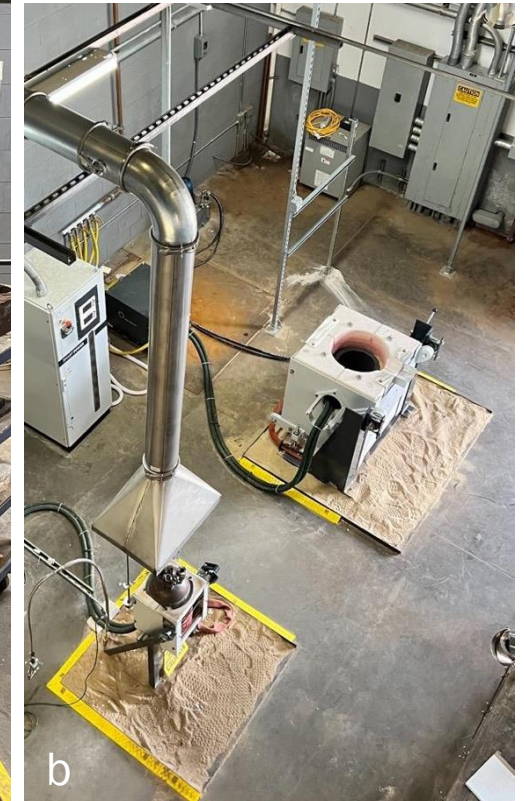
Achievements:

- Successfully completed refractory stability testing
- Demonstrated ability to add and sample slag in the crucible at temperature
 - Rate > 1 Kg/hr/m³ slag volume

Progress:

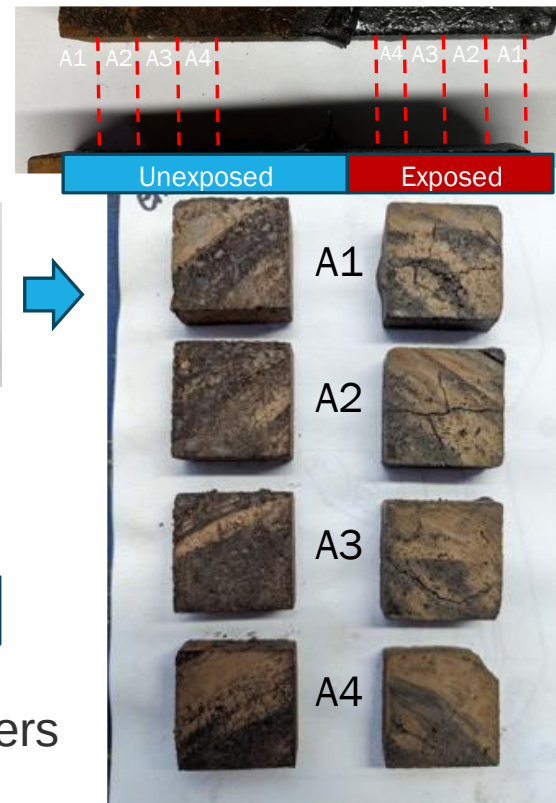
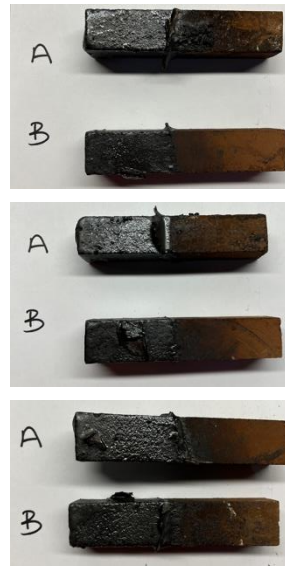
- Safely introducing hydrogen through proprietary method and producing iron
- Measured slag viscosity at operating temperatures
 - Newtonian fluid
- Testing “refractory” crucible

a) R2D2 (50 KW induction furnace) set-up for monitoring water vapor in exhaust; b) Birdseye view of lab; c) Dew point monitor

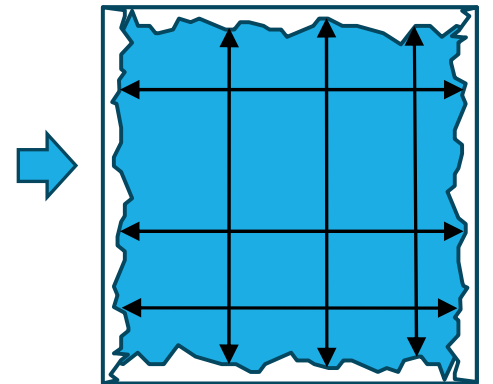


Achievement: Compatible Refractory Identified Through Experimental Testing

Finding a slag resistant refractory for pilot furnace



$$\text{Dissolution Loss} = \frac{L_{\text{Original}} - L_{\text{Final}}}{2}$$



Sample	Measured Width (mm)		Time (min)	Loss Rate (mm/Hr)
	Before	After		Width
1	26.3	25.7	60	0.192
	26.9	26.6	60	
	27.1	26.7	60	
	26.8	26.4	60	
	26.9	26.6	60	
	26.9	26.6	60	
2	26.1	25.7	60	0.170
	26.2	25.9	60	
	26.5	26.1	60	
	25.3	24.9	60	
	25.8	25.4	60	
	26	25.86	60	
3	26.5	26.1	60	0.200
	26.8	26.4	60	
	26.9	26.5	60	
	26.6	26.1	60	
	26.8	26.4	60	
	26.9	26.6	60	

Post immersion samples from 50 KW furnace

- Testing method recommended by refractory suppliers
 - Measurement methodology developed internally
- 3 monoliths x 3 sections x 6 measurements = 54 data points refractory

We recognize method would produce variability but by using statistics from multiple measurements it will minimize variability

Achievement: Slag Incorporation

Slag powder is readily absorbed into bath

Goal

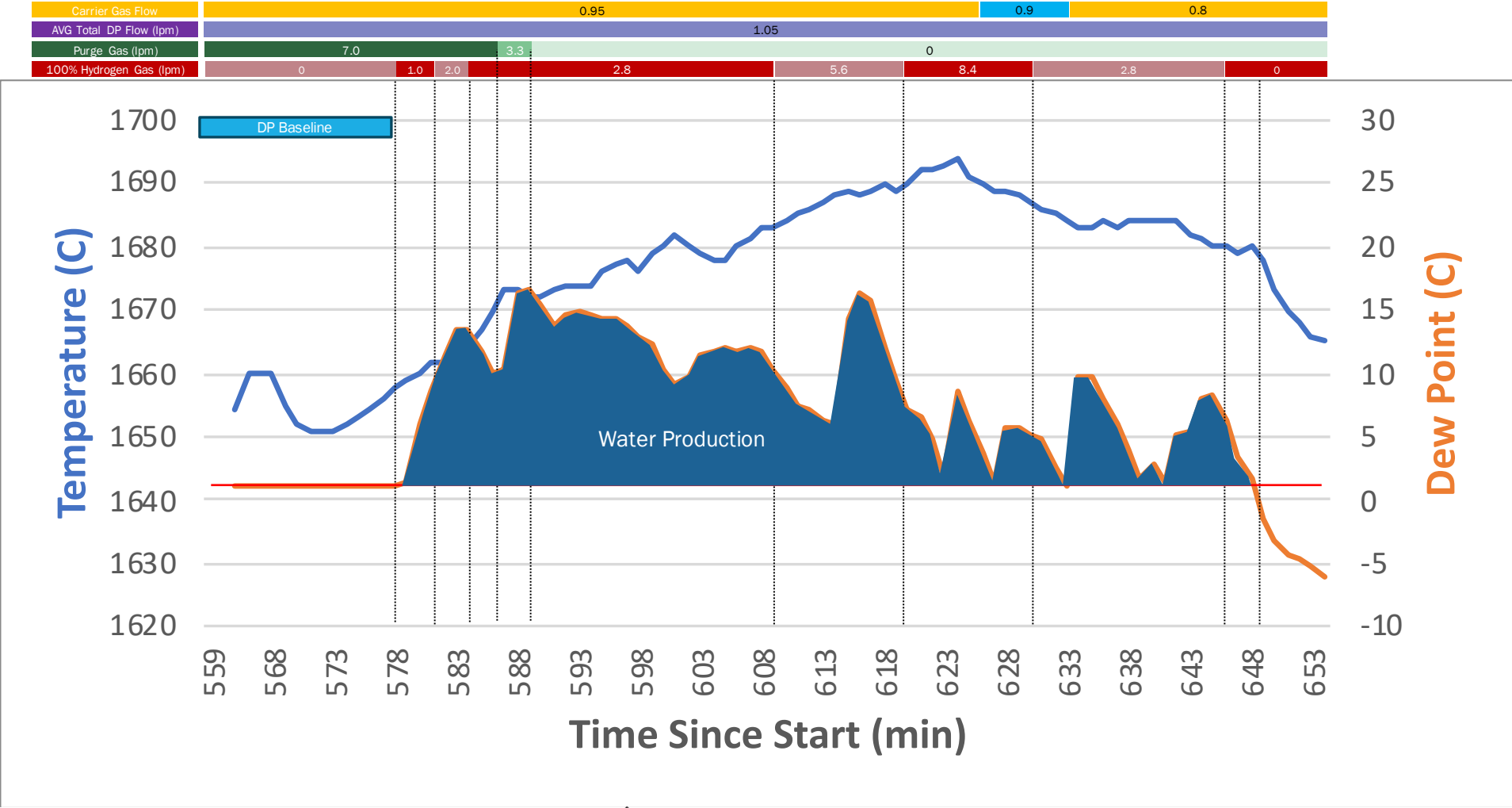
- Determine the time required to incorporate 333 g of dry Hertha slag made from US steel fluxed Blast Furnace pellets

Math

- Goal: incorporate 10 Kg of slag feed in 1 hour for each cubic meter of slag working volume
- This work:
 - Initial working volume of slag $\sim 48 \text{ in}^3$
 - (4.5" ID crucible, 3" bath depth)
 - Time to incorporate = 5 min (+/- 1 min)
 - Without injection
 - Rate $> 5000 \text{ Kg/hr/m}^3$

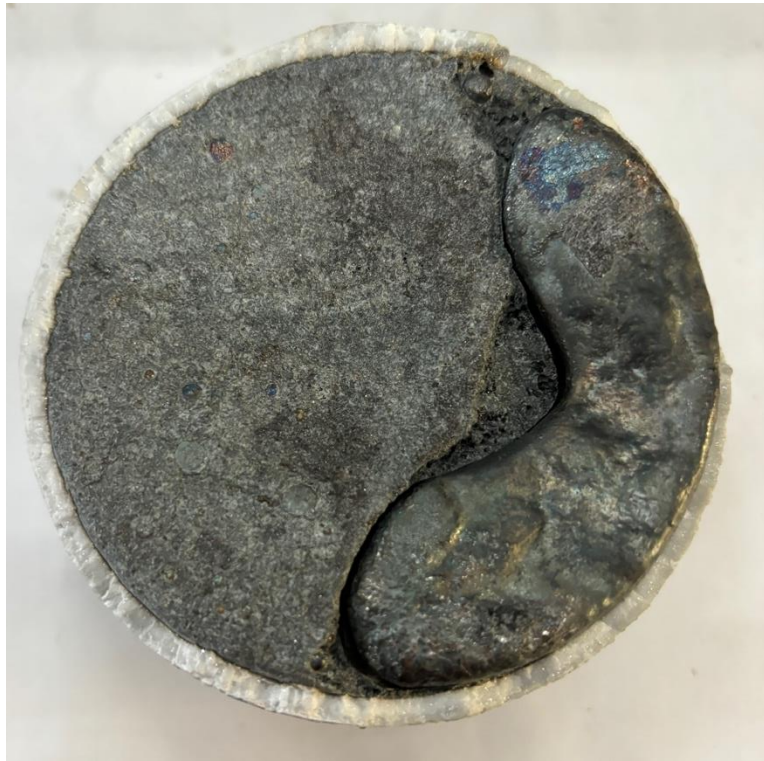


Progress: Real-Time measurement of Reaction Kinetics through Water Vapor Production



Progress: Iron Production Without CO₂ emissions

Producing up to 150g per hour in laboratory



Views of the bottom of the slag mass produced from several runs (after crucible bottom has been removed) showing the iron produced. The iron can coalesce as a nugget (left), remain as smaller droplets (center), or stay suspended in the slag. Producing ~150 g of Fe per hr.

Progress: Responses to 2023 Reviewer Comments

This is our first time presenting

2023 AMR Reviewer Comments - None

Collaboration & Coordination

We have not collaborators on this project

SDI008 Collaborators - None

DEIA / Community Benefits Activities

Active in our local community

Beyond the overall company goal of reducing GHG emissions associated with the production of steel, Team members are active in our local and technical communities:

Team members supporting our local community:

- Presenting at high school STEM events extolling the virtues of careers in science
- Supporting local job fares and hiring local talent – pulling in talent and training them to work on the HERSTTM process
- Utilizing local contractors to buildout our facilities and having a positive economic impact on our community

Team members supporting the technical community

- Member of AIST Electric Steelmaking Committee
- University of Arizona Industrial Advisory Board – providing industrial
- Members of Houston's Greentown Laboratory, doing community outreach to promote cleantech in the Houston

Remaining Challenges

New challenges have been identified

Barrier	Impact
Finding a crucible for the 150 KW induction furnace that is compatible with our slag ¹	• Restricts our ability to fully explore reaction kinetics and thus develop predictive models of HERS™ • Progressing from 25 KW to 50 KW to 150 KW furnaces is critical demonstration of process “scalability”
Integrating the RGA into laboratory exhaust system	• Long lead times impact the development of pertinent kinetic data • Important for quantifying leak rates in real time (N₂ signal)
Fe remains suspended in slag	• Limits ability to accurately quantify kinetics

1) Despite successfully qualifying a refractory system for the pilot furnace, these refractories do not yet support the work in the induction furnaces. Crucibles are not currently made from this refractory system and attempts to “build” crucibles from these refractories have been unsuccessful to date,

Future Work

Lots of work to do

While crucial progress has been made on several technical milestones, many technical goals remain unsolved.

In the next quarter, the plan is to work on:

- Understanding the influence of slag composition on properties relevant to the operation HERS furnace (slag composition varies with iron ore grade)
- Furthering our understanding of the reaction kinetics of our particular system on a larger scale
 - In the 150 KW furnace
- Further developing a working model for the reaction mechanism in HERS™

Note: Any proposed future work is subject to charge based on funding levels

Summary

Work is just beginning, but progress is being made

Project work officially began in January

- Timeline shifted to accommodate ICR negotiations and policy reviews

Two milestones nearly completed:

- Slag assimilation (Milestone 2.1.1)
- Refractory dissolution (Milestone 5.3.1)

Work on hydrogen safety plan ongoing but making progress.

- Controls in place and functional, documentation is the delay