TATA STEEL

#WeAlsoMakeTomorrow

THE INDIAN INSTITUTE OF METALS

IIM

Metallurgy
Materials Engineering

Presents

International Conference on

GREEN & SUSTAINABLE IRON MAKING

January 17 – 18, 2024

Critical parameters of gas-based direct reduction

Chris Pistorius
Center for Iron and Steelmaking Research
Carnegie Mellon University

International Conference on GREEN & SUSTAINABLE IRON MAKING

Context and presentation aims

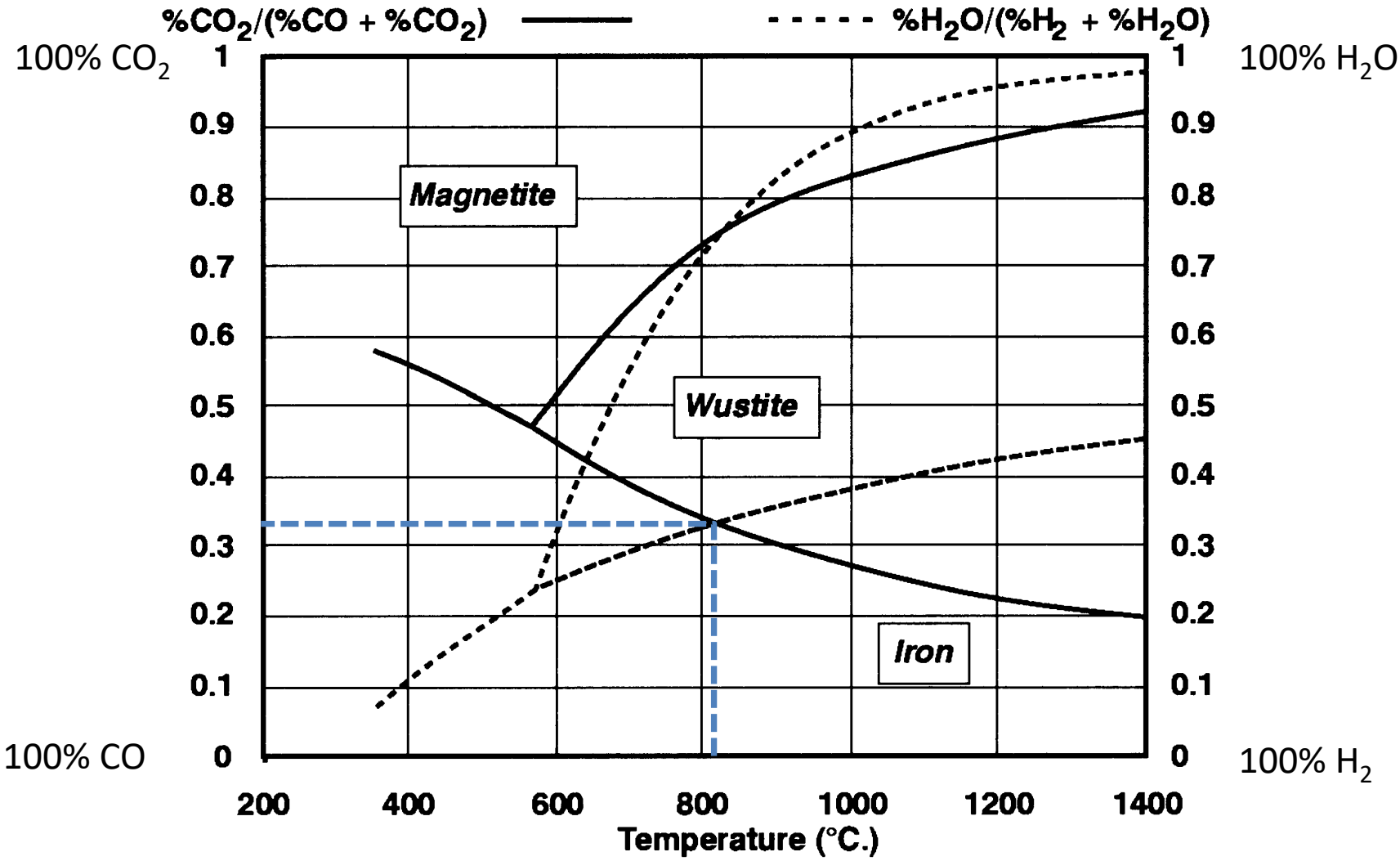
- Direct reduction:
  converting iron oxide to metallic iron without melting
  - Mostly using gaseous reductants (CO – H_2 mixtures)
  - Product: direct reduced iron (DRI)
  - Alternative to blast furnace ironmaking;
    current DRI production is about 0.1 billion tonne per year,
    compared with ~1.4 billion tonne of blast furnace iron
- Presentation aims
  - Process overview
  - Typical consumption figures (reductant & electricity)

Example: Nucor Steel Louisiana

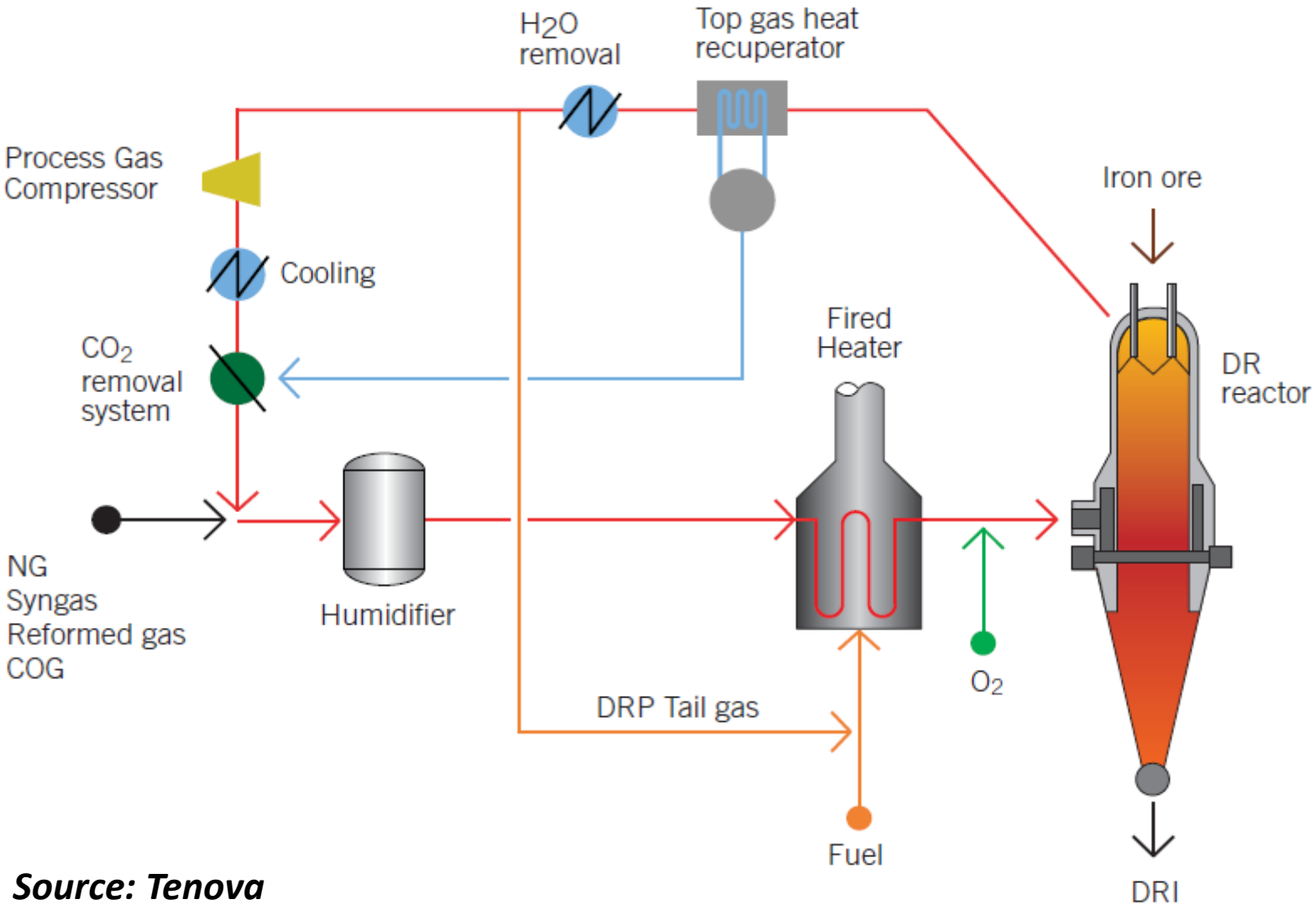
Source: Tenova HYL

Equilibrium gas compositions: Chaudron diagram

(Steiler, 1997, in Sano (ed.): *Advanced physical chemistry for process metallurgy)*

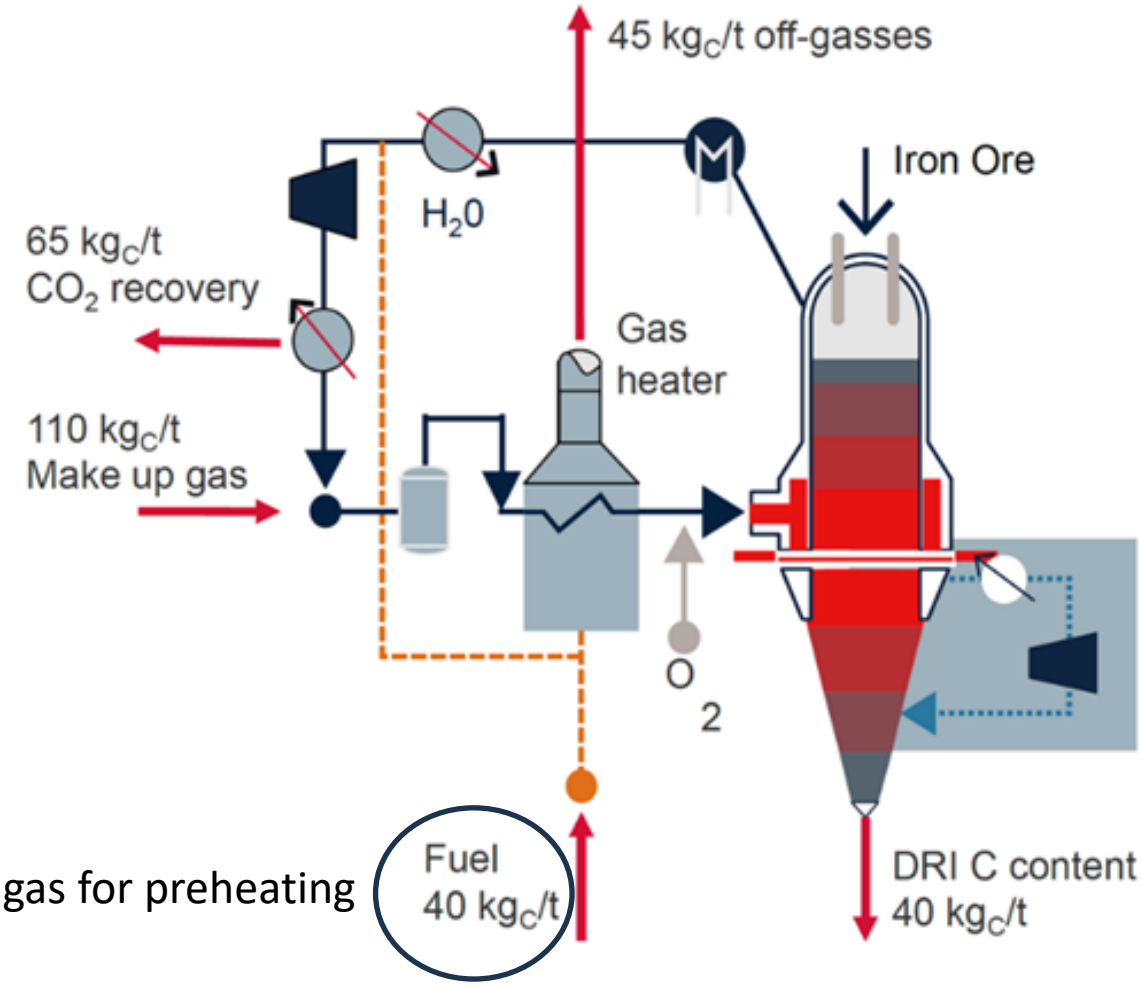


ENERGIRON ZR process flowsheet



Source: Tenova

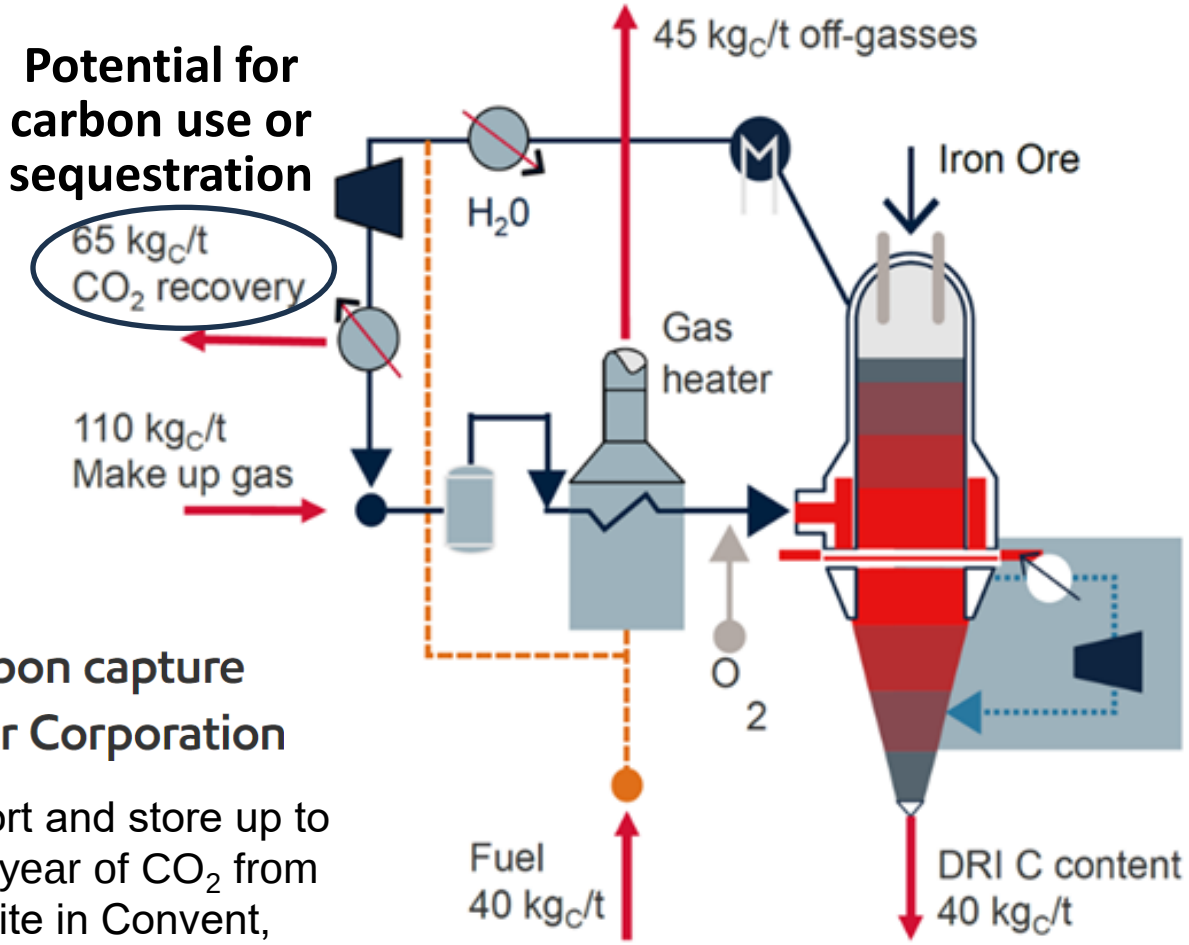
Carbon balance: Energiron ZR process



Natural gas for preheating

M. Dorndorff, "GrInHy2.0 - Another step towards hydrogen based steelmaking,"
Steel Times International webinar, November 20, 2020

Carbon balance: Energiron ZR process



News releases

June 1, 2023

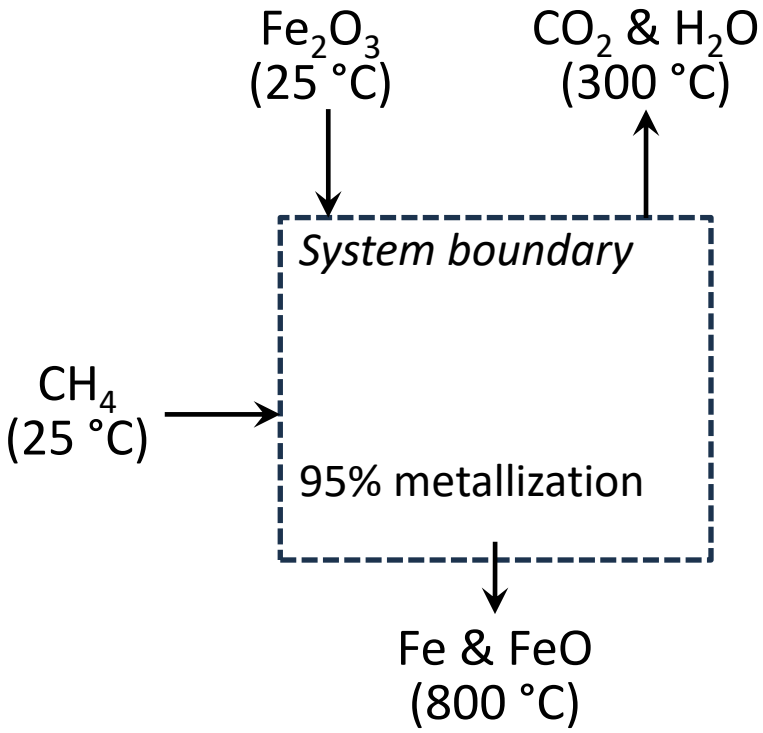
ExxonMobil signs carbon capture agreement with Nucor Corporation

"We will capture, transport and store up to 800,000 metric tons per year of CO_2 from Nucor's manufacturing site in Convent, Louisiana." (corporate.exxonmobil.com)

Significant energy for gas preheating

- 40 kg carbon per tonne DRI is approximately equivalent to:
  - 53 kg methane per tonne DRI
  - 0.75 MWh per tonne DRI (based on net calorific value)
- Why this large energy input?

Approximate energy balance of reduction process:

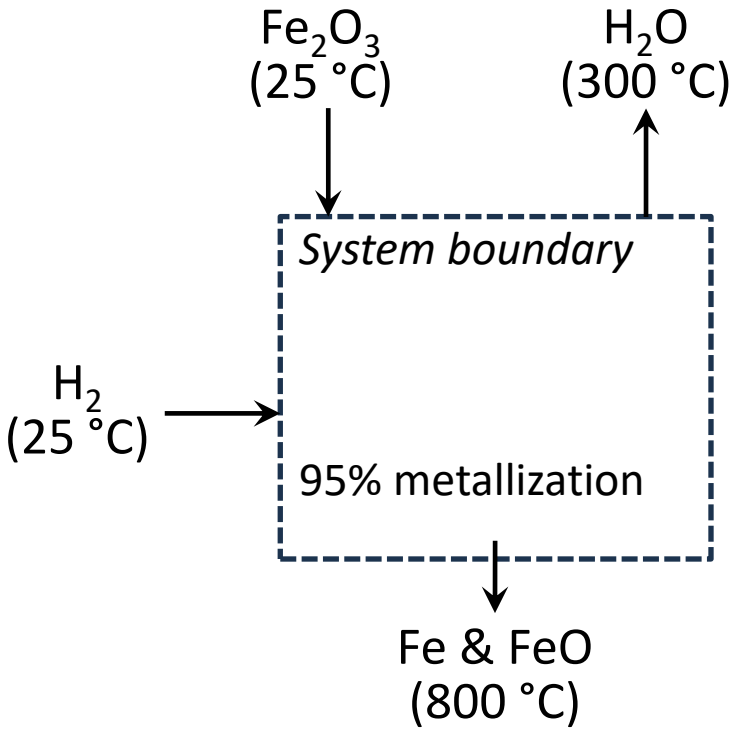


Calculated heat requirement:
0.66 MWh per tonne DRI

Energy requirement for hydrogen reduction?

- 0.41 MWh per tonne DRI could be provided by:
  - Electrical heating
  - Burning hydrogen:
    about 15 kg H_2 per tonne DRI,
    if efficiency = 80% relative to net calorific value

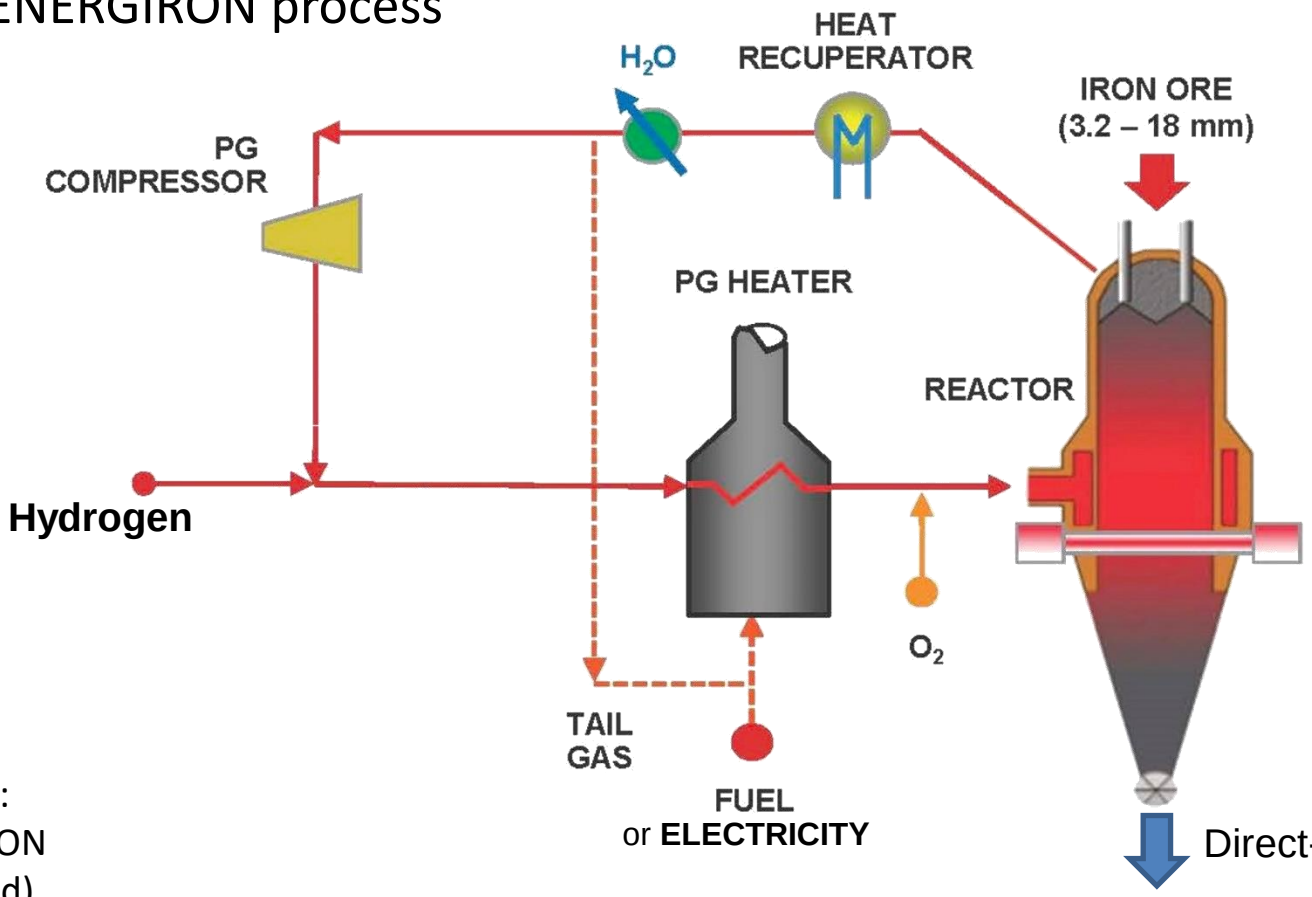
Approximate energy balance of reduction process:



Calculated heat requirement:
0.41 MWh per tonne DRI

Hydrogen-based direction reduction: Evolution from natural-gas process

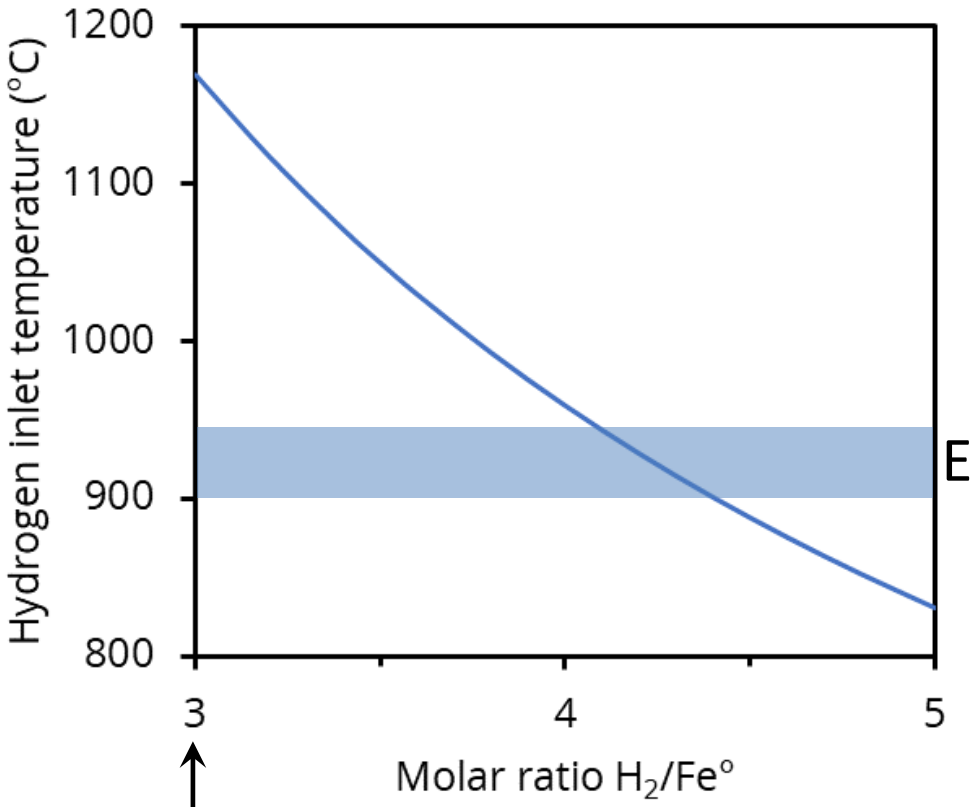
H_2-based ENERGIRON process



Source: ENERGIRON (modified)

Hydrogen-based direction reduction:

Required input gas temperature to meet process energy requirements



Approximate comparison: Inputs for direct reduction with natural gas and hydrogen

Process	Reductant amount (kg/tonne Fe°)	Electricity (MWh/tonne Fe°)	CO_2 intensity* (kg/kg Fe°)	
NG-DRI	236	0.1	0.6	Electricity emissions 0.4 kg CO_2 / kWh
H_2-DRI	55	3.4	1.3	

* Scope 1 + Scope 2

Process	Reductant amount (kg/tonne Fe°)	Electricity (MWh/tonne Fe°)	CO_2 intensity* (kg/kg Fe°)	
NG-DRI	236	0.1	0.6	Electricity emissions 0 kg CO_2 / kWh
H_2-DRI	55	3.4	0	

* Scope 1

Electricity requirement for hydrogen reduction based on:
50 kWh per kg H_2 for electrolysis;
0.4 MWh/tonne for gas preheating;
0.1 MWh/tonne for gas compression

Summary

- Gas-based direct reduction can be much less carbon intensive than blast furnace ironmaking:
  - ~0.6 tonne CO_2 per tonne Fe° with natural gas as reductant
- Large electricity requirement for H_2-based direct reduction:
  ~3.5 MWh per tonne Fe°
  - Low-carbon electricity would be essential for low-carbon direct reduction based on hydrogen
- Largest gas-based direct reduction modules:
  ~2.5 Mtonne per annum
  (smallest about 1/10 the capacity)