NRRI Direct Reduced Iron Simulator

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NATURAL RESOURCES RESEARCH INSTITUTE

UNIVERSITY OF MINNESOTA

Presentation Overview

- NRRI Background
- Project Overview
  - Introduction
  - Background – Why Build a DRI Simulator
  - Objectives
  - Milestone History
- Project Update
- Next Steps
- Questions/Comments

NRRI Background

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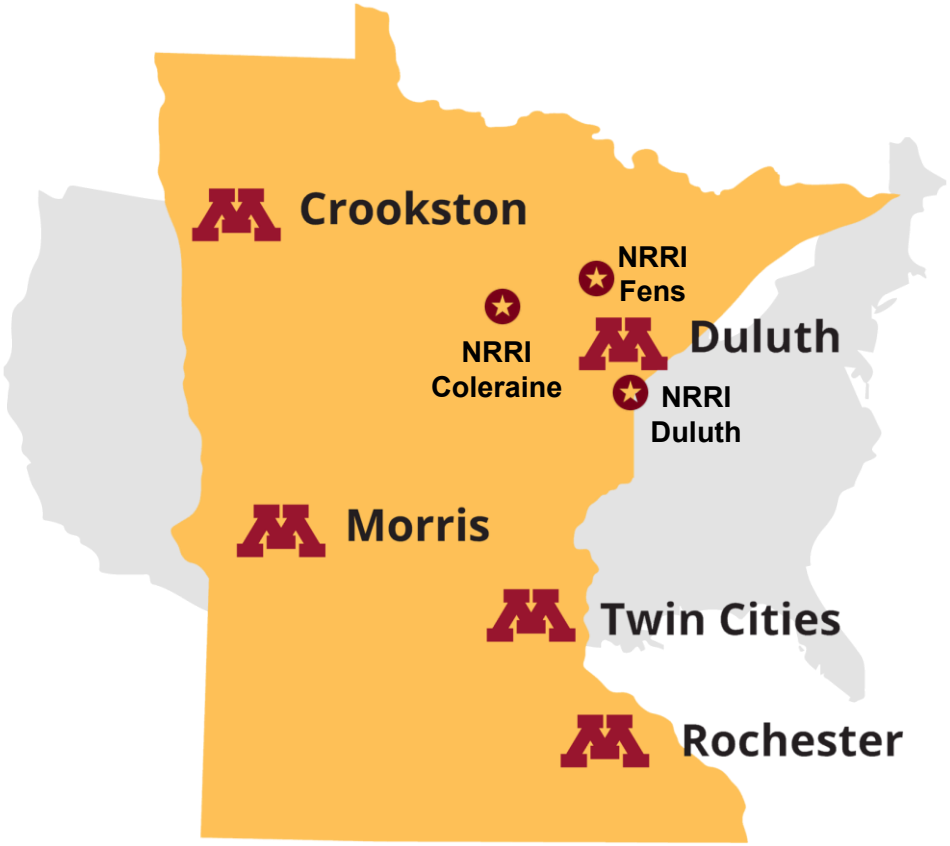
NRRI Delivers Integrated Research Solutions



ABOUT NRRI

- A **state-chartered applied research Institute of the University of Minnesota**
- **Three sites** in Northern Minnesota collaborating with partners around the globe

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

Visit our website for more information: NRRI.UMN.EDU

NRRI Background – Facilities and Capabilities

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NRRI Duluth

The NRRI admin facility has 19 labs that address the needs of land, wildlife, water and minerals research, as well as several technology development labs and the LP Innovation Center, developed in partnership with LP.

NRRI Coleraine

A 27-acre industrial-scale site which includes minerals processing and metallurgy labs to provide bench to pilot-scale research and the engineered biocarbon development lab to test processes for converting biomass into fuel and carbon materials.

NRRI Fens

A 425-acre property near Zim, MN where decades of ongoing research to restore its function as a valuable peatland - nature's most effective carbon sequestration solution - will continue to inform successful peatland restorations across the nation.

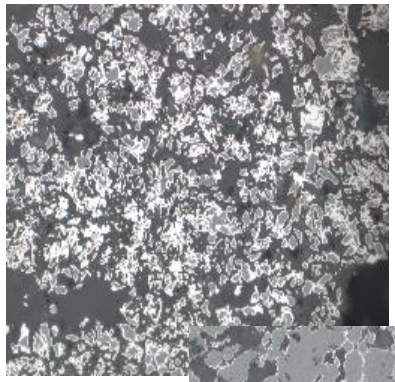
Project Overview

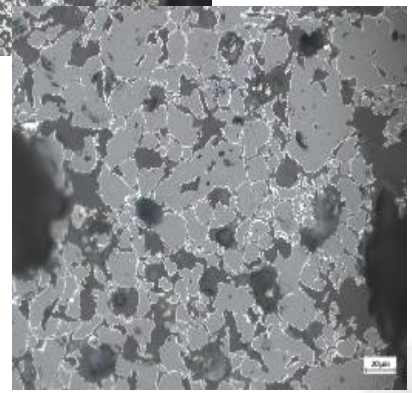
Introduction and Background

Introduction

Project: DOE AMO – Enhanced Pellet Chemistry

- **Duration:** 2021-2025/26
- **Federal Funding:** $2,100,000
- **State/NRRI Funding:** $1,600,000





Objectives:

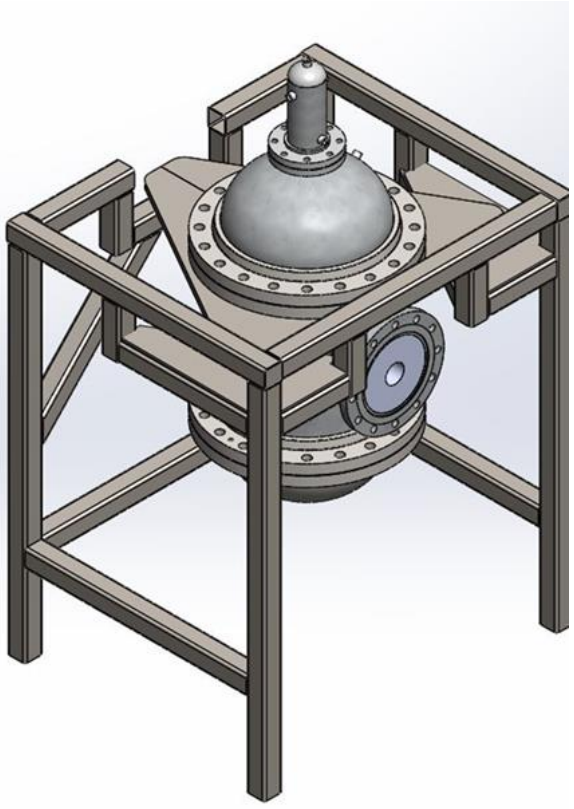
Improve the high temperature properties of DRI feed to:

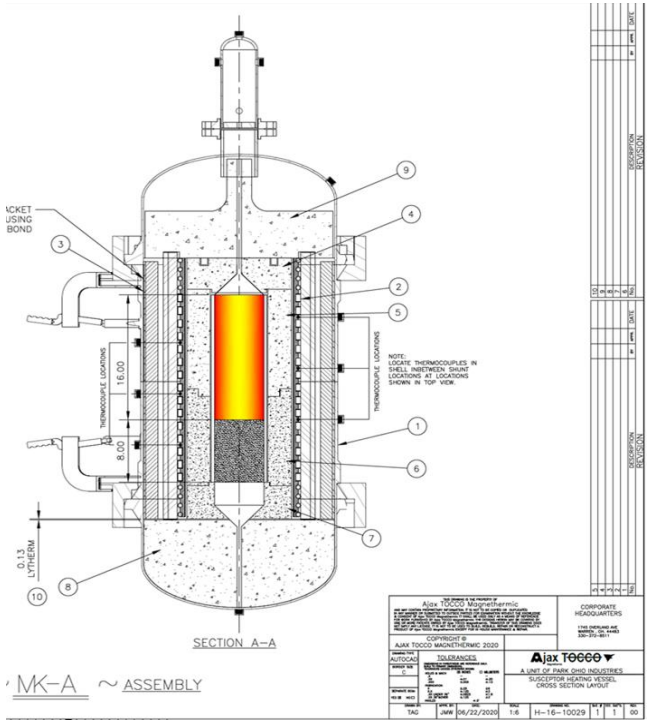
- Allow higher temperatures in reduction
- Enhance removal of gangue
- Promote smelting to produce granulated pig iron nodules
- Produce iron products from lower quality, oxidized, Minnesota iron ore
- **Design, build and commission the DRI Simulator**

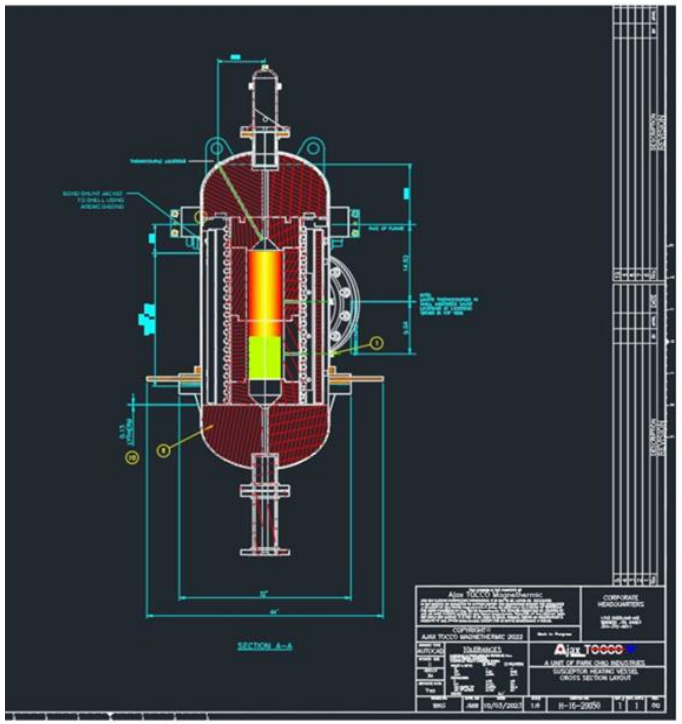
Impact to Minnesota and U.S.

Expanded iron product portfolio with reductions in energy and carbon for steelmaking

NRRI's Unique Applied Research Equipment
The DRI Simulator

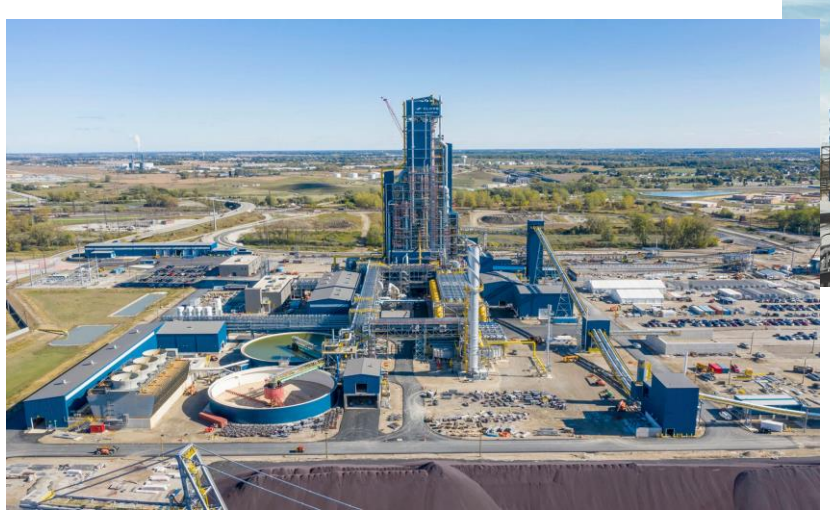






Background – Why Build a DRI Simulator
Industry Trends

- Minnesota Taconite operations can make EAF grade pellets
- U.S. DRI Capacity Growth
  - Nucor
    - Convent, LA
    - 2.5 million tons per year
    - Tenova HYL
  - Arcelor Mittal / Voestalpine
    - Corpus Christi, TX
    - 2 million tons per year
    - Midrex
  - Cleveland Cliffs
    - Toledo, OH
    - >1.5 million tons per year
    - Midrex



More in capital planning phase

Background – Why Build a DRI Simulator
Standardized Tests

Industry standard DRI reducibility tests generate **relative results** that are not representative of commercial-scale operations

- Small test portion (500 – 2000 grams)
- Temperatures limited to 1000 ^{o}C and atmospheric pressure
- Gas compositions are fixed and vary significantly from commercial operations
- Does not involve real time gas analysis

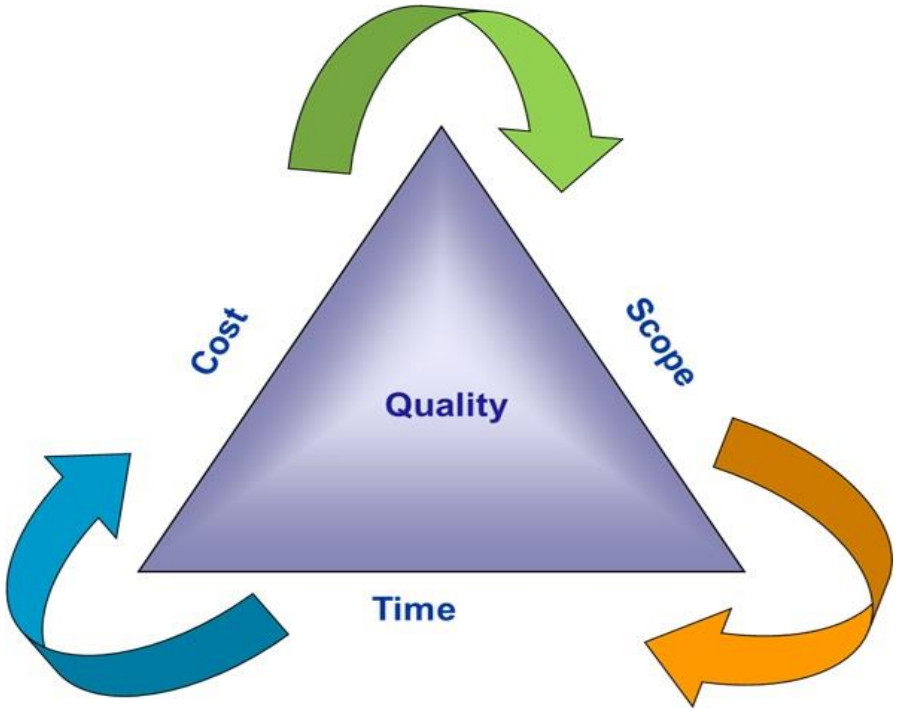
Project Overview

Objectives

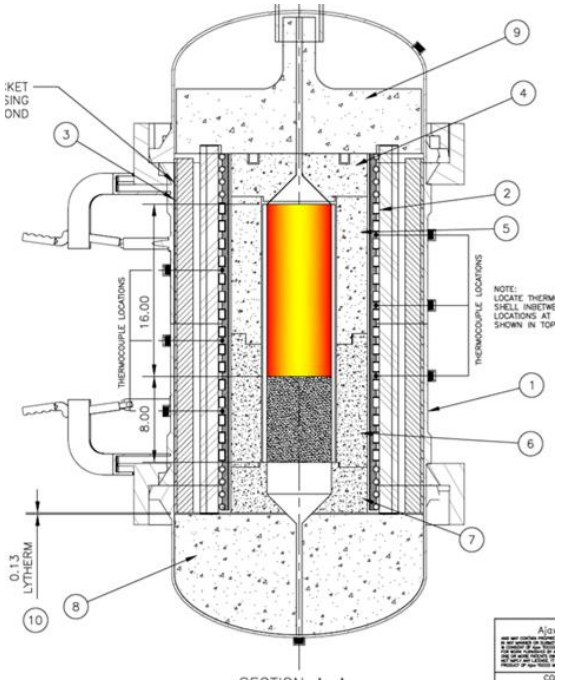
Milestone History

Project Management Objectives

- Design to operate safely with minimal risk to employees and equipment
- Like a pot grate test for induration, be able to complete at least one test per day for similar cost
- Manage the triple constraint
  - Scope well defined
  - DOE Grant and NRRI Funded
  - Commission in Q3 2026
- Quality: deliver on achieving industry research objectives, including digital twinning

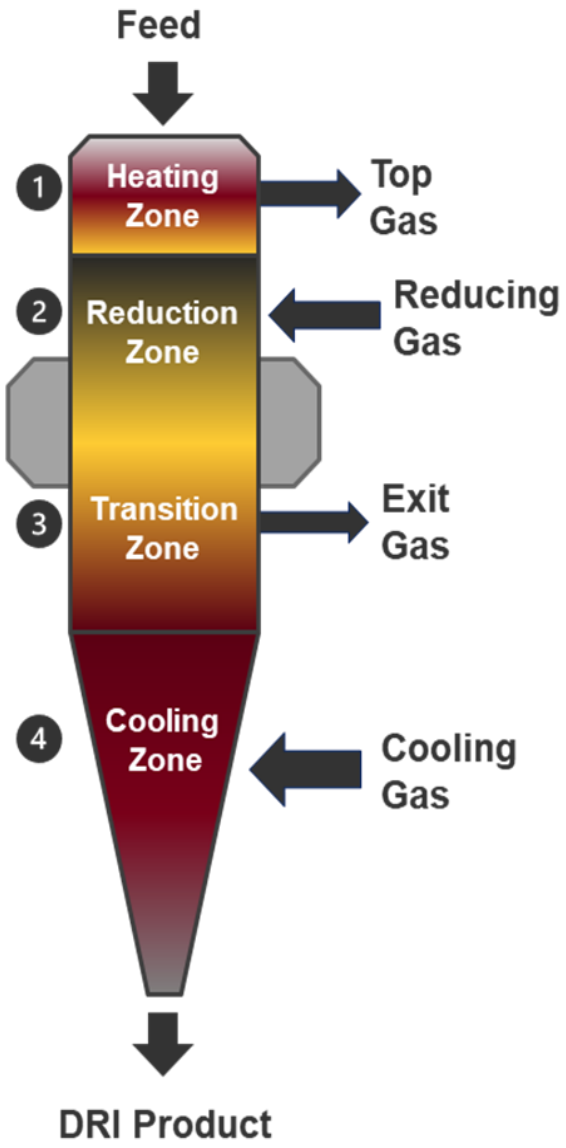


Project Design Objectives



- **Test portion 10 kg** max (22 lbs)
- Operating temperatures up to **1100 °C** (2012 F)
- Operating pressures up **to 8 bar** (116 psi)
- Reactor geometry length / diameter (L/D) similar to commercial shaft furnace
- Commercial **reducing gas conditions**, including composition and relative flow rates
- **Carbon** addition to DRI materials in the transition (isobaric) and cooling zones using gas composition and temperature transients similar to commercial systems
- **Real Time Gas Analysis** via mass spectrometry to understand reaction kinetics

Commercial Operations at Research Scale



DRI PROCESS TRANSITIONS

1) Pre-Heating
- Moisture Evaporation
- Under N_2

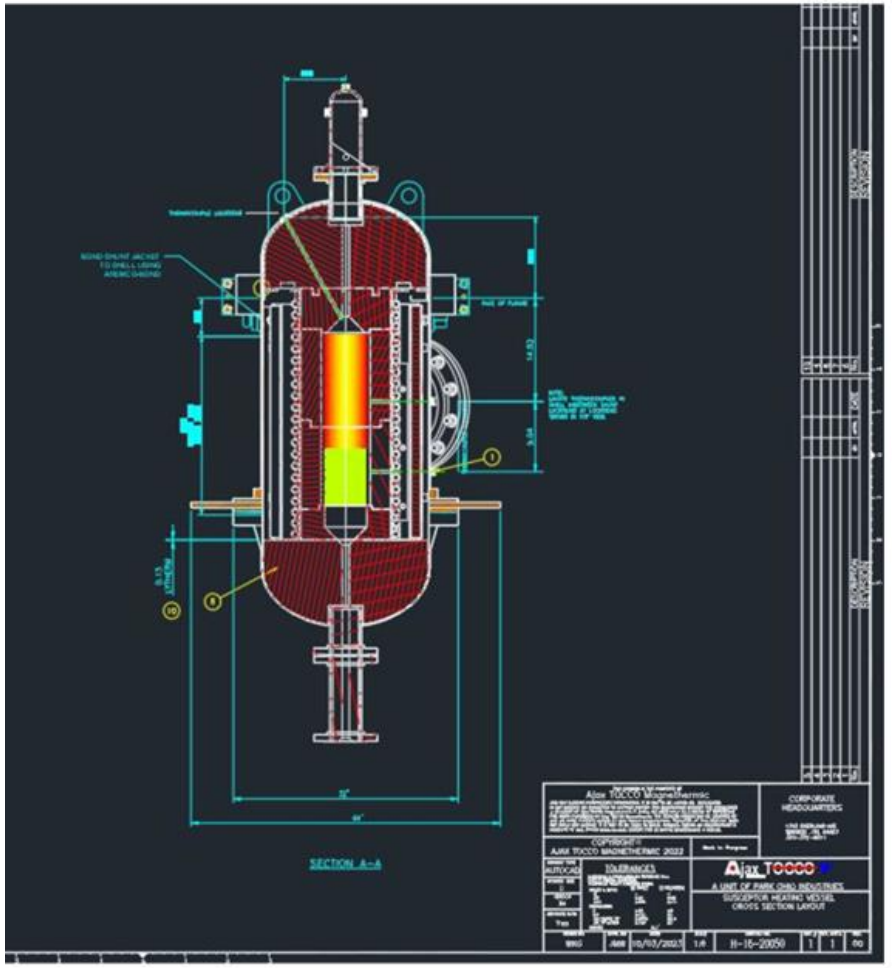
2) Reduction
- Hematite to Magnetite
  - $3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2$
  - $3Fe_2O_3 + H_2 \rightarrow 2Fe_3O_4 + H_2O$
- Magnetite to Wustite
  - $Fe_3O_4 + CO \rightarrow 3FeO + CO_2$
  - $Fe_3O_4 + H_2 \rightarrow 3FeO + H_2O$

3) Metallization
- Wustite to Iron
  - $FeO + CO \rightarrow Fe^o + CO_2$
  - $FeO + H_2 \rightarrow Fe^o + H_2O$

4) Carburization and Cooling
- $3Fe^o + CH_4 \rightarrow Fe_3C + 2H_2$
- $3Fe^o + 2CO \rightarrow Fe_3C + CO_2$
- $3Fe^o + CO + H_2 \rightarrow Fe_3C + H_2O$

Final Cooling
- N_2

Simulate the changing temperature and gas profile



Reduction Gas Composition

- Mixes designed to simulate what a pellet would see as it falls through the shaft furnace
- Gas composition varies widely, in both existing tests and commercially
- Existing tests vary from commercial compositions (data is % by volume unless otherwise noted):

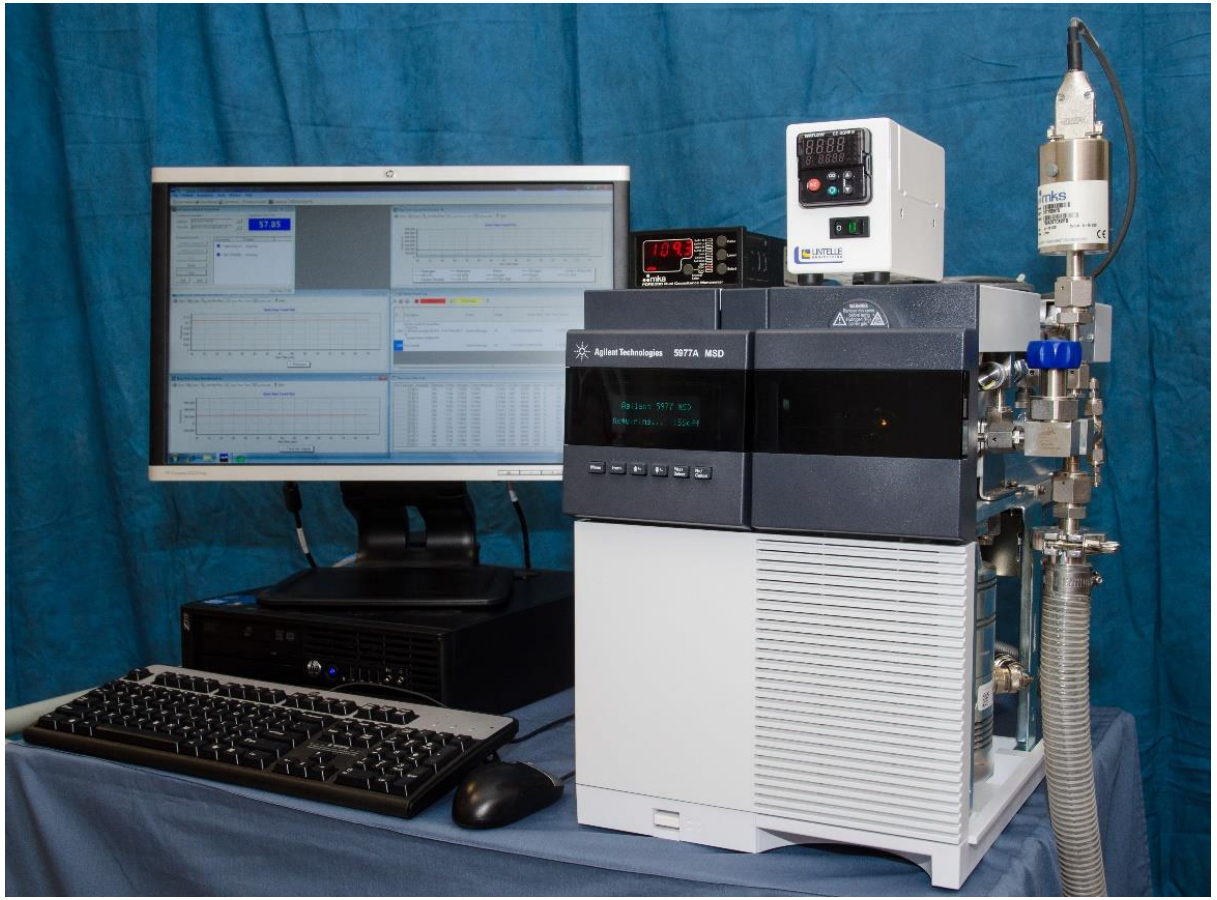
Test/Process:		H_2	CO	CO_2	N_2	CH_4	H_2O	H_2S[1]
ISO 11256		45	30	15	10			
ISO 11257		55	36	5		4		
ISO 11258		45	30	15	10			
DRI Plant #1[2]	Process[3]	55.6	33.5	2.5	0.4	3.0	5	
	Cooling	6.6	1.3	1.3	3.5	83		
DRI Plant #2[2]	Process[3]	58.7	14.0	0.1	3.4	18.8	5	0.4
	Cooling	38.9		0.2		62.3		0.7

[1] Values in ppm [2] Commercial data [3] Scaled to include water

Reduction Gas Composition

Quantum Analytics

- The Diablo 5000B Real-Time Gas Analyzer (RTGA) combines the MS Sensor software with an Agilent Technologies 5977 MSD and a high-performance, differentially pumped direct sampling interface.
- The Real-Time Gas Analyzer is a real-time chemical measurement tool for continuous process improvements.
- It is ideal for applications where very fast analysis is required, such as monitoring for transients and continuous reactions.

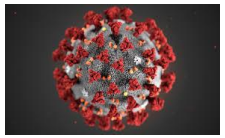


Milestone History

2017 - 2018

2018 - 2020

COVID 19



2021 - 2024

2024 - 2025/26

You are here

Phase I: Conceptual Design

- **Goal:** complete conceptual design and get input from steel industry

Phase II: Preliminary Engineering

- **Goal:** complete preliminary engineering design and process hazard analysis

Phase III: Detailed Engineering and Major Item Procurement

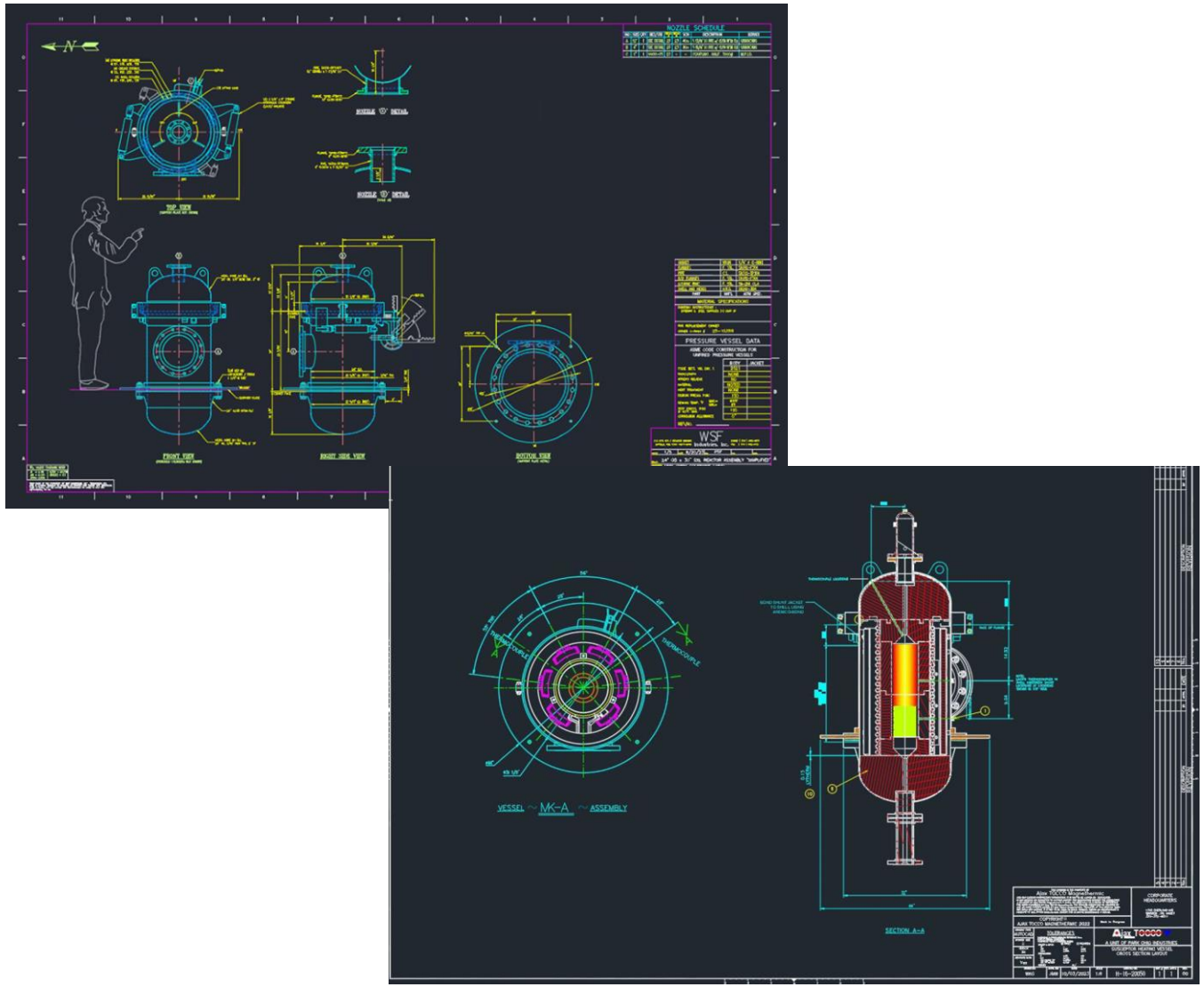
- **Goal:** select vendors and complete detailed engineering for major equipment components

Phase IV: Balance of Plant Engineering, Procurement, Site Prep and Construction

- **Goal:** Detailed engineering for "balance of plant" requirements, procurement of all items, site preparation and construction

Project Update

Engineering and Procurement



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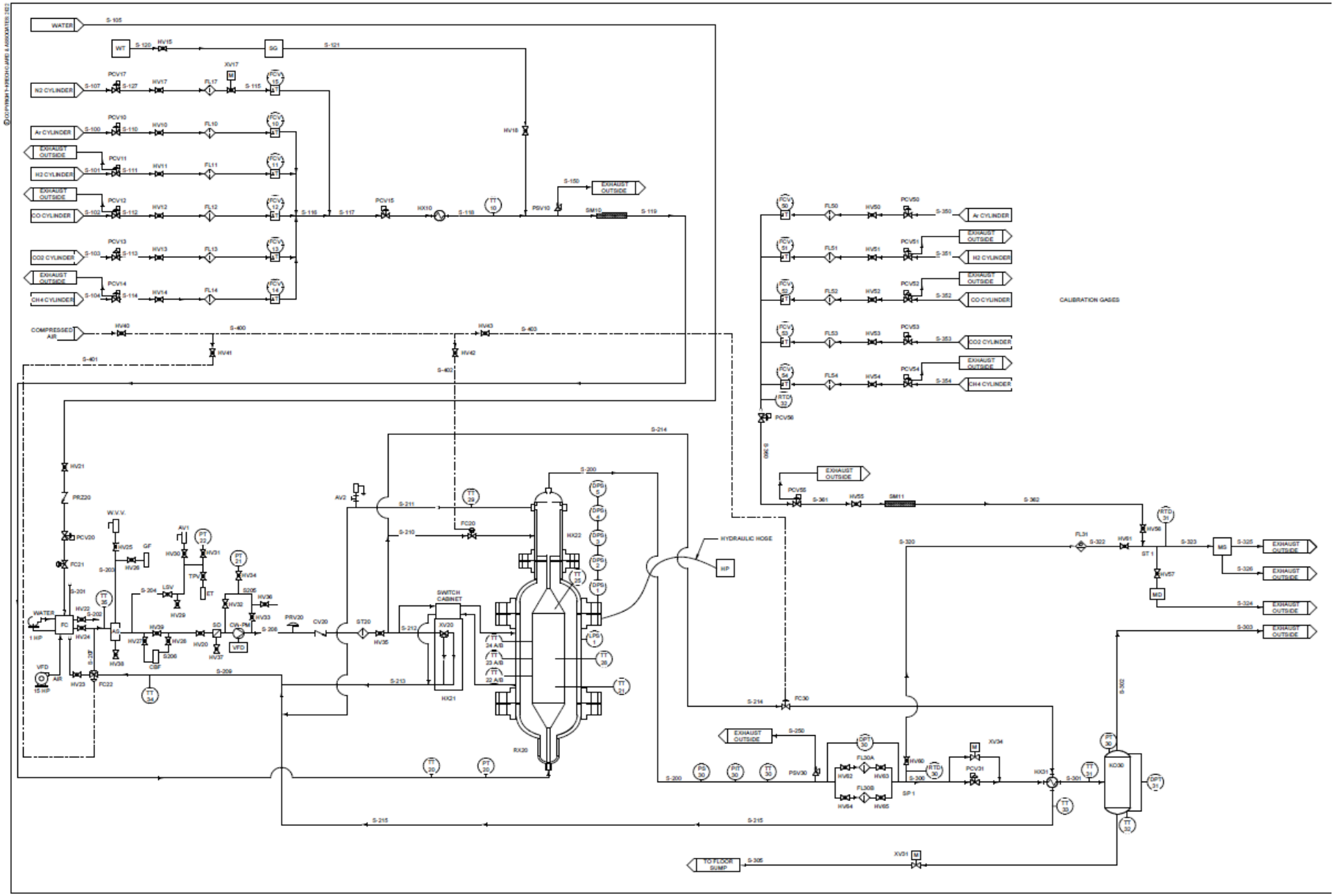
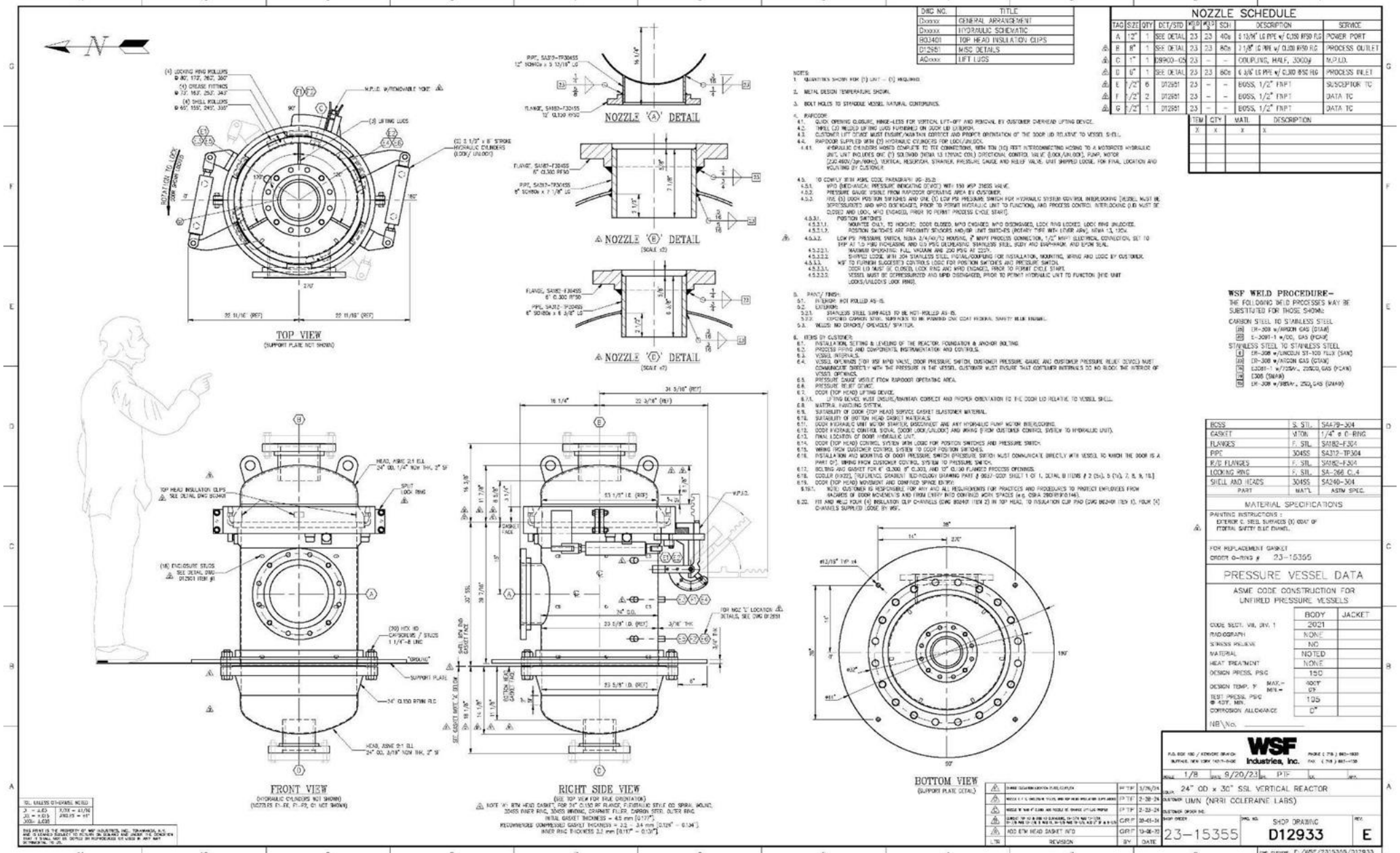
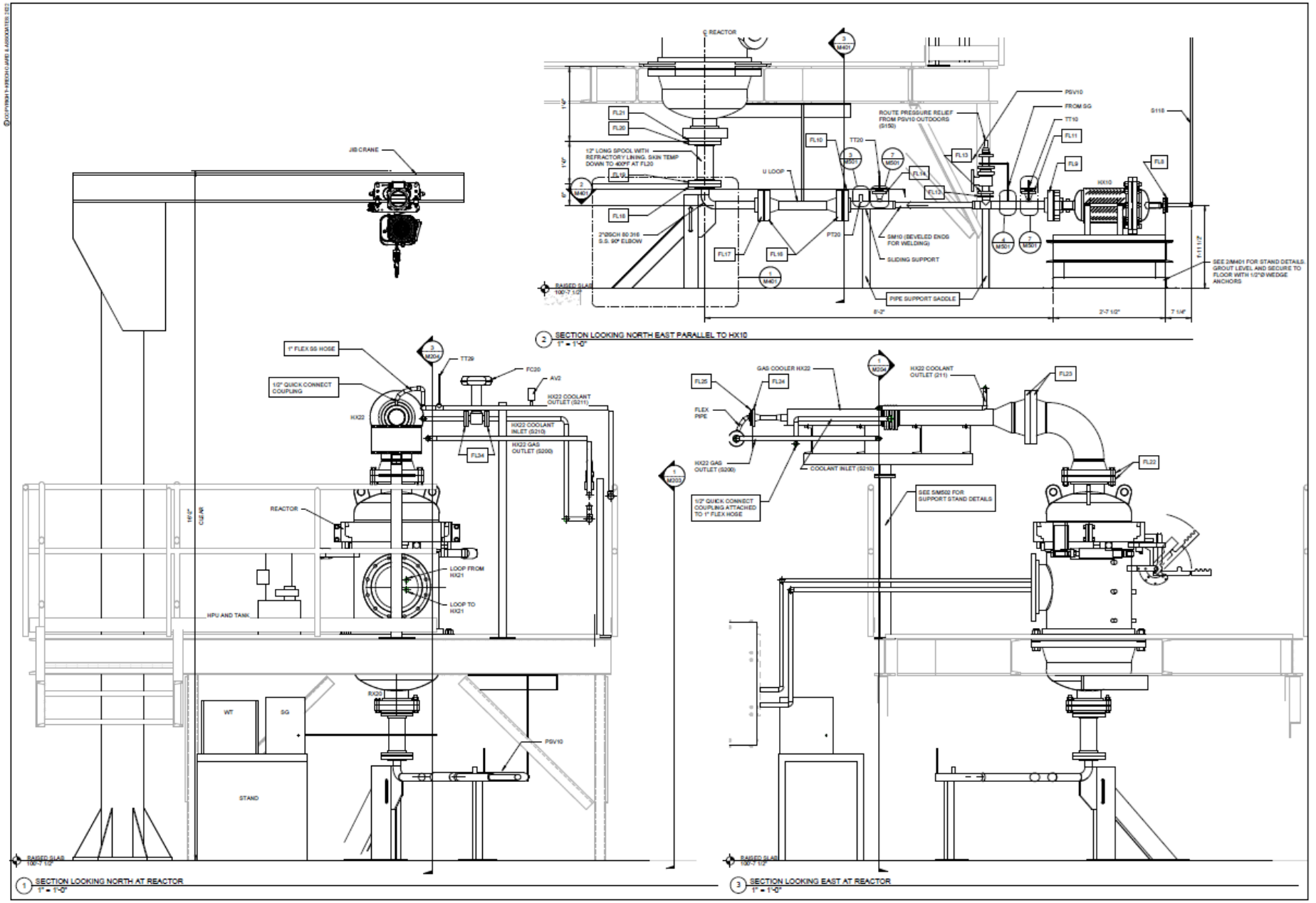

WATER
N2 CYLINDER
Ar CYLINDER
H2 CYLINDER
CO CYLINDER
CO2 CYLINDER
CH4 CYLINDER
EXHAUST OUTSIDE
COMPRESSED AIR
CALIBRATION GASES
HYDRAULIC HOSE
SWITCH CABINET
VFD
TO FLOOR SUMP

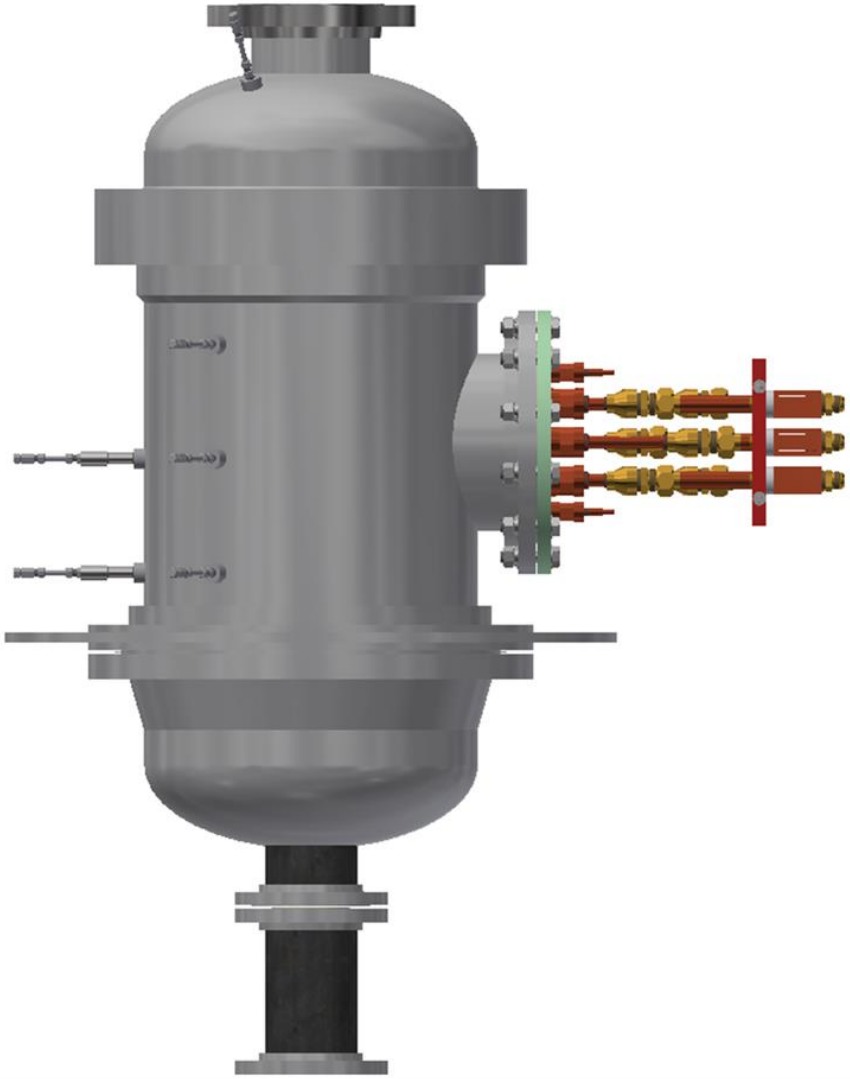
Design

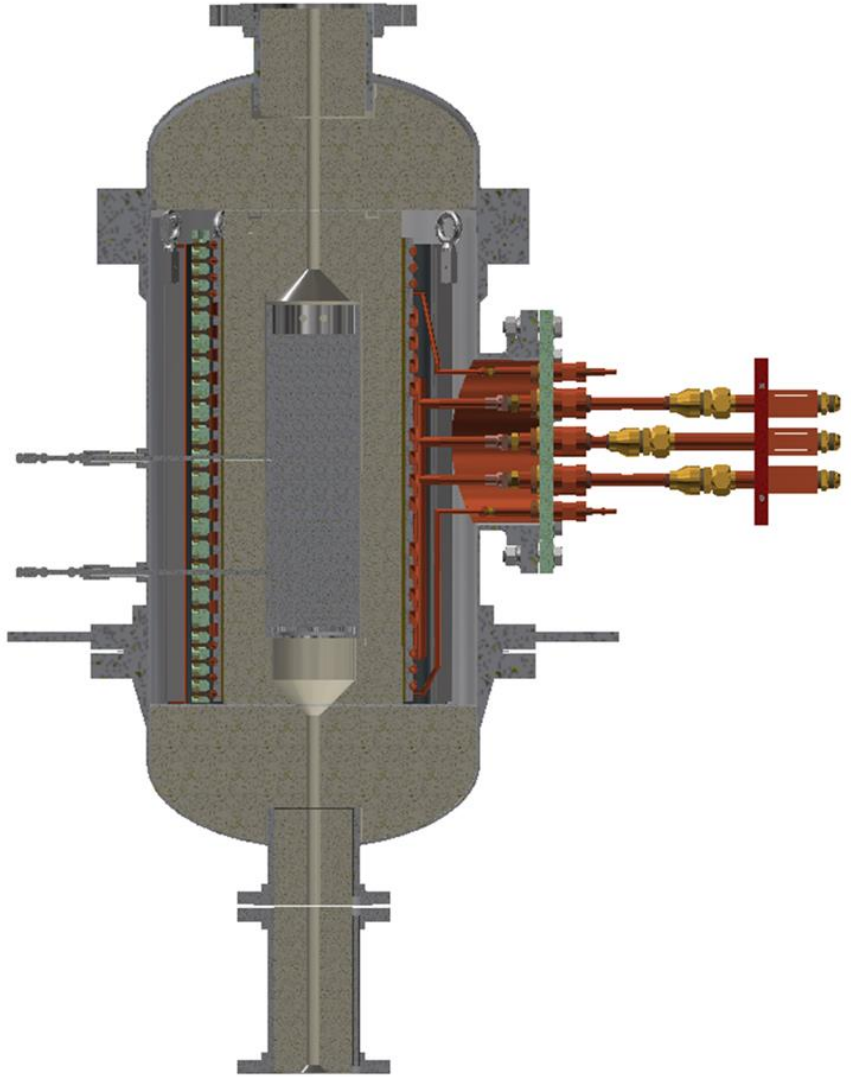

NOZZLE SCHEDULE
TOP VIEW
FRONT VIEW
RIGHT SIDE VIEW
BOTTOM VIEW
NOZZLE 'A' DETAIL
NOZZLE 'B' DETAIL
NOZZLE 'D' DETAIL
PRESSURE VESSEL DATA
WSF WELD PROCEDURE
WSF Industries, Inc.
24" OD x 30" SSL VERTICAL REACTOR
SHOP DRAWING
D12933
23-15355

Design


JIB CRANE
1" FLEX SS HOSE
1/2" QUICK CONNECT COUPLING
HX22
TT29
FC30
AV2
HX22 COOLANT OUTLET (S211)
HX22 COOLANT INLET (S210)
HX22 GAS OUTLET (S200)
FL34
REACTOR
16'-0" CLEAR
LOOP FROM HX21
LOOP TO HX21
HPU AND TANK
HX20
WT
SG
PSV10
STAND
RAISED SLAB 100'-7 1/2"
1 SECTION LOOKING NORTH AT REACTOR
1" = 1'-0"
℄ REACTOR
12" LONG SPOOL WITH REFRACTORY LINING. SKIN TEMP DOWN TO 400°F AT FL20
FL21
FL20
FL19
FL18
2"ØSCH 80 316 S.S. 90° ELBOW
U LOOP
FL10
TT20
FL13
FL14
FL12
PT20
SM10 (BEVELED ENDS FOR WELDING)
SLIDING SUPPORT
FL17
FL16
PIPE SUPPORT SADDLE
ROUTE PRESSURE RELIEF FROM PSV10 OUTDOORS (S150)
PSV10
FROM SG
TT10
FL11
FL9
FL8
HX10
S110
SEE 2/M401 FOR STAND DETAILS. GROUT LEVEL AND SECURE TO FLOOR WITH 1/2"Ø WEDGE ANCHORS
8'-0"
2'-7 1/2"
7 1/4"
2 SECTION LOOKING NORTH EAST PARALLEL TO HX10
1" = 1'-0"
GAS COOLER HX22
FL25
FL24
FLEX PIPE
HX22 GAS OUTLET (S200)
COOLANT INLET (S210)
HX22 COOLANT OUTLET (211)
FL23
FL22
1/2" QUICK CONNECT COUPLING ATTACHED TO 1" FLEX HOSE
SEE SM502 FOR SUPPORT STAND DETAILS
RAISED SLAB 100'-7 1/2"
3 SECTION LOOKING EAST AT REACTOR
1" = 1'-0"

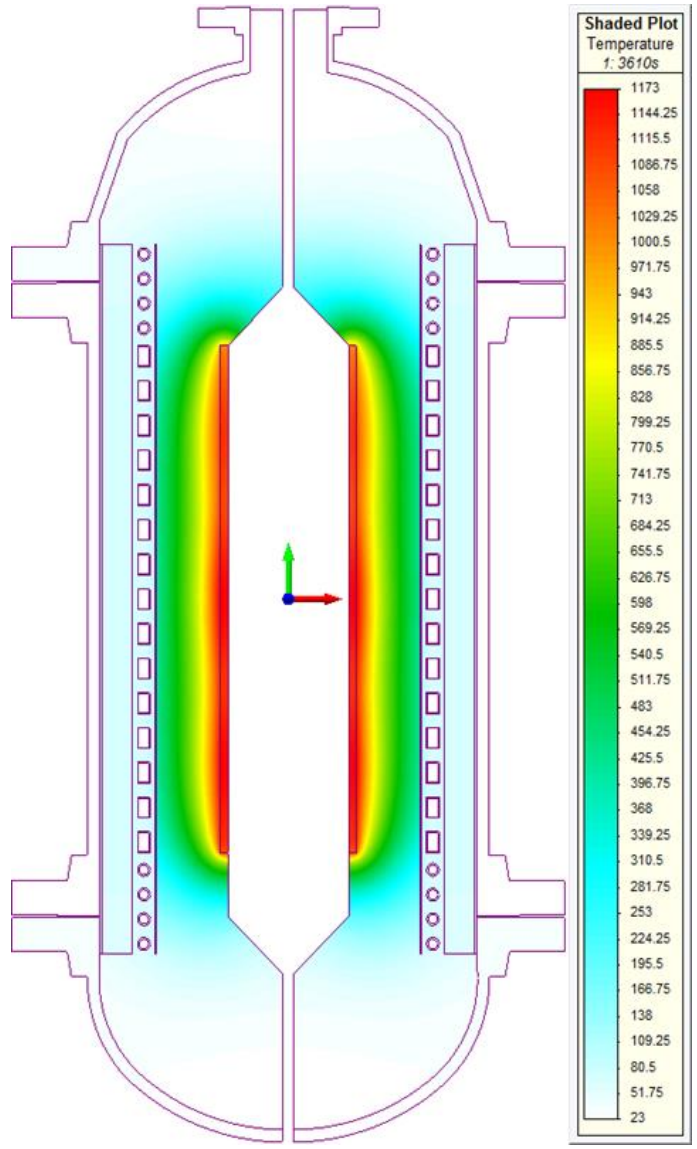
3-D Model of the Reactor





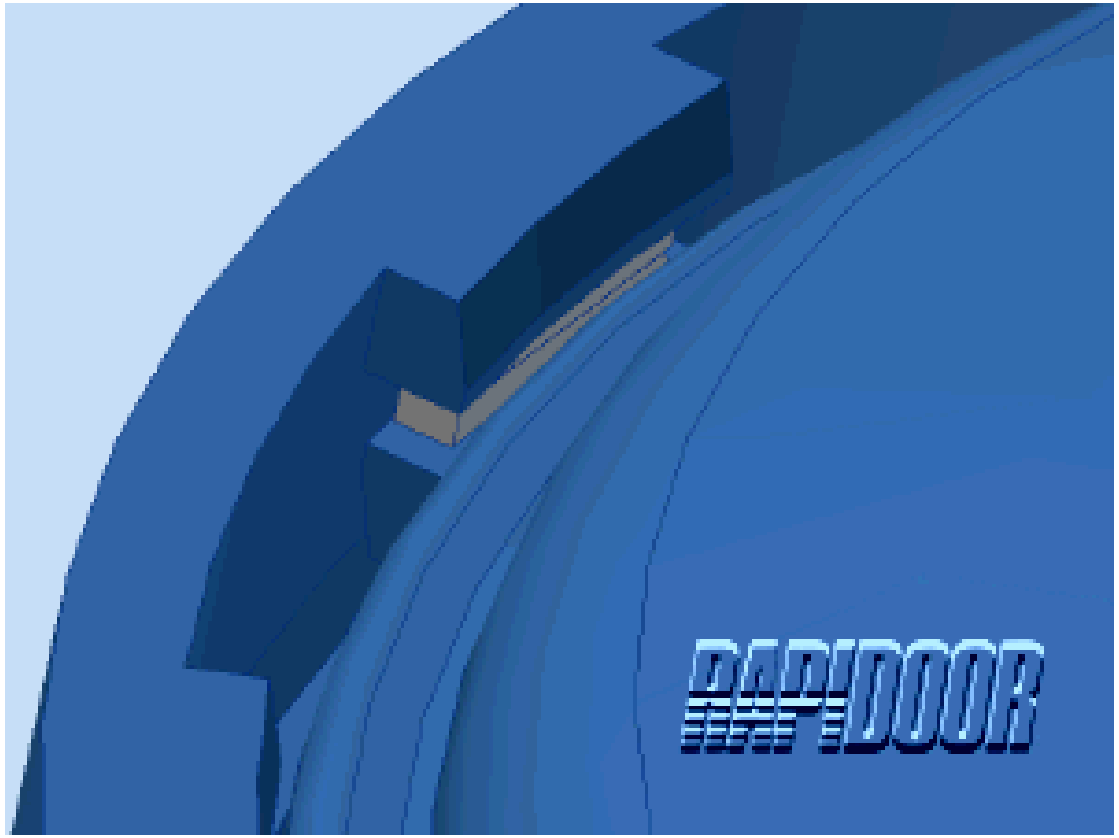
3 Iteration Thermal Modeling Recap

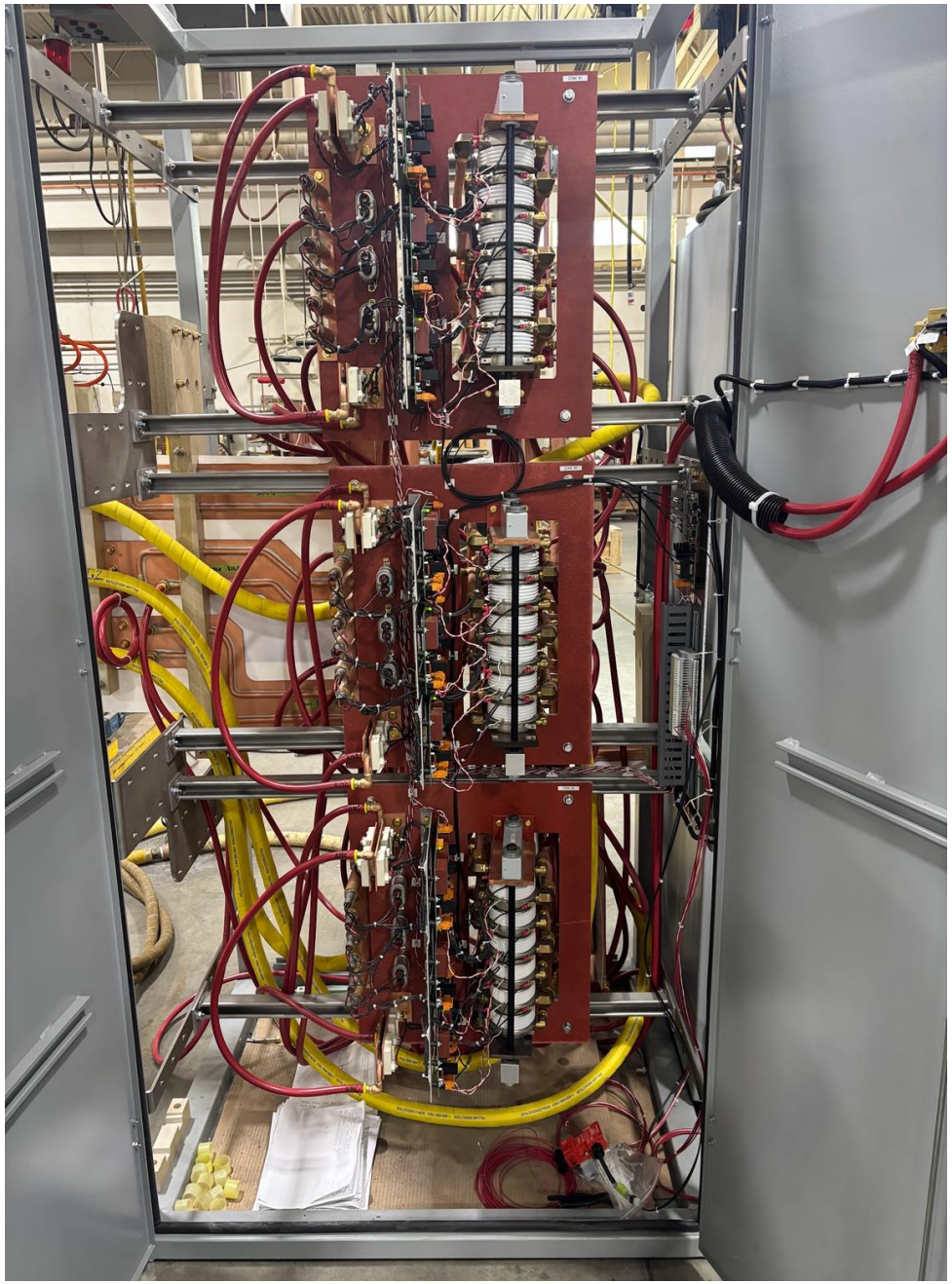
- Thermal energy balance successfully completed at 1100 °C operating temperature
- Susceptor specifications – Inconel 718
- Refractory specifications – Alumina
- Power requirements – minimum power supply rating of 150 kW
- Frequency – 3 kHz
- Vessel diameter increased from 20 inches to 24 inches to account for coil terminations



Reactor Top Flange Design - Rapidoor by WSF

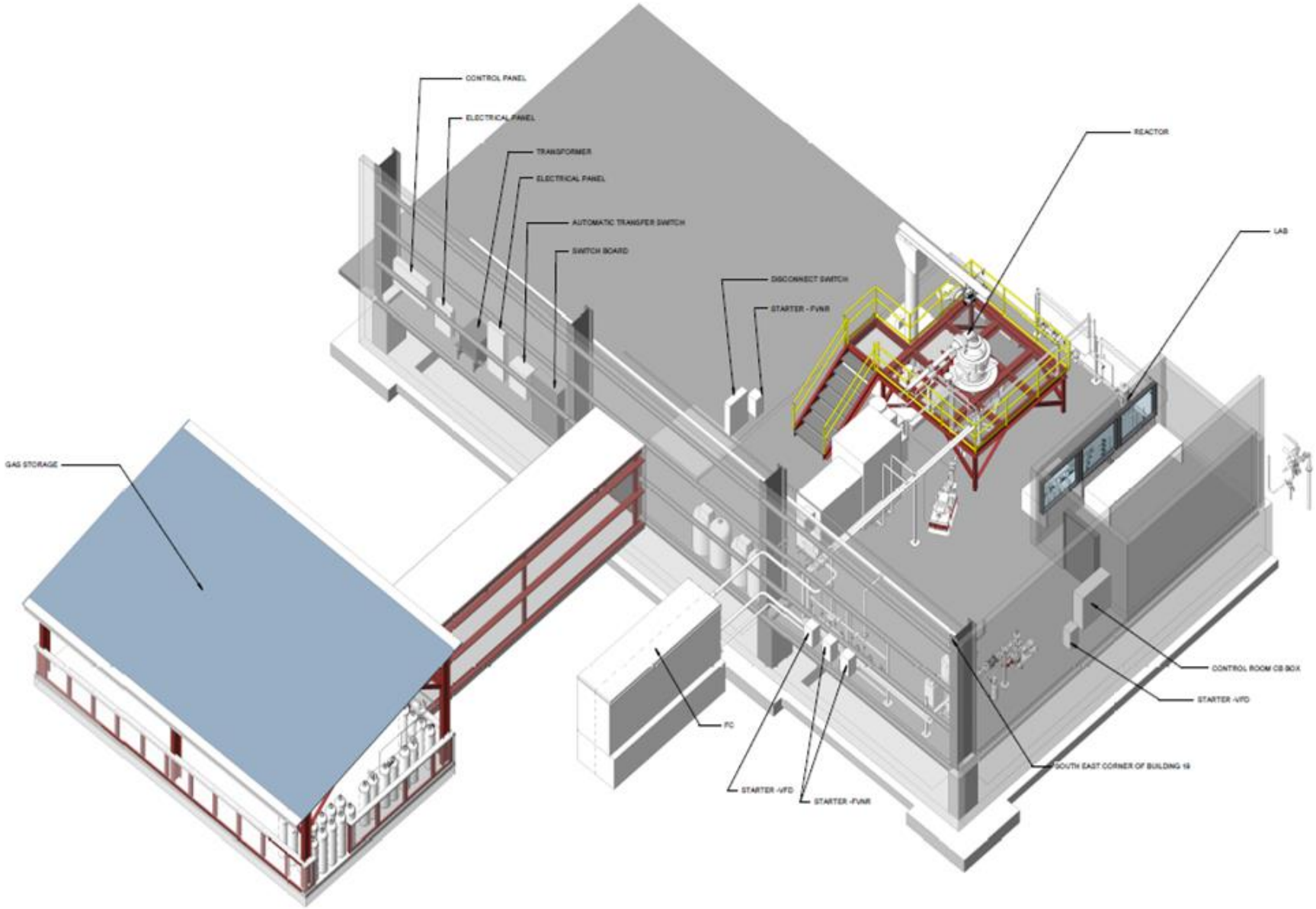
- Quick-access pressure vessel head styles are available
  - ✓ ASME Section VIII, Division 1 rated
  - ✓ Open and close in just a minute with a single actuation point
  - ✓ Easy to incorporate into fabrication
  - × More expensive, longer lead time





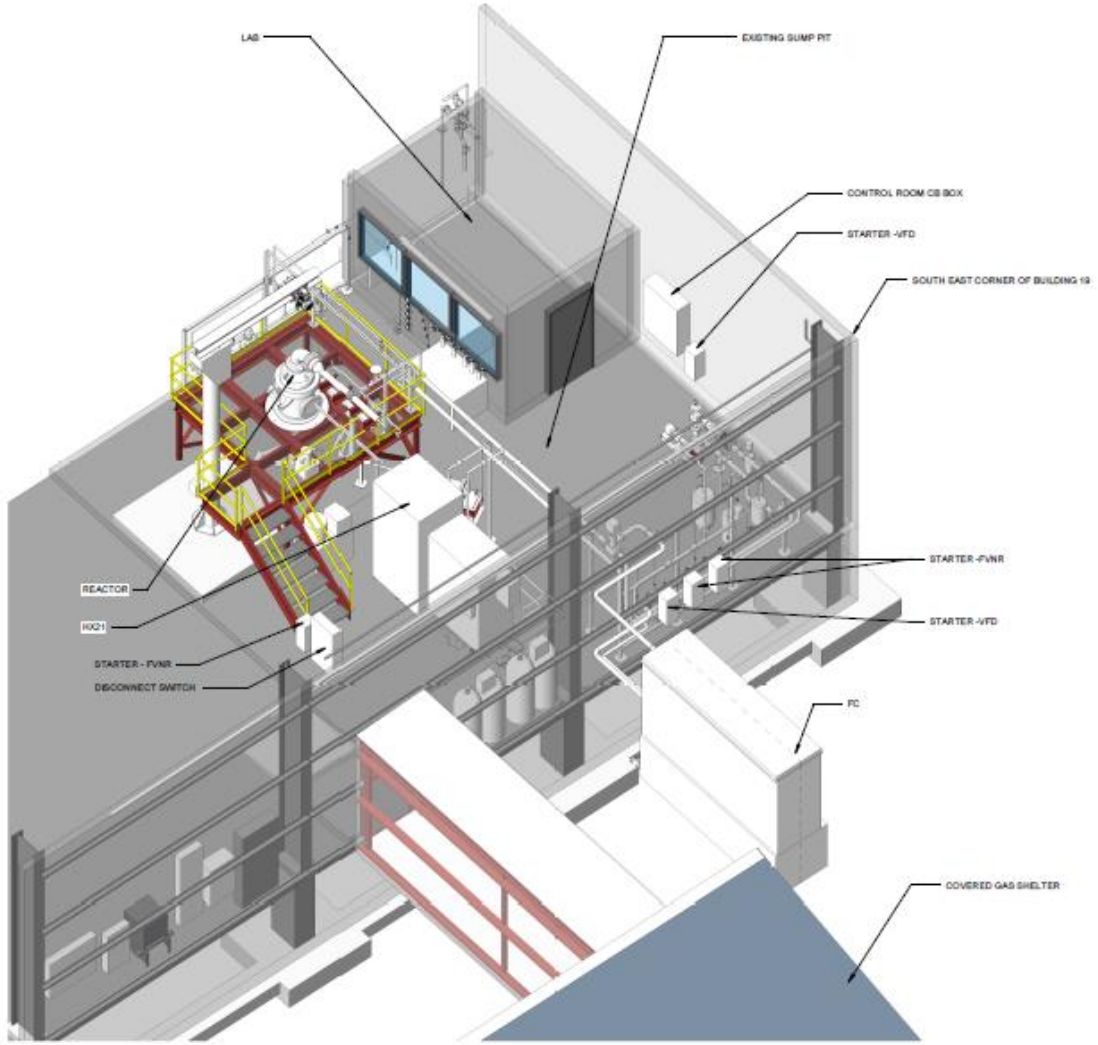

480 VOLTS

DRI Simulator Layout

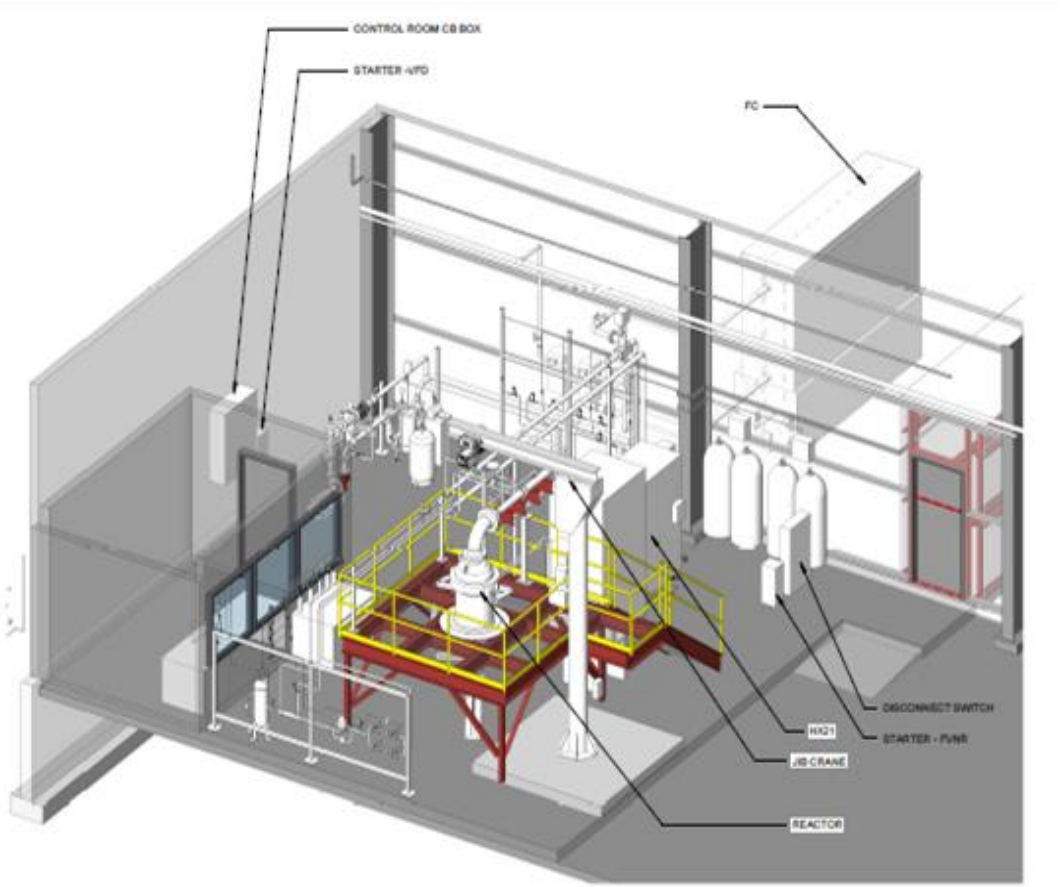


DRI Simulator Layout – Compressed Gas Storage

DRI Simulator Layout



1 ISOMETRIC VIEW - LOOKING NORTH EAST



2 ISOMETRIC VIEW - LOOKING SOUTH EAST

Project Status Update – Summary

100%

Detailed Engineering

Engineering completed in collaboration with Krech Ojard, Gradient Technology, Architectural Advantage and Equipment Suppliers according to all relevant codes and standards

- Reactor engineering
- Induction heating system
- General arrangement drawings
- Structural drawings
- Electrical one-lines
- UMN Building Codes Review

90%

Procurement

Procurement of all equipment and components through NRRI Finance and UMN Central Purchasing, source mainly from the USA

- Engineering
- Equipment
- Parts and Supplies
- Compressed gases
- Contractors

60%

Offsite Construction - complete
On-site Construction - in process

Off-site construction at key suppliers and on-site construction by contractors with field support from suppliers for system assembly and connection to infrastructure

- Electrical supply by Minnesota Power
- Site preparation in Building 19
- Gas Storage Building
- Reactor and Induction Heating System
- **On-site construction and assembly planned for March-May 2026**

DRI Simulator as a Research Tool

- Process Measurements
  - Gas composition – continuous inlet and outlet
  - Temperature – test portion, reducing gas, and reactor
  - Reactor pressure
  - Gas flow – inlet and outlet
  - Time
- Outcome Measurements
  - Reducibility
  - Clustering/sticking index
  - Metallization
  - Morphology

NRRI possesses the unique capabilities to offer a **holistic product development approach** from processing run-of-mine iron ore to value-added iron products such as DRI

Project Partners

- **Department of Energy -** funding and technical support
- **Department of Iron Range Resources and Rehabilitation -** funding
- **Krech Ojard -** Integration & Engineering
  - Sub: **Architectural Advantage**
- **Gradient Technologies –** Technical Support
- **Ajax Tocco Magnethermic / Pillar –** induction heating, exhaust gas cooling, automation
  - Sub: **Sterling Thermal** - suspectors and exhaust gas cooler
  - Sub: **Marshall Nelson** - automation and controls
- **Quantum Analytics / Agilent** - real time gas analysis via mass spectrometry
- **WSF –** reactor vessel fabrication and flanges
- **Airgas** - compressed gases
- **Gardner Builders** - general contractor
    - Sub: **Jamar** - carpentry and plumbing
    - Sub: **Archkey / Parsons** - electrical

Project Partners

U.S. DEPARTMENT OF ENERGY

MINNESOTA

KRECH OJARD

Ajax TOCCO Magnethermic

Quantum Analytics

Sterling thermal technology

WSF Industries, Inc. Tonawanda, NY USA

GRADIENT TECHNOLOGY

Marshall W. Nelson & Associates
Process Heating and Control Engineering Since 1958
a relevant. company

ARCHITECTURE ADVANTAGE
ARCHITECTURE & INTERIOR DESIGN SERVICES

GARDNER BUILDERS

JAMAR
POWERED BY API GROUP

ArchKEY SOLUTIONS

minnesota power

Airgas
an Air Liquide company

NATURAL RESOURCES RESEARCH INSTITUTE

UNIVERSITY OF MINNESOTA

Thank you!

Questions?

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ABOUT NRRI

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NRRI MISSION

Deliver integrated research solutions that value our resources, environment and economy for a sustainable and resilient future.

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