SCRAP SUPPLEMENTS & ALTERNATIVE IRONMAKING 101

Green Steel
Past and Present Outlook

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Green Steel Past and Present Outlook

Overview

- Introduction
- Industry Challenges
- Original solution
- Today's reality
- Anticipated future
- Summary

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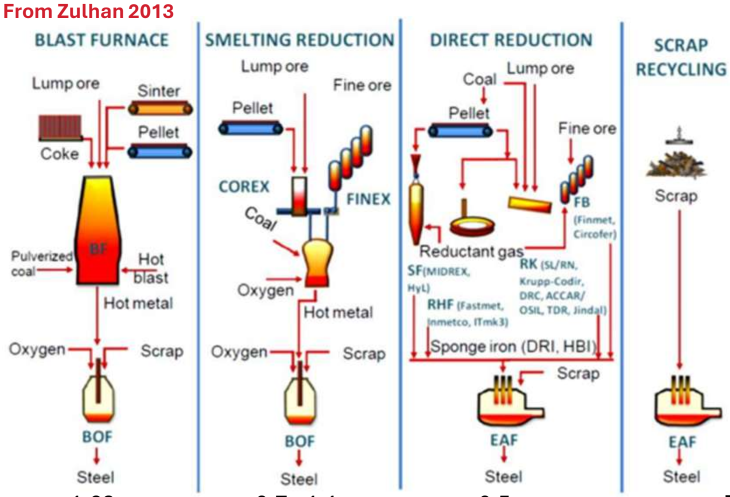
Introduction – Current Iron & Steelmaking

From Zulhan 2013



Blast Furnace	Smelting Reduction	Direct Reduction	Scrap Recycling	
1.62	0.7 - 1.1	0.5	-	Te_{CO2}/T_{steel} Ironmaking
2.2	**1.28 – 1.68**	**0.95**	**0.38**	**Te_{CO2}/T_{steel} Steelmaking**

- “Green steel” definition: Net-zero steelmaking using fossil free energy
- Moving from legacy steelmaking (BF/BOF) to modern EAF steelmaking
- H_2 enhanced steelmaking promises (90+%) CO_2 emission
- 2015 IEA solution was 95% H_2 DRI EAF steelmaking by 2070

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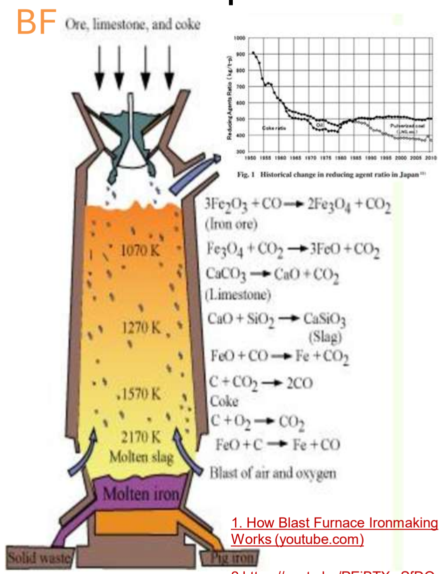
Carbon Dependence

BF



1. How Blast Furnace Ironmaking Works (youtube.com)
2. https://youtu.be/PEiBTXwSfDQ

EAF Foamy Slag (FS), chemical energy & reactions

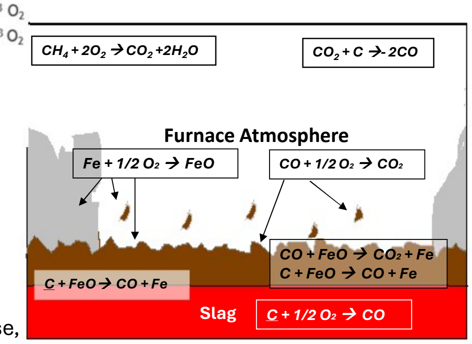
$C_{(solid)} + O_{2(gas)} \rightarrow CO_{(gas)}$ & FS

Exothermic Oxidation Reactions

- $2C + O_2 \Rightarrow CO_2$ 9.8 kWh/Nm³ O_2
- $CO + O_2 \Rightarrow CO_2$ 6.3 kWh/Nm³ O_2
- $Fe + ½O_2 \Rightarrow FeO$ 19.0kWh/Nm³ O_2
- $4Al + 3O_2 \Rightarrow 2Al_2O_3$
- $Si + O_2 \Rightarrow SiO_2$
- $Mn + ½O_2 \Rightarrow MnO$
- $4P + 5O_2 \Rightarrow 2P_2O_5$

Reduction Reactions

- $CO_2 + C \Rightarrow 2CO$
- $Fe_3O_4 + CO \Rightarrow 3FeO + CO_2$
- $FeO + CO \Rightarrow Fe + CO_2$
- $Fe_3O_4 + 4C \Rightarrow 3Fe + 4CO$



- FS reduces kWh/Te, heat loss, wall attack, arc noise, increases Surface Area (SA), yield & productivity
- The “green steel solution” challenges EAF reactions as **0%C** H_2 DRI

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Global Warming Target – 1.5°C

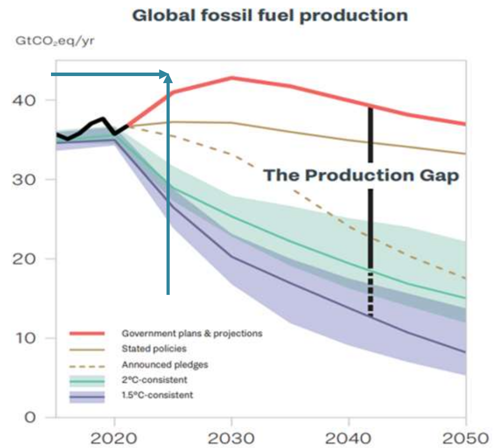
- We are missing it! (Our World in Data 2024)

  Global CO_2^e 37.8GTe (2023) → 42.2GTe (2025 estimate)*

  - 86.6% from fossil fuel combustion (coal, oil, & NG -2023)
  - Steel industry produces 7% to 9% (depending upon source)!

2022
- Coal: 15.5 GtCO2 eq
- Oil: 11.2 GtCO2 eq
- Natural gas: 7.3 GtCO2 eq
- Waste: 0.3 GtCO2 eq
- Industrial processes: 2.6 GtCO2 eq
- Methane: 4.0 GtCO2 eq
- Nitrous oxide: 0.3 GtCO2 eq
- CO2 flaring: 0.3 GtCO2 eq

2023	
Other industry	301.13 million t
Flaring	410.94 million t
Cement	1.57 billion t
Gas	7.90 billion t
Oil	12.21 billion t
Coal	15.40 billion t



- https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors - 4 graphs identifying global emissions
  - Energy represents 75.7% global emissions (manufacturing & construction = 12.7%)
  - Agriculture 11.7%; Industrial processes 6.5%; Waste 3.4%; land use, changes & forestry 2.7%

*2025 est. = 38.1GTe FF (+1.1% YoY) + land-use changes = 42.2GTe

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Net-zero – Conversion to 95% H_2 DRI EAFs (International Energy Authority (IEA) 2015)

Estimated H_2 Use in Industry by 2040
Linde STI H_2 Seminar1/2026

DRI Production	2.6MTe	Reducing gas 70%
Blast Furnaces	0.4MTe	
EAF, Preheating, Cutting	0.2MTe	
Reheating	1.0MTe	Fuel 30%
Total	4.2MTe	

- Technically feasible though fraught with challenges
  - Driving new technologies R&D – TRL 3 (lab) to 7 (demo) some in <4y
- Green Challenges:
  - Unreachable "Build Rates"
    - 411MTeDRI/y (15.2MTe/y build) total, 213MTe H_2DRI, 11.5MTeH_2/y, 692TW, (1240 x 20MW) PEMs for H_2 & 810EAFs (& >TW to melt 0%CDRI) (Defossilization: Through the Looking Glass, STI Sustainable Steel Strategies, 9/22, S. Hornby)
    - Supply chain challenges (Dustin Bruce – Keiwit 2024 AIST DeCTC presentation) - delivery & costs
  - Sourcing:
    - Renewable Energy (RE)
    - Green H_2
    - DRI grade ore
    - Scrap
    - Green C
  - Melting 0%C DRI
  - CCUS suitability & capacity
  - Conversions costs – Infrastructure, technology capex
  - Regional challenges – Governments; local technology; infrastructure
- All leading to the delay or demise of the projects

Time Kleier et al, SMS Group, forecasted data for steel to 2050 on March 6th, 2024
MTe/y steel production @ constant steel consumption/capita

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Industry Status

- EU driving conversion (C Neutral by 2050):
  - 70%BFs; no NG; Clients' demand; 60 projects \$91.8B (\$33.5B Capex
    Nicole Voigt & Felix Schmitz, Global Steel Sustainability Summit, Hamburg 1/2024; GMK Center
- Currently, lots of projects delayed/stopped
  - Policy stagnation; Market conditions
  - Immature technologies
  - Excessive cost & infrastructure challenges (E, H_2)
    - Need 75TWh grid & self-gen (process gas & TGR)
    - H_2 pricing - €2.5/kg breakeven; reality 3/25 - €9.35/kg
  - **ArcelorMittal** – most projects delayed / stopped; Dunkirk EAF "a go"
    - 2 German projects; 2.3MTeDRP Gijon; Ghent; Dofasco DRPgo"
  - **Thyssen Krupp** – suspended H_2 tender (3/25)
    - 151kTeGrH_2 over 10y for the 2.5MTeDRI/y plant in Duisburg
  - **SSAB Lulea** – 12 mo. delay for power transmission expansion
    - Completed 2.5MTe/y green mill project funding (€4.5B for -7% Sweden's CO_2) 6/30/25
  - **Green Steel premium** – disparity between mills (€200- €300/Te) & clients (€100 - €150/Te)
    - Steelmills might compromise €20 - €30/Te

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Committed Green Installations

- 2022 - Tata Steel Ijmuiden - Heracles (H_2 Era Carbon Less) 8/29/22
  - -35 to -40% CO_2 by 2030, neutral by 2045 (not HiSarna - CCUS forbidden locally)2023 - Hylron DRI pilot plant, Lingen, Germany – R&D project, 1Te/h using GH_2 in rotary kiln (RK - 15kTe)
  - 4Q/2025 (delayed from 4Q24) Start-up of Hylron Oshivela GH_2 Green Iron plant @ HYRON Steel Namibia, 15kTe/y
    - Zero H_2O mining; Integrated DRI, using RE (14MW) from solar & wind RE; producing green iron & O_2
- 1/2024 – ZHyRON project (EU), Zaragoza, Spain – extract Fe & Zn from steelmaking waste & recycle
  - AM + 9 partners; Pyro & hydro process (<30kTe waste/y) producing DRI for EAFs & ZnO for various industries
  - MOU 2023 - test Rio Tinto Pilbara Ores thro 20kTe/y plant (pelletize/preheat, N_2 flush/H_2 roast in bell furnace)
- 2025 - HBIS Group, China, agreed to supply H_2DRI EAF green steel to Italy late 8/25. CO_2 -50%
  - 30%NG 70H_2, reached 60%H_2 6/1/23 with CCUS (125kgCO_2/Te_{steel} possible)
- 4/25 - Algoma Steel 1st EAF steel. \$0.7B → <\$0.875B (+25% by 7/23); 80% de-risked - pre-contracts
- 2025 - Stegra (H2Green Steel) Sweden, \$7.02B (€6.5B); 2.5MTe/y MidrexH$_2$, 700MW TK electrolyzer (300TeH_2/d)
- 9/2/2025 - Saltzgitter ground-breaking - €30M large scale shredder to compliment H_2 DRI EAF conversion 2027
- 2025/2029 - Hydnum Steel, Spain – 2.6MTe green Steelmill on the Iberian Peninsula, MOU with Euroports – integrated logistics solutions received \$65M from Spanish Government DeC fund 4/29/25
- 2026 start-up - Ternium, Pesquería, MX – 11/20/23 - 2.1MTe/y with CCUS; DRI will have C (use NG)
- 2027 start-up - BLASTR Green Steel, Finland \$4.32B (€4B) with integrated RE/H_2/DRI/EAF facility
  - 1st French H_2 DRP (2MTeDRI/HBI/y merchant); \$108B (€100B) GH_2 economy by 2025
- 2027 start-up - GravitHy, Fos Sur Mer, France, 2MTe/y H_2 DRI/HBI – \$2.37B (€2.2B)
- 2027 2Q - Meranti Green Steel, Singapore to put 90%H_2 DRP in Thailand and Oman to produce DRI with C

(For other green steel industry initiatives see "The H_2 Initiatives – Where Are They?", Hornby, 5th A & NZ Annual Steel Symposium, 2/12/2024)

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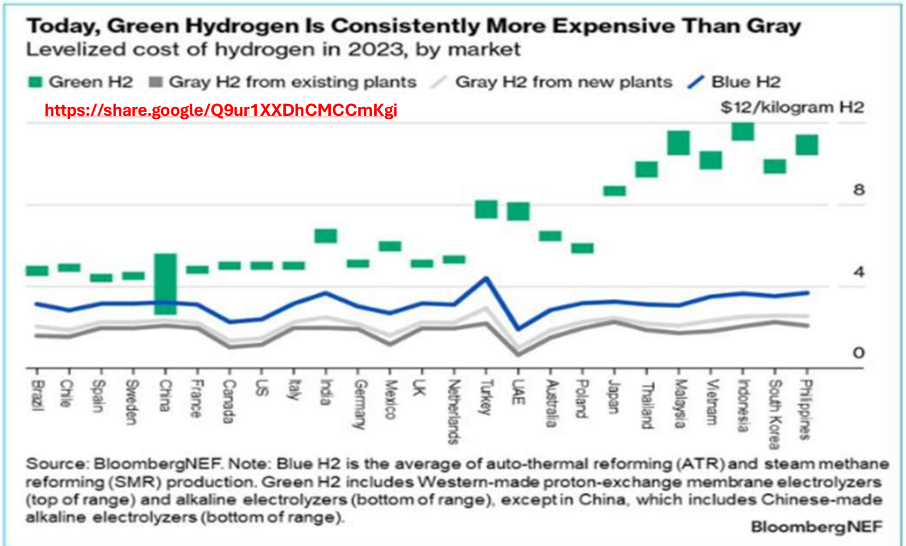
Cost of Green H_2 versus Grey & Blue H_2 by Country



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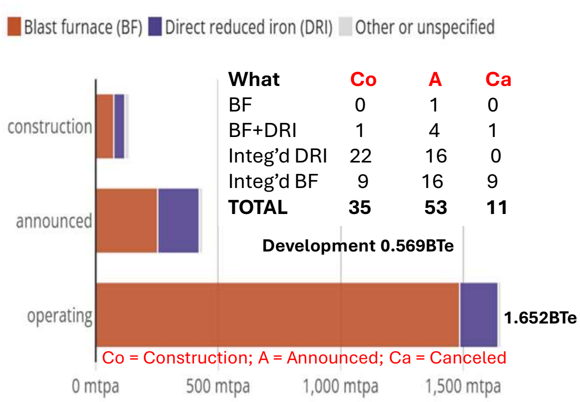
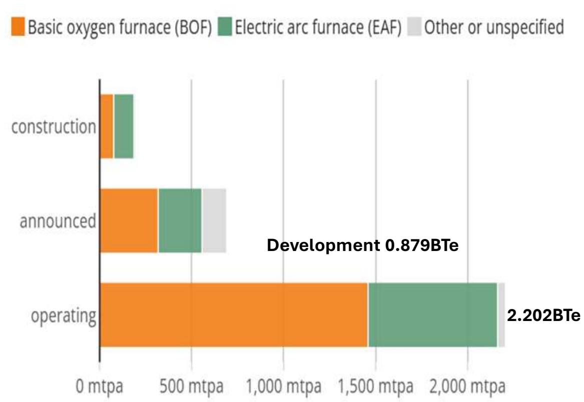
Industry Status

- **https://globalenergymonitor.org/projects/global-plant-tracker/tracker-map & https://globalenergymonitor.org/projects/global-plant-tracker/tracker-map /dashboard**
- Operating & developing ironmaking capacity Operating & developing steelmaking capacity by status and technology type



What	Co	A	Ca
BF	0	1	0
BF+DRI	1	4	1
Integ'd DRI	22	16	0
Integ'd BF	9	16	9
TOTAL	**35**	**53**	**11**



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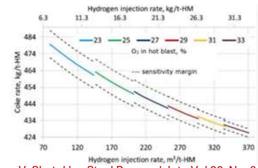
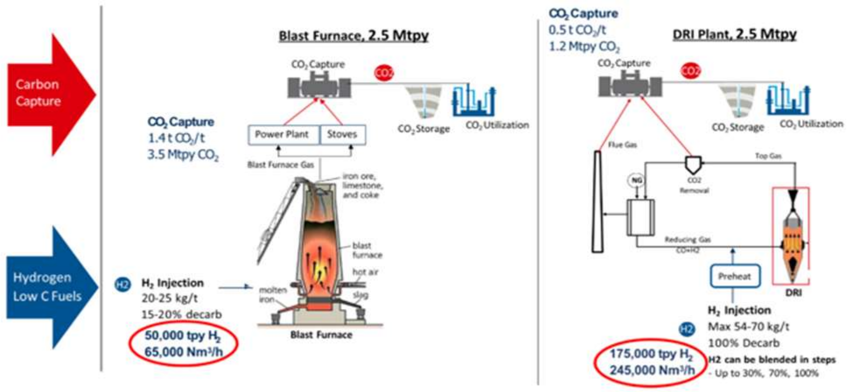
Some Ironmaking Decarbonization Solutions



V. Shatokha, Steel Research Int., Vol 96, No. 8, p. 2400346, Aug 2025, doi: 10.1002/srin.202400346

- World Steel anticipates 50% ore-based steelmaking to 2050; BAT (25%)CO_2
  Claire Broadbent, AIST Green Steel Labeling Webinar Sept 5th, 2024; Sunil, Hatch AISTech 2024
- Significant decarb. with existing infrastructure
  SteelUniversity Sept 2025, The "Green Steel" Revolution - 10 years on, S. Hornby
  - Hatch projected 35kgH_2 injection +TGR + CCUS → (80%)CO_2 or ≈ ~0.4Te_{CO2}/Te_{HM} close to EAF 100% scrap
  - Japanese Course50 Program, (30%)CO_2 proven; 2024 test with 90kgH_2/h achieved (43%)CO_2

System	Economics	Benefits
H_2 Injection	\$50-\$100M /BF	• Decreased coke rate • Increased productivity (HBI & efficient operations) • Reduced C cost & environmental compliance • Enhanced operational flexibility • Fuel diversification
Adv PCI+O_2	\$20-\$40M /BF	
HBI Handling & Prep	\$30-\$60M /facility	
Cold Bonded Pellets	\$200-\$400M /new facility	



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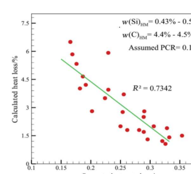
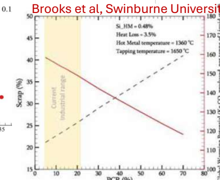
Brownfield Steelmaking Decarbonization Solutions

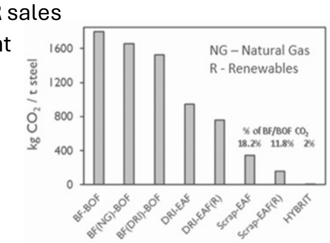
- BOF – minimal 0.181TeCO_2/Te $_{\text{liquid steel}}$
  - Increase scrap to 40% to 50%? (17% world ave.)
    - 35% scrap charge, 0.9% heat loss; 10% scrap, ~6.75% heat loss
    - Increasing PCR from 10% to 30%:
      - ✓ Scrap 22% → 28%; GWP decreases by 10% (red line)
  - HBI - > cooling intensity, quality, density & productivity vs scrap



Brooks et al, Swinburne University



- EAF - Green energy is the key! Followed by scrap quality
  - RE 100% scrap melting - 0.18Te_{CO2}/Te_{steel} (w/out RE 0.38Te_{CO2})
  - Beneficiate scrap; maximize use (reduce OBM use)
    - Shred in-house - > quality, densify (1.6Te/m^3), yield (89%→98.5%) & SR sales
    - Residual control - guaranteed chemistry or continuous analysis in-plant
  - Burners – OFB or OH_2B – support CCUS
    - (25%) flue gas volume (reduction) & increased %CO_2
    - Preheat combustion "air" - ≤ 200kWh/Te & 16m MDT savings
  - Lowest cost liquid steel; maximize operating efficiency using
    - Value in Use (VIU) to define charge mixes (CO_2)
    - OGA - < heat loss to OGS; lower C footprint, >combustion efficiency; explosion prevention



C. Pistorius, CMU3

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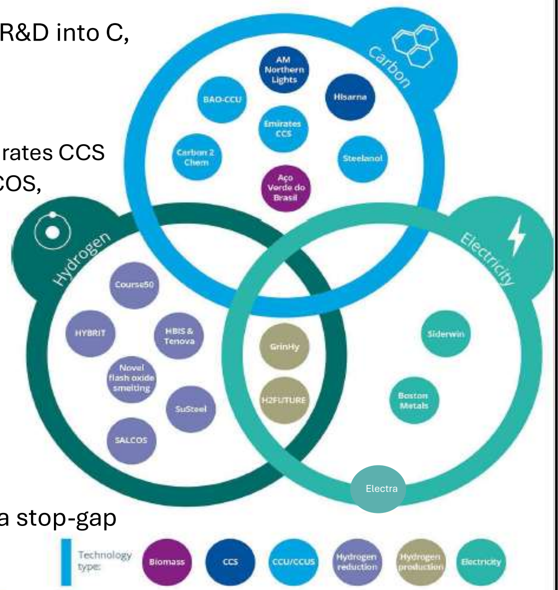
New Technology Developments

- Concurrent with conversion to H_2 DRI EAF steelmaking, R&D into C, Electricity & H_2, electrolysis; projects coded
  - Biomass – Aço Verde do Brasil
  - CCS – AM Northern Lights, HIsarna
  - CCU/CCUS – Steelanol, Bao-CCU, Carbon2Chem, Emirates CCS
  - H_2 reduction – Course 50, HBIS & Tenova, SuSteel, SALCOS, HYBRIT, Flash Oxide Smelting
  - H_2 production – GrinHy, H2Future
  - Electricity – SiderWin, Boston Metals, Electra
- Upscaling non-steel "old technologies"?
  - ESFs (SAF, OSBF), IF...
- Challenges appear to be
  - Increased energy (MOE, low T Electra...)
  - Scalability (MOE, IFs, OSBFs, H_2, CCUS ....)
  - Timeliness to market
  - Chinese techno-economic advantage (H_2, GE)
- BAT, & more AR&D, at brownfield sites must be used as a stop-gap whilst adequate cheap RE &, thus, H_2 arrive
  - Less socio-economical impact



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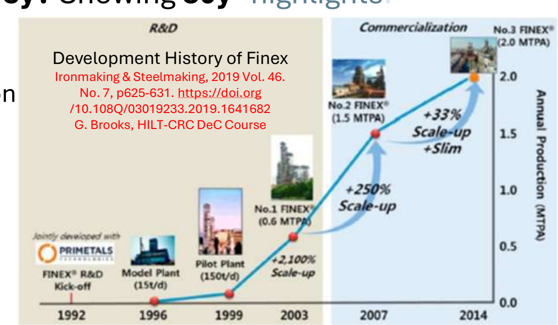
New Technology Developments – Timely Solutions?

- **Finex** fluidized bed (FB) smelt reduction - **15y?** Showing **80y**$^+$ highlights
  - 1940s - modern FB reaction technology pioneered through petroleum catalytic cracking
  - 2020s – FB/SR crucial, on-going, R&D focused on greater efficiency, less cost & GHG



- **HIsarna – 38y** cyclone converter over a smelt reduction furnace (Tata Steel youTube)
  - 1986 - Hoogovens, Corus Ijmuiden, Tata began investigating to decrease E & C footprint
  - 2024 – Further testing in collaboration with ArcelorMittal, ThyssenKrupp, voestalpine, Paul Wurth to design, build & test industrial scale pilot for commercial viability demo (Global Energy Monitor)

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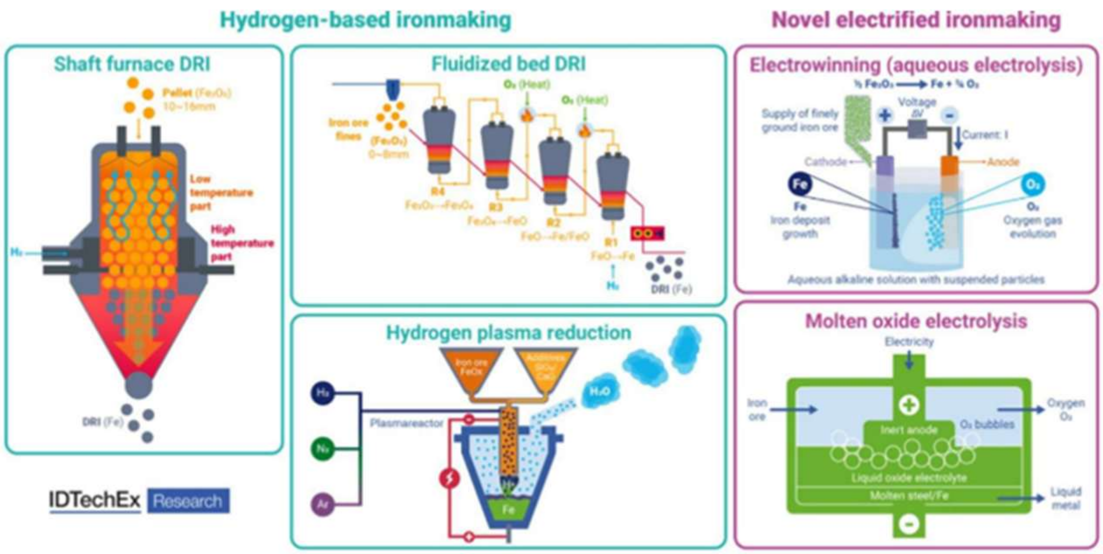
Green Ironmaking Technologies for Green Steel



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DRI Processes – Shaft & Rotary Kiln

- DRI Shafts are shown as “TRL 6-8”? Why?
  - HYBRIT H_2DRI EAF pilot only?
  - C_{DRI} or not C_{DRI} ?
  - Lean ore melting definition? (DRI – ESF)
- HYBRIT – proven pilot & H_2 Lined Rock Storage (100m^3)
  - 1.3MTe/y demo @ SSAB/LKAB/Vattenfall, Gallivare, Sweden; ≤120km^3 LRS (100GWh, 3d ops)

  STI International 12/18/23
- Calix ZESTY – pilot tested fines “flash reduction” process
  - 30kTe/y demo – ARENA; Rio Tinto
- FerroSilva - claims a 0.845Te$_{CO2}$ **sink**/Te$_{steel}$ making green DRI with
  - Syngas (forestry, agricultural waste); Biochar to mill + CCU biogenic CO_2 for ship e-fuel
  - Swedish Agency funded $3.42M study for 1st 50kTe$_{DRI}$/y plant @ Ovako Hyfors Sweden
- H_2 Rotary Kiln - solar & wind RE sources
  - 1Q23 - 0.5Te/h HyIron DRI pilot Lingen Germany, 14MW RE
  - 4Q24 HyIron JV with Hyron Steel, Namibia - 15kTe$_{DRI}$/y with 20MW solar
    - 2MTe$_{DRI}$/y ultimately with additional 18MW wind & 140MW solar E

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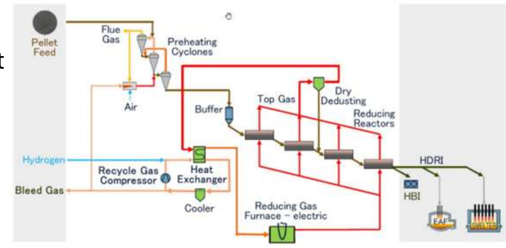
Fluidized Bed Fines Processes

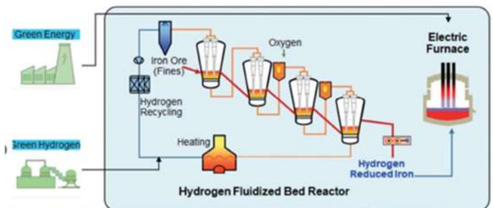
- HIsarna (ULCOS) – Tata "Isarna" cyclone + Rio Tinto HIsmelt
- FB "proven" in W. Indes commercial Circored (300kTe)
  - Metso Tech Frankfurt pilot; SMS purchase by New Year 2026
- HYFOR & HyREX – new gen 4-staged FB reactors (>4 in future?)
  - Under development, differentiated by final products
  - No pelletisation; Temp control to prevent sticking issues

Feature	HYFOR H_2 Fine Ore (<0.15mm) Reduction	HyREX H_2 Reduction
Final Product	HDRI/HBI – direct charge EAF (-90%CO_2) 1Te/h pilot since 2021 (2016)	Liquid HM similar to the BF. Pilot 2024, 24Te_{HM}/d, 8760Te/y – H_2 optimization; 0%C DRI melting; stable Fe production
Smelting Step	Solid DRI fed to an EAF If low-grade ore charge to smelter for HM (Hy4Smelt; ESTEP, voestalpine, PM: R&D green HM)	Integrated ESF to melt fines from FB reactors. (ESF replaces FINEX melt-gasifier)
Integrated process	DR process. Modular Smelter can be added - 3TeHM/h prototype by mid-2027 with RE smelter (Hy4Smelt)	2-step process: FB + ESF. 315,360Te/y (36Te/h), $591M, demo plant due 2027 (funding secured). 1MTe/y commercial production anticipated by 2030
Developers	Primetals/Mitsubishi HI, HILT-CRC, voestalpine, Rio Tinto (Fortescue pulled out). VA "green wire rod" in Spring 2024	Posco & Primetals (FINEX extension)) Challenges: Costly H_2; E demand strain S Korean grid



HyFOR – Hydrogen-based Fine-Ore Reduction, Mitsubishi Heavy Industries Technical Review Vol. 59 No. 2 (June 2022)

HyREX - Overview of Australian Initiatives in Decarbonisation of Iron & Steel Production, G. Brooks, Seoul National University lecture June 2025



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Plasma Ironmaking (& H_2)

- H_2 plasma arc to the ore in an EAF or melter - single step steelmaking "proven"
  - SuSteel (SuStainable Steelmaking) U of Loeben pre-pilot, voestalpine collaboration
  - Very energetic exothermic H_2 species overcomes endothermic reduction
    - Promotes efficient redox reactions; enhanced kinetics & energy savings; lower reaction T
- Historically, overpriced failure in 80's/90s.
  - Hi Capex, refractory use & kWh/Te; low reactant efficiency (use rate); batch process
- Process examples:
  - Hertha Metals, TX – 1Te/d (9/24) iron or semi-continuous, single step, steelmaking
    - US made 99.7%Fe permanent (rare earth) magnets (70%Fe - NdFeB) versus
    - Importing 90% hi purity Fe imported from China
    - 9kTe/y 01/2026 ($17M funding); next phase 0.5MTe/y
    - CO_2 reduction: 50% (NG) to 99% (H_2)
  - PlasmaRed – EU R&D, 2024 lab smelt reactor at Max Planck Institute
    - 2025 pilot (100kg HSPR+5Te DC EAF) – EU Horizon Europe Fund + investors
    (Emerging Technology Concepts to Fully Decarbonize Ironmaking Christina M. Chang et al, ARPA-E 2021) & (Max Planck Institute for Sustainable Materials)
  - Turn Alumina Bauxite waste (180MTe/y, 4BTe globally) into ironmaking feedstock

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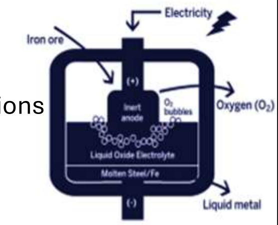
Electrolytic Ironmaking



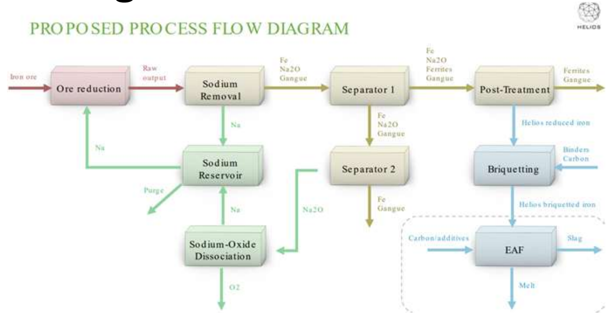
www.greencarcongress.com/2021/02/20210214-bostonmetal.html
Allanore et al Nature, 2013

- Electro-win @ high (>~1500ºC) & low (<-110ºC) temp; redox using ore's oxide anions
- **High Temp.** process dissolves ores in molten electrolyte → Liquid Iron
  - Faster kinetics; higher Capex & Opex
  - Boston Metals (MIT Spin-off) – Batch MOE @ <u><</u>2000ºC addressing a wide ore range
    - Limited productivity/cell due to current density & Faraday's Law
    - Critical factors – re-carburizing, anode, scale-up, cell V, batch; 400 cells for 0.5MTe/y; automation? (None for Aluminium Hall-Héroult MOE in >100y)
    - Missed Brazil n& US funding window in February - Brazilian equipment failure (Cr, Mn, Nb)
    - *Steel commercial – 2026?*
  - Ulcolysis - AM ULCOS Off-Shoot - high temperature electrolysis (like Boston Metals)
- **Low-Temp.** solid iron process - slow reaction rate; lower RE use, Capex / Opex?
  - AM ULCOS Off-shoots (2004-2010) (TGR Hisarna+)
    - SIDERWIN (now VOLTERON) is the evolution & industrial continuation of Ulcowin
      - ✓ Aqueous ~110°C process using RE to transform prime & non-Fe^{++} waste into Fe plates
      - ✓ TRL 6 ; (87%)CO_2 & (31%) direct E use
  - Electra, Boulder, CO – 60ºC process p
    - Producing >99%Fe plate from <55%Fe ore with (90%)CO_2 with variable scrap
    - Gates & Amazon backed; $186M to scale to 0.5MTe/y 2026; 1MTe/y by 2029 Modular – 1 electrical array = 50kTe/y
    - Nucor, Yamato Kogyo, Interfer Edelstahl Gp, BHP, RT, Roy Hill, Toyota Tsuho Corp, + investment Co's
  - Element Zero, Port Headland, OZ – electrochemical non-aqueous process for winning multiple metals

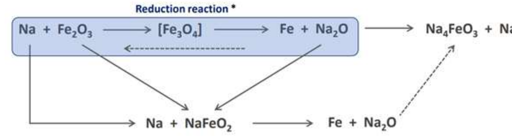
Green Steel Past and Present Outlook

Helios™ - Sodium Based Ironmaking

- Helios Cycle, developed in Israel:
  - Dissolution of iron ores to produce hi purity Fe @ 250-350ºC
    - Recycle Na
  - HILT-CRC project in Australia
  - Benefits:
    - No CO_2; >efficiency (-30% E); -30% OPEX
      - ✓ No ore beneficiation
      - ✓ High cost H_2 production or storage
    - Na is available worldwide
    - Can be used for Cu, Ni, Co, etc.
    - **Can still be C intensive**
  - 1st pilot 2026 several kTe/y; commercial by 2028
  - $6M seed funding + BlueScope MOU to use HGI
  - Only non-steelmaking member of World Steel



The Helios Cycle – A Novel Way to Reduce Iron – World Steel Breakthrough Technology Conference 12/2023

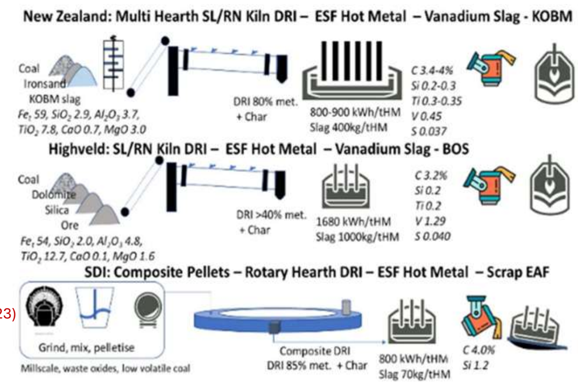


* Addison, C. C. et al. Journal of the Chemical Society, Dalton Transactions 1017–1019 (1972)
Bhat, N. P. et al. Journal of Nuclear Materials 158, 7–11 (1988).

Green Steel Past and Present Outlook

Electric Smelting Furnaces

- ESF (OSBFs, SAFs) – new smelting tech.?
- "Saviour" for XS "lean ore", unsuitable DRI for EAF melt?
  - Reduction/melting in 1 vessel (BHP, Pathways to deC, Episode 7 – ESF)
  - Expected 0.18-0.29kg_{CO2}/Te_{HM} DRI-OSBF-BOF-CCUS
- Need to determine integration viability; scalability, melting & final product implications:
  - Gangue & C impact – melting, chemistry (C, Si); Slag (250-330kg/Te_{HM}?) & off-take VIU (Cement?)
  - Optimum power intensity, RE use, electrodes
    (Handling the Future Dearth of H_2 and DRI Quality Iron Ore, 4th ANZ Symposium 3/8/23)
- NeoSmelt, (-85% CO_2) Kwinana, WA; FID 2026
  - BlueScope, BHP & Rio Tinto, ARENA, Woodside Energy, Mitsui Iron Ore Development
    (BHP, Pathways to deC, Episode 7 – ESF)
  - 30kTe_{HM} (Energiron DRP + CRISP® ESF) pilot - low/med ore
    - $50.25M WA gov't & $13.27M ARENA; 2028 NG start-up → H_2
- RedSmelt NST, RHF + SAF, claiming C Neutrality
  - 35kTe/y Italian demo (SMS Demag/Luchini) in 2003
  - Commercialization – Brazil? When?
- Other ESF participants:
  - Primetals EU, HILT-CRC (Swinburne) & ARENA (U of Newcastle)
  - ESF selected by Tata EU, Thyssen Krupp, voestalpine, POSCO



Hedging Bets?

BlueScope	Rio Tinto
Relining BF – gov't funding	Calix investment – BioIron (microwave technology) delayed
H_2 injection to BFs & DRP	High grade ore supply to: GravitHy DRP (IOC) & market HBI HyFOR prototype, Austria & Stegra H_2 DRI EAF mill, Sweden
Helios Green Iron	
New EAF in NZ Steel	

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Green Steel Past and Present Outlook

International Solution? Decoupling?

- Global Warming Solutions & RE sources vary considerably by location:
  - China - young BFs (54% world steel); largest RE investor $676B (≈ 810$MTeCO_2$)/y ?export RE?
    Reuters quoting Nature study in C Briefings 8/29/24
  - India - low Te_{scrap} – produce 2nd largest steel tonnage; 36.34% world DRI; 42%EAF
  - EU – transition costs stalling adoption of H_2DI EAF;
  - MENA – potential green iron (& steel) world leader & global DRI/HBI & E/RE supplier
  - Australia – slow adoption?! Great potential RE, ship 36% ore, government & investment support
  - Brazil – High grade ore; 80+% RE
  - Africa – 1st Simandou shipments
- International alliances/agreements
  - Magnum Mining, Moolong & SDM China – Licensing HIsmelt IP & plant & are licensing
  - Magnum's Buena Vista N. NV Fe project (≥67%Fe magnetite ore) → merchant PI
  - RT – IOC pellets to GravitHy France; market HBI
  - Saudi Arabia green HIsmelt PI plant 50/50 MidMetal JV – Malaysian biochar, Saudi mill waste

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Green Steel Past and Present Outlook

Summary

- Scale of progress & investment in the "Green Steel" Revolution falls short of 1.5ºC Global Warming Goal Accenture.com "Powered for Change, A pathway to faster, financially viable decarbonization" research report
- H_2 DRI EAF steelmaking - technically viable but significantly challenged
- BF ironmaking will continue (50% out to 2060 now?)
- CCUS are not a true "fix" for steel – currently 0.12% total CO_2^e
- Innovation & new technologies are a long way from commercialization
- Solutions?
  - Education – governments, investors (technology, infrastructure needs)
  - Apply BAT & continue AR&D for the BF as a techno-economic stop gap
  - Speed up "innovation to market" & build rates
  - Improve availability, cost & delivery – RE & H_2
  - Decouple iron & steelmaking
  - Determine an equitable International Carbon accounting system

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Green Steel
Past and Present Outlook

Thank you for your attention!

Questions?

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