WSA - BREAKTHROUGH TECHNOLOGY CONFERENCE

DECEMBER 5-6, ABU DHABI

GREEN STEEL IN MOTION – IRON FEEDSTOCK MEETS RENEWABLE ENERGY

Dr. Alexander Fleischanderl
Why this is a make-or-break decade

• 71% of blast furnaces will require major refurbishment ("relining") by 2030, according to International Renewable Energy Agency. The question is … what comes next?

• Investors must choose between refurbishing existing furnaces or switching to EAFs.

• Factors that determine to turn steel into the decade of green steel:
  - Penalties for CO₂: New ETS, CBAM
  - Renewable energy availability and price
  - Low-carbon hydrogen availability
  - Raw material quality, availability and price
  - Location (feasibility and skilled people)
THREE PHASES TO GREEN STEEL

THE SUSTAINABLE METALS REVOLUTION

1. THE OPTIMIZATION PHASE
   Redefining solutions for sustained impact

2. THE TRANSITION PHASE
   Redefining metals production

3. ACHIEVING GREEN STEEL
   The new standard of production
The pathways to achieve net-zero in the sector

Electrification of production
• Expansion to clean, renewable energy to enable sustainable production processes
• Growing number of electric furnaces
• Produce the green hydrogen required to replace carbon-based reductants
• Direct electrolysis of steel, still in its infancy

Carbon Direct Avoidance (CDA)
• Stop the common practice of fossil-based reduction and move to hydrogen-based reduction
• Scaling-up and establishing a hydrogen eco-system

Carbon Capture Usage & Storage (CCUS)
• CCUS for long life-time assets in upstream ironmaking facilities in e.g., India, China
• Mitsubishi Heavy Industry’s KM CDR amine scrubber-based capturing system: store or use
• LanzaTech Carbon Smart technology to lock-in carbon from industrial waste gasses
The Scale for the Transition is Massive
There is no technological silver bullet yet, but pathways are set

Steel production [mtpy]

- Low Carbon technologies will more than double from currently 26% to over 60% of the total steel production by 2050.
- This represents over 850 million tons of additional low-carbon steel production by 2050.
- In addition to currently available technologies, new low carbon technologies will be required.
- BOF steel production will also be transformed away from coal-based BF technologies.
- Steel produced from coal-based technologies will also be transformed by 2050 using CCS and other technologies such as hydrogen injection etc.
Europe is most active in the industry transition based on DRI, EAF and Smelter. In total 37 DRI plants, 63 EAF and 6 Smelter are announced.
Strong growth of DR plants are expected for the next 30-50 years

### Number of DR Plants operating and planned
(Shaft Technology)

<table>
<thead>
<tr>
<th>Year of Start-up</th>
<th>Operating</th>
<th>Projects</th>
<th>Announced</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970-1975</td>
<td>3</td>
<td>4</td>
<td>6</td>
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<tr>
<td>1976-1980</td>
<td>10</td>
<td>8</td>
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<tr>
<td>1981-1985</td>
<td>14</td>
<td>20</td>
<td>16</td>
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<tr>
<td>1986-1990</td>
<td>25</td>
<td>5</td>
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<td>1991-1995</td>
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<tr>
<td>1996-2000</td>
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<td>2001-2005</td>
<td>30</td>
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</tr>
</tbody>
</table>

Source: BCG Plantfacts, PT

### DRI Production Forecast
(mio ton DRI)

<table>
<thead>
<tr>
<th>Year</th>
<th>DRI (NG)</th>
<th>DRI (NG+CCUS)</th>
<th>DRI (100% H2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>43</td>
<td>71</td>
<td>106</td>
</tr>
<tr>
<td>2010</td>
<td>106</td>
<td>125</td>
<td>186</td>
</tr>
<tr>
<td>2020</td>
<td>268</td>
<td>213</td>
<td>412</td>
</tr>
<tr>
<td>2030</td>
<td>350</td>
<td>37</td>
<td>213</td>
</tr>
<tr>
<td>2040</td>
<td>471</td>
<td>92</td>
<td>412</td>
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<tr>
<td>2050</td>
<td>371</td>
<td>141</td>
<td>637</td>
</tr>
<tr>
<td>2060</td>
<td>350</td>
<td>141</td>
<td>637</td>
</tr>
<tr>
<td>2070</td>
<td>471</td>
<td>141</td>
<td>637</td>
</tr>
</tbody>
</table>

Source: iima - International Iron Metallics Association, PT
Scrap Availability and it’s Impact for De-Carbonization

Steel Production and Scrap Availability in MTPA

- Crude Steel Production: +249 MTPA
- Scrap Available (PT): +516 MTPA

Weighted average Life span 43 years, recycling rate 85%

Source: BIR, WSA, McKinsey, Primetals Scrap Model
The Feedstock Playground

**Global metallics consumption (mt)**

- **2019**:
  - Ore for pig iron: 1,432 mt
  - Ore for DRI: 392 mt
  - BOF scrap: 208 mt
  - EAF scrap: 119 mt
- **2030**:
  - Ore for pig iron: 2,150 mt
  - Ore for DRI: 527 mt
  - BOF scrap: 225 mt
  - EAF scrap: 182 mt

**Development of seaborne iron ore trade (mt)**

- **2019**:
  - China: 1,545 mt
  - Other: -326 mt
  - Middle East: -39 mt
  - India: 22 mt
  - Other Asia: 49 mt
  - EU: 16 mt
  - All other (net): 6 mt
- **2030**:
  - China: 1,285 mt

Source: WSD analysis
The iron quality determines the process route

Fe content of iron ore world production – 2021

Source: National Minerals Information Center USA, Primetals

% Fe

Production in mio metric tons

Low/medium quality

High quality

Source: National Minerals Information Center USA, Primetals
Current Iron Ore Supply by Grade

Supply of DR Grade Ores is limited, accounting only for 4% of current seaborne grades.

*An indication of the grade range in which high-grade ore can be produced by pulverizing powdered ore through additional investment.

(Source: Woodmac and MC)
Energy cost is the main driver for electrification and a hydrogen eco system

Energy cost 12/2021 in US$/kWh

Source: GlobalPetrolPrices.com, BGR - Federal Institute for Geosciences and Natural Resources, IEA, Primetals
Energy cost is the main driver for electrification and a hydrogen eco system.

Hydrogen Market Space after 2030

Source: Frost & Sullivan
2030 EU pro forma configuration H₂ cost scenarios

The BF/EAF configuration with a 40% hot metal charge is the lowest cost configuration: EAF operations with high percentages of green DRI have higher costs at $2/t H₂ and are extremely uncompetitive at $5/t.

The hydrogen price is assumed to be either a fully-loaded (with capital return) production cost or a purchased price based on a supply contract, assumes 0 free allowances although they will not be fully phased out until 2034; the configuration D with 100% scrap will not be able to produce the same high quality flat roll steels as the others - included for illustrative purposes.

Source: WSD analysis
Process Routes for Transitioning to Net-Zero

**Carbon based technologies**

**Low/medium grade iron ore**
- Sinter feed (0.15 - 6.3 mm)
- Pellet feed (< 0.15 mm)
- Lump ore (> 6.3 mm)
- Sinter feed (0.15 - 6.3 mm)

**Decarbonization – NG/H₂ based technologies**
- Pellet feed (< 0.5 mm)
- Pellet feed (< 0.15 mm)
- Sinter feed (0.15 - 6.3 mm)

**High grade iron ore**
- Pellet feed (< 0.5 mm)
- Pellet feed (< 0.15 mm)
- Sinter feed (0.15 - 6.3 mm)

**Scrap based technologies**
- Scrap

**Metallics Agglomeration**
- Sinter plant
- Pelletizing

**Iron making**
- Low CO₂ blast furnace including H₂ + CCS
- COREX⁺ CCS
- FINEX⁺ CCS
- HYFOR⁺
- MIDREX⁺
- Finored⁺

**Steel making**
- Hot metal
- BOF converter
- Low CO₂ coal-based technologies
- Pig Iron
- DRI
- DRI EAF
- NG/H₂ based technologies using low/medium grade ores
- NG/H₂ based technologies using high grade ores

**Crude steel**

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Dr. Alexander Fleischanderl 05/122023
Process Routes for Transitioning to Net-Zero

**Commercially available**

**MIDREX**
- Natural Gas
- Hydrogen
- Pellets

**Finored / HyREX**
- Natural Gas
- Hydrogen
- Sinter Feed

**HYFOR**
- Hydrogen
- Fines

**Technologies in pilot phase**

**High Grade**

**Low Grade**

*High-grade ores: Electric arc furnaces (EAF)*

*Low-grade ores: “Smelter” for DRI melting and final reduction*
HYFOR Pilot Plant

- No Pelletizing required – Fines Feed (any type of ore)
- Extremely high Yield (Low Temperature / Pressure Operation)
- Feed: ~ 1 t Iron Ore/Campaign
- Product: ~ 0.6 t DRI Fines/Campaign
- Hydrogen Supply by Truck
- CE – certified for high Temperature and Over-Pressure Operation with 100 % H₂
- Fully Equipped with State-of-the-Art Automation System
Flowsheet Hy4Smelt

Iron Ore feed
2-3 t/h

Dryer
Bell Mill

Lock Hopper

Flue Gas

Preheating
Oxidation

Air

Dry Dedusting

H2-PSA

Recycle Gas
Compressor

Cooler

Bleed Gas

External Hydrogen supply

Existing PEM Electrolyser

Heat Exchanger

Buffer

FB Reactors

Reducing Gas
Electric Heating

Cycle Gas

Slag

<1 t/h

Off gas

HDRI

1.5-2 t/h

HCl

Solid Additions

Carbon Injection

Carbon Carrier
• Bio char, anthracite, coke...

Fluxes
• Lime, limestone, dolomite...

Recycling Material
• Dusts, Slags...

Scrap

Alternative DRI
• HBI, Cold DRI...

H2-PSI
Shifting Gears – From Concepts to Execution

3D Model Hy4Smelt Project
2.5 MTPA Plant → 2x90 MW Smelter

- Electrical energy supplied by three transformers – energy is required for melting, final reduction.
- Hot DRI transport connects direct reduction plant with Smelters.
- Reducing atmosphere in the furnace ensures CO rich off gas – off gas is collected and prepared for further usage.
- Slag is adjusted to fit for application in cement industry. Slag is tapped on one side and granulated right after tapping.
- Large furnace ensure big surface between slag and metal and good slag reduction, big hot heel to buffer hot metal before tapping as well as long refractory lifetime.
- Tapping System for hot metal tapping into torpedo car. Existing hot metal logistics can be reused.
Break-Through Innovations
HYFOR & Smelter for low-grade DRI processing

Pilot testing

Hy4Smelt – Industrial Prototype, 3 t/h
HyREX - Industrial Demonstrator

Commercial plant

2022 2023 2024 2025 2026 2027 2028

Dr. Alexander Fleischanderl
05/12/2023
Protectionism for local steel

Trade flows & Green Steel pace are impacted by:

• Raw material supply chain (scrap protectionism)
  Backwards integration of scrap processors
  (i.e. Arcellor Mittal, SDI)

• Scrap availability and quality (crafted scrap)

• DR-grade ores become an undersupply – DRPs will have to use lower ore grade feedstock plus Smelter

• Cheap energy might drive a decoupling of iron- and steelmaking (MENA, Australia, US or Brazil)

• Green metallics will become an undersupply (high premium of 300-500 $ per ton after 2025 expected), but regionally different – import into EU, Japan, Korea?

• New steel players & business models become visible
  - Salzgitter - Orsted (circularity/synergy)
  - H2GS – Automotive sector
  - GravitHy (VALE, cross-industry approach)

Source: partly from McKinsey & Company: The resilience of steel
Decarbonization Highlights (announced or in execution)

**Hy4Smelt, Austria**
- Strategic Partners
- HYFOR & Smelter
- 1st continuous industrial prototype green metal plant based on 100% green H2
- Start-up 2026
- 95% CO2 reduction

**SALCOS, Germany**
- Steelmaker investment
- Transformation of an integrated 6 mtpy steel plant to an H2-DRI-EAF
- 1.7 bn€ investment to produce 1.9 mtpy green steel
- Start-up 2025
- 95% CO2 reduction

**GravitHy, France, Finland**
- Strategic investors
- Planning to build, own and operate its first green iron and steel plant in France
- 2.2 bn€ investment to produce 2 mtpy green DRI
- Start-up 2027
- 95% CO2 reduction

**CCS, AM Gent Belgium**
- KM CDR amine-based CCS pilot plant
- De-risk CCS application at BF, later at Reheating Furnace and DRP
- Data acquisition and scale-up

**HyREX, POSCO, Korea**
- Strategic Partnership
- Fluidized Bed DRP incl. Smelter
- Demonstrator plant 40 TPH, 300,000 TPA
- Start-up 2026
- 90% CO2 reduction

**Steelanol, Belgium**
- Strategic investment
- LanzaTechs uniqubio-fermentation smart carbon technology
- 100,000 m³/h BF waste gas feed stock into 80,000 m³ per year bio-ethanol
- Start-up 2023

**Active Power Feeder, Germany**
- Grid friendly power supply solution
- Connects EAF to power grid on MV MCC basis highest power quality
- Industrial Prototype at50 t EAF at BGH Edelstahl
THANK YOU

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