THE PATH TO CLIMATE-NEUTRAL STEEL
Steel is one of the most energy and emissions intensive industries globally and is considered ‘hard-to-abate’

Energy facts for Iron & Steel industry:

- Energy comes from 75% coal and 25% electrical and natural gas. [88 Mtce of coal, 1200 TWh of electrical energy and 86 bcm of natural gas were used in 2018]
- Iron & Steel is the 2nd largest industrial consumer of energy after the Chemical sector
- Iron & Steel uses 22% of the industrial energy or 8% of the total energy

Emissions (CO₂) facts for the Iron & Steel industry:

- Iron and Steel is the 2nd largest emitter of CO₂ after the Cement industry
- Responsible for 25% of industrial CO₂ emissions or over 9% of total CO₂ emissions
- Iron and Steel industry emissions were 3.7 Gt CO₂ equivalent in 2019. Thereof 2.6 Gt were direct emissions, and 1.1 Gt were indirect emissions.
Changing customer requirements and growing demand for carbon-friendly steel products – focus of automakers to reduce their overall CO₂ emission (including scope 3).

Further tightening of carbon emission regulations and higher carbon tax expected

Growing investor and public interest in sustainability and impact on the shareholder value creation.

Despite economic downturn, focus of policy makers on ‘green’ have snowballed. Large Covid-19 Stimulus funds directed towards “Green” Initiatives.

Major Steel Companies have announced carbon neutral by/before 2050
IRON & STEEL INDUSTRY REQUIREMENT
LOW CARBON ECONOMY

To approach these huge potential markets, the technology chain for providing overall solutions to the customers becomes more important.

Steel companies announced so far to become Climate Neutral by 2050
- Arcelor Mittal
- POSCO
- Thyssenkrupp
- SSAB
- Liberty Steel
- Tata Steel
- NISMC
- JSW
- ...

Total Investment required up to 2050 is estimated at USD 1,4 trillion

Average investment required per year
- 2021-2030 = USD 39 billion
- 2031-2040 = USD 46 billion
- 2041-2050 = USD 54 billion

Source: IEA Iron & Steel Technology Roadmap October 2020
DECARBONIZING STEEL —
A GLOBAL PERSPECTIVE

Pledging net-zero by mid-century

- China pledges net-zero 2060
- E.U. aims for minus 55% by 2030, net-zero 2050
- Japan announces carbon-neutral 2050 and green growth plan
- U.S. to rejoin Paris Agreement, Biden administration eyes carbon-neutral 2050
- A host of additional nations are at least considering a pledge
Trading schemes and carbon taxes are on the rise globally.
MAIN STEEL PRODUCTION ROUTES — TODAY
(84% HM / 16% SCRAP RESP. 80% HDRI + 20% SCRAP)

Raw materials preparation
- Coal
- Additives
- Iron ore
- Scrap
- Reduction gas CH₄

Ironmaking
- Coking plant + PCI production 0.27
- Sinter plant 0.22
- Blast furnace 0.93
- DR plant 0.54
- Pelletizing 0.04

Steelmaking
- LD (BOF) converter 0.15
- 84% hot metal
- 80% HDRI

Casting & rolling
- Billet caster
- Twin ladle furnace
- Twin VD
- Bar mill
- Coils
- EAF 0.21

CO₂ emissions in tons — considering OECD EU-28 – emission factor of 452 grams CO₂ / kWh and BAT utilization of BF top gas and LD gas in power plant
Scope 3 emissions for raw materials and credits also considered

BF-BOF 1.586
DR-EAF 0.785
MAIN STEEL PRODUCTION ROUTES — FUTURE 2050
BASED ON SCRAP AND HBI

Raw materials preparation
- Coal
- Biomass
- Additives
- Tree iron ore
- Scrap
- Methane (CH4) / Green H2

Ironmaking
- Coking plant + PCI production
- Sinter plant
- Blast furnace
- DR plant
- LD (BOF) converter
- Twin ladle furnace

Steelmaking
- CO2 separation
- EAF
- Twin VD

Casting & rolling
- Billet caster
- Bar mill

CO2 emissions in tons — considering OECD EU-27 — emissions factor of 80 grams CO2 / kWh and BAT
Scope 3 emissions for raw materials and credits also considered

Crude steel production will still rely on BF at certain level.
(c.70%@CY2020 → c.60%@CY2030 → c.45%@CY2050)
DECARBONIZING STEEL: THE CASE OF EUROPE
THE LATEST TRENDS IN EUROPE

Dec. 2019 “European Green Deal”

- Raising GHG reduction target
  2030: at least 55% reduction from 1990 level (original goal: 40%)
  2050: Net Carbon Zero
- Investment plan of €1 trillion in 10 years to realize “environmental measures and economic growth”

May 2020 “Green (COVID-19) Recovery Plan”

- “Next Generation EU” — €750 billion
  (including investment in green and digital transition)

July 2020 “EU Hydrogen Strategy”

- Green hydrogen introduction target
  2024: 1 million tons/yr, 6GW (electrolyzer scale)
  2030: 10 million tons/yr, 40GW
- Total investment of up to €470 billion by 2050
- Launch of “European Clean Hydrogen Alliance”

Frans Timmermans
European Commissioner for Climate Action

"There is no future for grey steel in Europe. But an incredible future for green steel and hydrogen."

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DECARBONIZING STEEL — CARBON PRICING

The price tag on carbon is increasing

- The case of Europe: Emissions certificates have seen steep price increases.
- Supply of certificates to be tightened in 2021
- Carbon taxes are on the horizon.

CO₂ European Emissions Allowance (€/t)
DECARBONIZING STEEL: THE U.S. PERSPECTIVE
DECARBONIZING STEEL —
U.S. STEEL INDUSTRY HAS A HEADSTART

The U.S. steel industry has several starting advantages when it comes to decarbonization.
EXISTING TECHNOLOGIES THAT LEAD THE WAY FORWARD
DECARBONIZING YOUR PLANT — OPTIMIZING INTEGRATED PLANTS (TODAY)

**AGGLOMERATION**
- BF-gas injection into waste-gas recirculation system (-6–9%)
- BF-gas injection furnace (-0.5–1%)
- Waste-heat recovery circular cooler (-5–12%)
- L2 automation (-2–3%)

**BLAST FURNACE**
- BF-scrap feed (-5–10%)
- Top gas recovery turbine (TRT) (-1.2%)
- Dry slag granulation + waste heat recovery (-1–2%)
- H₂ injection (up to -20%)
- L2 automation (-2.5%)

**BASIC OXYGEN FURNACE**
- Gas recovery (-2%)
- KOBM / Jet Process (up to -23%)
- Process / heat optimization (up to -9%)
- Scrap preheating (-8%)
- DFPC lance (-4%)
- Slag valorization / ZEWA (-6%)

-25%* CO₂ equivalents
* (Selective) waste gas recirculation, shaft cooler incl. WHR, BF gas injection WGR, BF gas ignition furnace

-40%* CO₂ equivalents
* H₂ injection, HBI feed, advanced stove system, MERIM dry gas cleaning incl. TRT & DSG dry slag granulation

-25%* CO₂ equivalents
* Combination of process optimization, scrap preheating, DFPC Lance and KOBM without hot blast (JET), gas recovery, MERCON & cooling stack extension

CO₂ reduction
- Main benefit CO₂ reduction
- Additional value besides CO₂ reduction

CO₂ reduction
- Main benefit CO₂ reduction
- Additional value besides CO₂ reduction

CO₂ reduction
- Main benefit CO₂ reduction
- Additional value besides CO₂ reduction

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DECARBONIZING YOUR PLANT — OPTIMIZING DIRECT REDUCTION

Today

**MIDREX — Natural Gas**
- BSG dry dedusting (-0.2%)
- Hot fines recycling system for HBI Plants (-3%)
- L2 automation (up to -1%)

**MIDREX — H₂**
- Top-gas waste-heat recovery (-2–3%)
- Hot transport (-6%)
- Hydrogen (0–100%)

**HYFOR**
HYDROGEN-BASED FINE-ORE REDUCTION
- Hydrogen

**FUTURE**

- **-12%**
  CO₂ equivalents
  * Use of up to 100% hydrogen,

- **-91%**
  CO₂ equivalents
  * Use of 100% hydrogen
DECARBONIZING YOUR PLANT — ELECTRIC ARC FURNACES (TODAY)

Potentials and solutions

- **EAF Quantum (-13%)**
  With scrap preheating compared to conventional EAF (both 150 t heat size)

- **Waste-heat recovery EAF (-12-14%)**
  Energy recovery of off gases

- **Waste-heat recovery reheating furnace (-2%)**
  Uses off gas heat for steam production

- **Waste-heat recovery EAF-Quantum (-6-9%)**
  Energy recovery of off gases

- **Arvedi ESP (-39%)**
  Combined casting/rolling

- **WinLink (-40%)**
  Direct rolling of long products

**TOTAL**

-25%* CO₂ equivalents

*Quantum Scrap Pre-Heating, Waste-heat recovery EAF & RHF, Energy Saving Assistant

Total CO₂ savings potential
115,200 tons p.a.
DECARBONIZING YOUR PLANT —
FLEXIBLE EAF SOLUTIONS

Integrated plants

- DRI Melter
- EAF Fusion

Minimills

- EAF
- EAF Quantum
- EAF Ultimate
BREAKTHROUGH TECHNOLOGIES
DECARBONIZING YOUR PLANT —
HYFOR — HYDROGEN-BASED FINE-ORE REDUCTION

-91%* CO₂ equivalents

* 100% hydrogen, hot DRI transport into EAF

- Direct reduction process for HDRI / HBI production
- Direct use of any iron-ore pellet feed concentrate < 0.15 mm; hematite or magnetite
- Utilizes hydrogen as reducing gas

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DECARBONIZING YOUR PLANT — HYFOR — HYDROGEN-BASED FINE-ORE REDUCTION

TOTAL

-91%* CO₂ equivalents

* 100% hydrogen, hot DRI transport into EAF

- 91% CO₂ equivalents

- No pelletizing required
  Lowers operation costs

- High oxide yield
  Due to dry dedusting and recycling of oxide dust

- High reduction rate at low temperatures and pressures
  Due to high particle surface
### H2 DR–EAF Based Steel Plant

**Production of 1 MTPA Steel**

<table>
<thead>
<tr>
<th>Process</th>
<th>30% H₂ Use</th>
<th>100% H₂ Use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>H₂ amount required for reduction:</strong></td>
<td>29,250 Nm³/h, 2,630 kg/h, 21,040 tons/annum</td>
<td>97,500 Nm³/h, 8,765 kg/h, 70,120 tons/annum</td>
</tr>
<tr>
<td><strong>H₂ purity:</strong></td>
<td>≥ 99.8 vol%</td>
<td>≥ 99.8 vol%</td>
</tr>
<tr>
<td><strong>H₂ pressure (at TOP):</strong></td>
<td>4.5 barg</td>
<td>4.5 barg</td>
</tr>
<tr>
<td><strong>Electrolyser Capacity(^1) (green electricity):</strong></td>
<td>138 MW(^1)</td>
<td>458 MW(^1)</td>
</tr>
<tr>
<td><strong>Electric Power required for 1 mtpa liquid Steel:</strong></td>
<td>~1,75 – 1,82 Twh/a</td>
<td>~5.0 - 5.2 Twh/a</td>
</tr>
<tr>
<td><strong>CO₂ Emission(^2)</strong></td>
<td>570 kgCO₂/tLS</td>
<td>200 kgCO₂/tLS</td>
</tr>
</tbody>
</table>

**Note:** 1) assumed PEM efficiency 52.2 kW/kg; 2) CO₂ emission factor for grid considered: 80 grm CO₂ / kWh (green electricity);
DECARBONIZING YOUR PLANT —
CARBON CAPTURE AND UTILIZATION / STORAGE

CCU — CARBON CAPTURE AND UTILIZATION
GasFerm*

[Diagram of CCU process]

CCS — CARBON CAPTURE AND STORAGE
Amine Scrubber (KM-CDR PROCESS®)

[Diagram of CCS process]

*Developed by LanzaTech. Primetals Technologies is the partner for plant implementation for the iron and steel industry.
STRATEGIC COOPERATION LANZATECH
GREEN STEEL – BIO-FERMENTATION (CCU)

PT is engaged into AM Gent commercial plant. Start-up in Q1/2021. PT is shareholder of LanzaTech.
BY-PRODUCT UTILIZATION

DRY SLAG GRANULATION
BY-PRODUCT UTILIZATION
DRY BF SLAG GRANULATION

Blast Furnace

Slag Buffer

Slag 1.5 / 2.1 t/min

Hot Off Air
590 / 560°C
160 / 215 t/h

Granulate Bulk Heat Exchanger

Granulate discharge 190 / 240°C
1.5 / 2.1 t/min

Granulator

Air to Granulator 180 / 200°C

Granulate discharge Granulator 490 / 490°C

Blower Fan 1.2 / 1.8 MW

Ambient Air 10°C
180 / 240 t/h

Stack

Suction Fan 0.4 / 0.9 MW

Bag Filter

Waste Heat Recovery Steam Boiler

Slag Wool & Coarse Dust Separator

Superheated Steam
290 / 290°C 8.26 bar(g)
20 / 30 t/h

Nom / Max

Air recirculation (only used in part load cases)
DECARBONIZATION: THE DIGITAL ANGLE
AUTOMATIC SCRAP CLASSIFICATION AND AUTOMATIC OPERATION

Scrap order with defined scrap quality

Assured scrap quality

Increased yield through better charging materials

Reproducible quality in steel production

Improved claim management

Automatic scrap quality inspection

Automatic loading and handling

Automatic transportation

Scrap supplier

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KEY CHALLENGES & POLICY INTERVENTION

KEY TAKE AWAY

The path to Low Carbon Steel making faces multiple challenges with significant costs:

- Lower Emission but significant increase in renewable electricity capacity required
- Availability of higher-grade iron ores/Pellets
- Scaling up the low carbon H₂-based on Electrolysis/Pyrolysis must rise, and prices must fall substantially.
- Storage of Hydrogen / Captured CO₂ on Large Scale
- Quality of Scrap and collection should increase
- Break-through technologies like H2-DRI and Carbon Capture & Utilisation must scale-up.
- Competitiveness of Low CO₂ steel due to its higher production cost
- Generate demand for Low carbon intensity products by corporates and public procurement, establish green product standards, introduce incentives for steel users (such as automotive, among others) to use ‘green steel’
- Promote Large-Scale Green Finance, Carbon Taxes including Carbon border Adjustment tax etc.
- Transition support for scale-up of low carbon technologies and remain competitive.
- Promote material efficiency and circular economy