THE PATH TO CLIMATE-NEUTRAL STEEL

primetals.com

DECARBONIZING STEEL: A GLOBAL PERSPECTIVE

IRON & STEEL INDUSTRY
ENERGY AND EMISSIONS

PRIMETALS TECHNOLOGIES

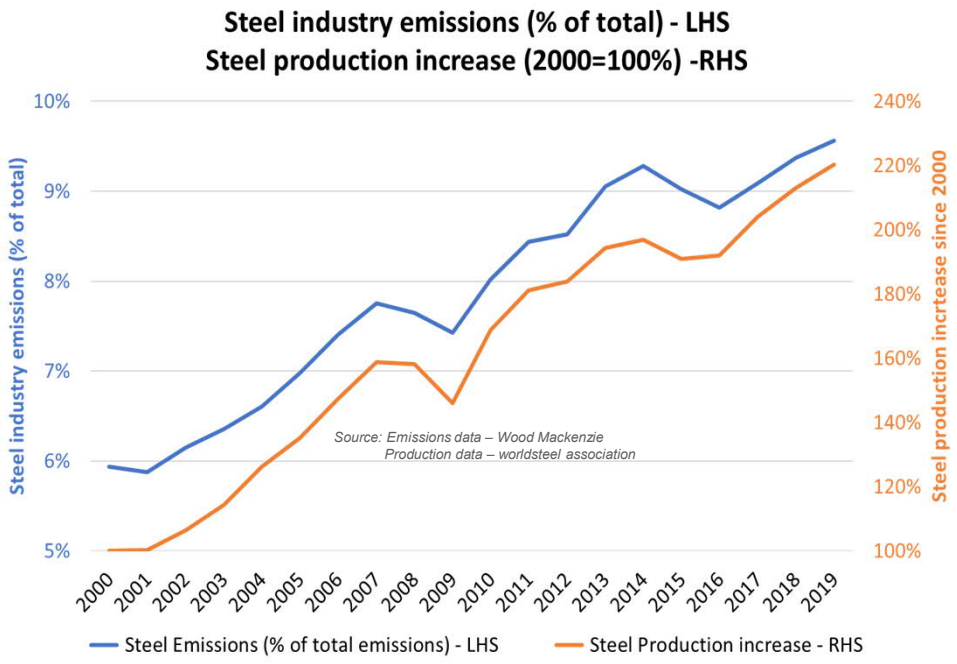
Steel is one of the most energy and emissions intensive industries globally and is considered 'hard-to-abate'

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 Chemical sector
- Iron & Steel uses 22% of the industrial energy or 8% of the total energy

Emissions (CO_2) facts for the Iron & Steel industry:

- Iron and Steel is the 2nd largest emitter of CO_2 after the Cement industry
- Responsible for 25% of industrial CO_2 emissions or over 9% of total CO_2 emissions
- Iron and Steel industry emissions were 3.7 Gt CO_2 equivalent in 2019. Thereof 2.6 Gt were direct emissions, and 1.1 Gt were indirect emissions.



KEY MAJOR TRENDS DRIVING STEEL INDUSTRY

Urbanisation Social Changes

Increase in Steel and Energy Consumption as economies grow

Scarcity of Natural Resources

Solutions to use Low Grade Ores

Climate Change & Environment

De-Carbonisation of Steel Industry and Net Zero by 2050 Regulatory Push

Circular Economy

Maximise Scrap Usage
Drives EAF based steel production.

Digitalization

Advances new business models and improves efficiency, availability and safety.

- *Changing customer requirements and growing demand for carbon-friendly steel products – focus of automakers to reduce their overall CO_2 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*

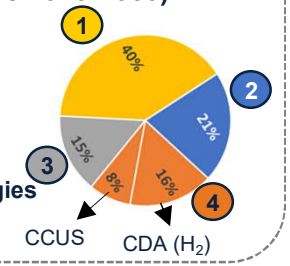
IRON & STEEL INDUSTRY REQUIREMENT
LOW CARBON ECONOMY

PRIMETALS TECHNOLOGIES

Crude Steel CO_2 emission reduction in SDS by mitigation strategy (cumulative 2020-2050)

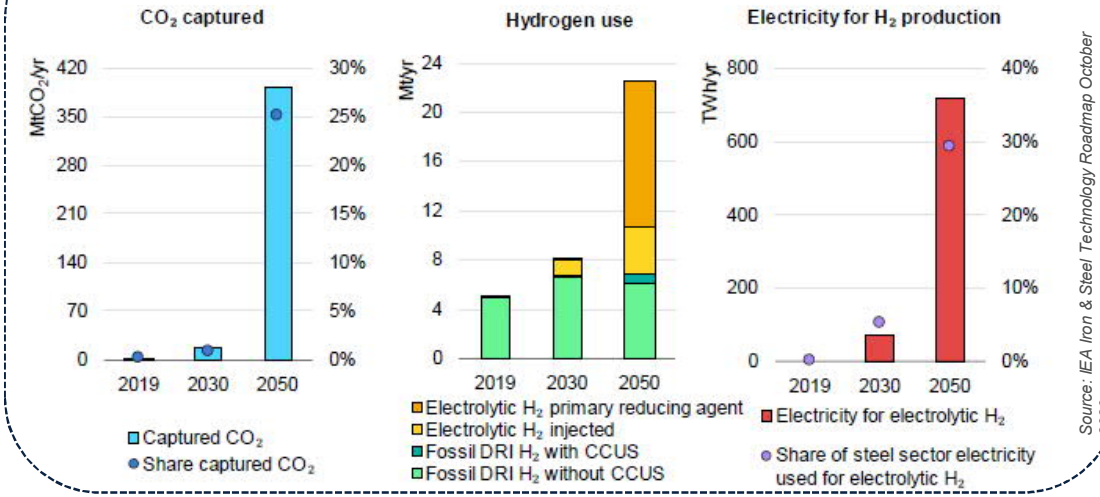
PT
1. Material Efficiency
2. Energy Efficiency
3. Fuel Switching

MHI
4. Near-zero emission technologies



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

4 Near-zero emission technologies; Carbon Capture (CCU, CCS), H_2 use



Source: IEA Iron & Steel Technology Roadmap October 2020

Steel companies announced so far to become Climate Neutral by 2050

- Arcelor Mittal
- POSCO
- Thyssenkrupp
- SSAB
- Liberty Steel
- Tata Steel
- NSSMC
- JSW
- ….

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

Average investment <u>required per year</u>

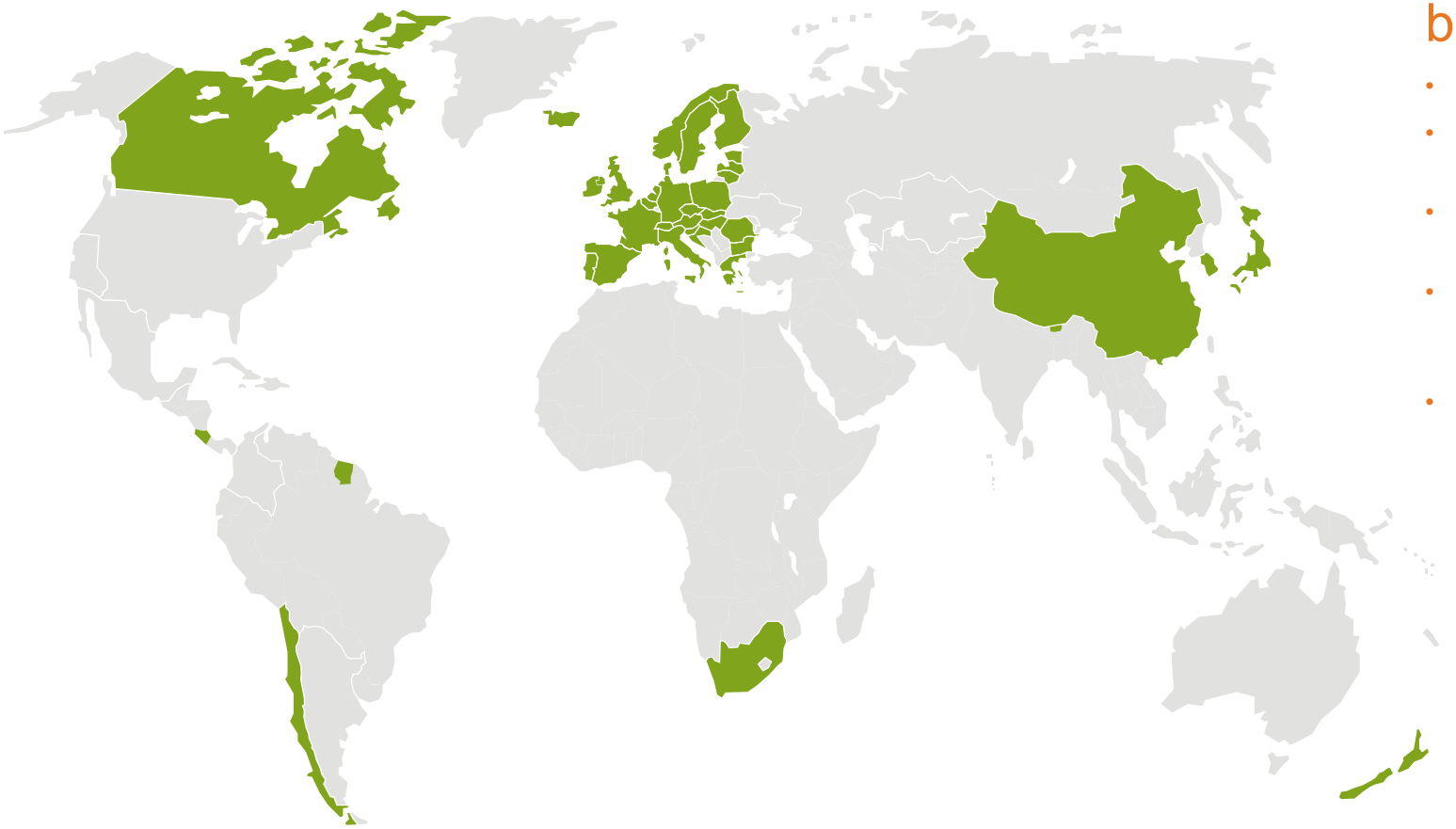
2021-2030 = USD 39 billion

2031-2040 = USD 46 billion

2041-2050 = USD 54 billion

Source: IEA Iron & Steel Technology Roadmap October 2020

DECARBONIZING STEEL — A GLOBAL PERSPECTIVE

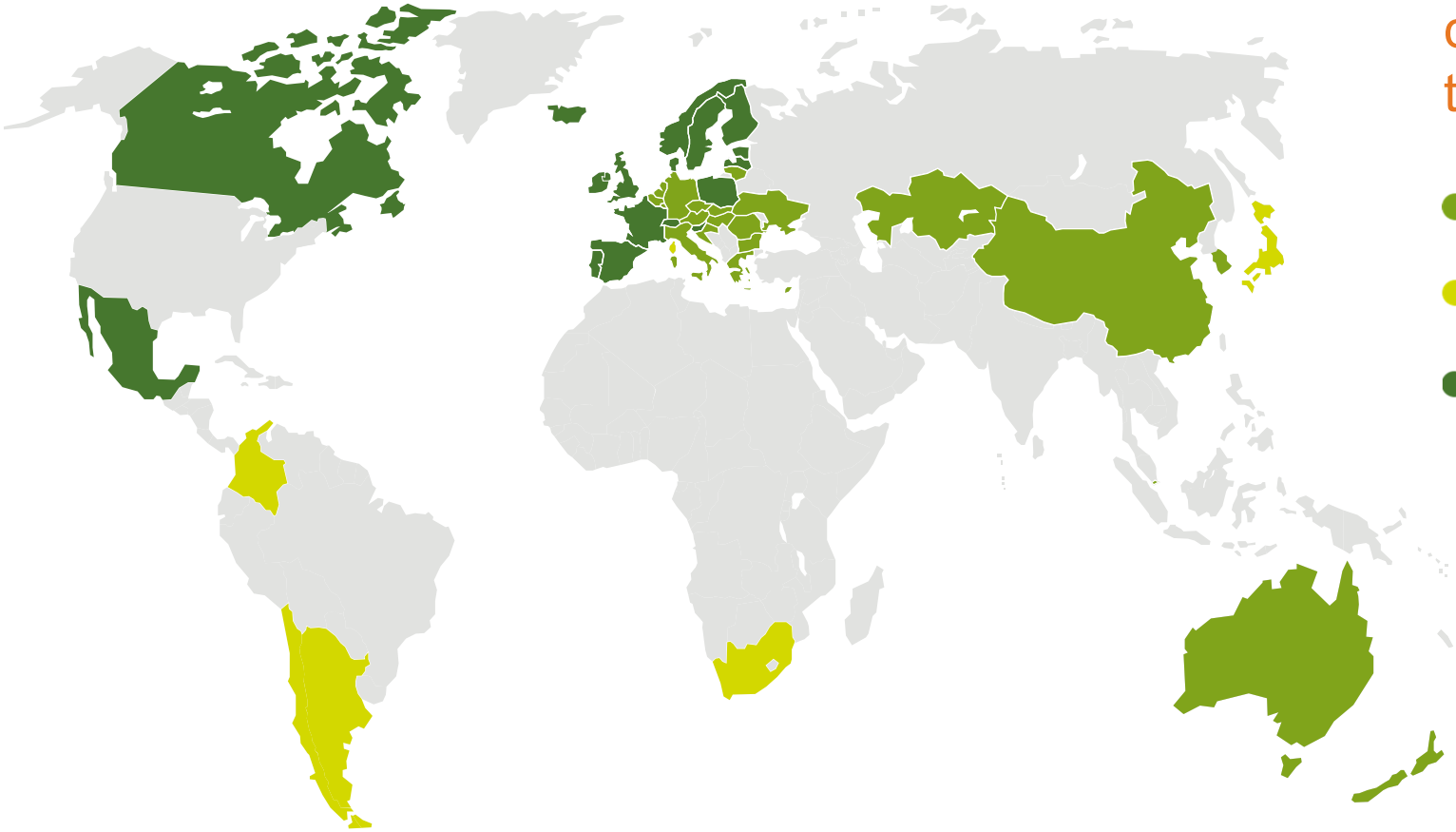


Pledging net-zero by mid-century

- 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

DECARBONIZING STEEL —
A GLOBAL PERSPECTIVE

PRIMETALS TECHNOLOGIES

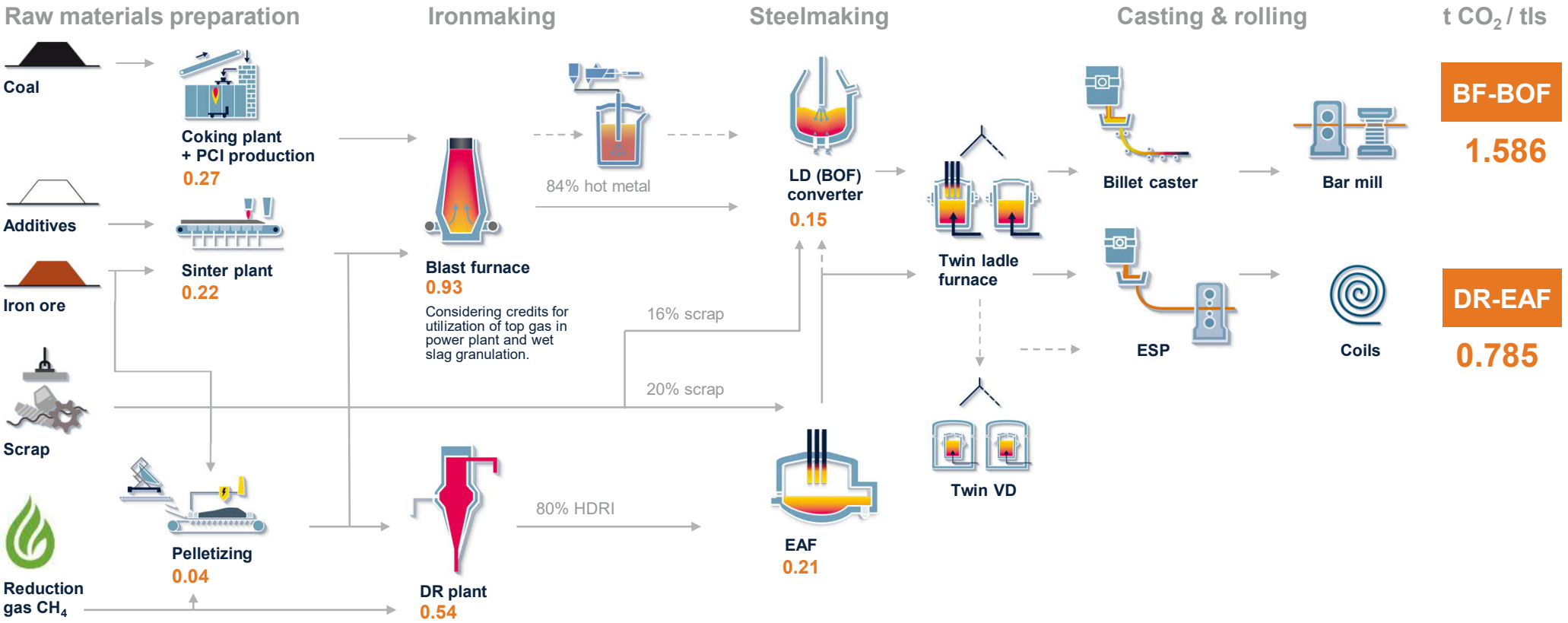


Trading schemes and carbon taxes are on the rise globally

- Emissions trading scheme implemented or scheduled for implementation
- Carbon tax implemented or scheduled for implementation
- Emissions trading scheme and carbon tax implemented or scheduled

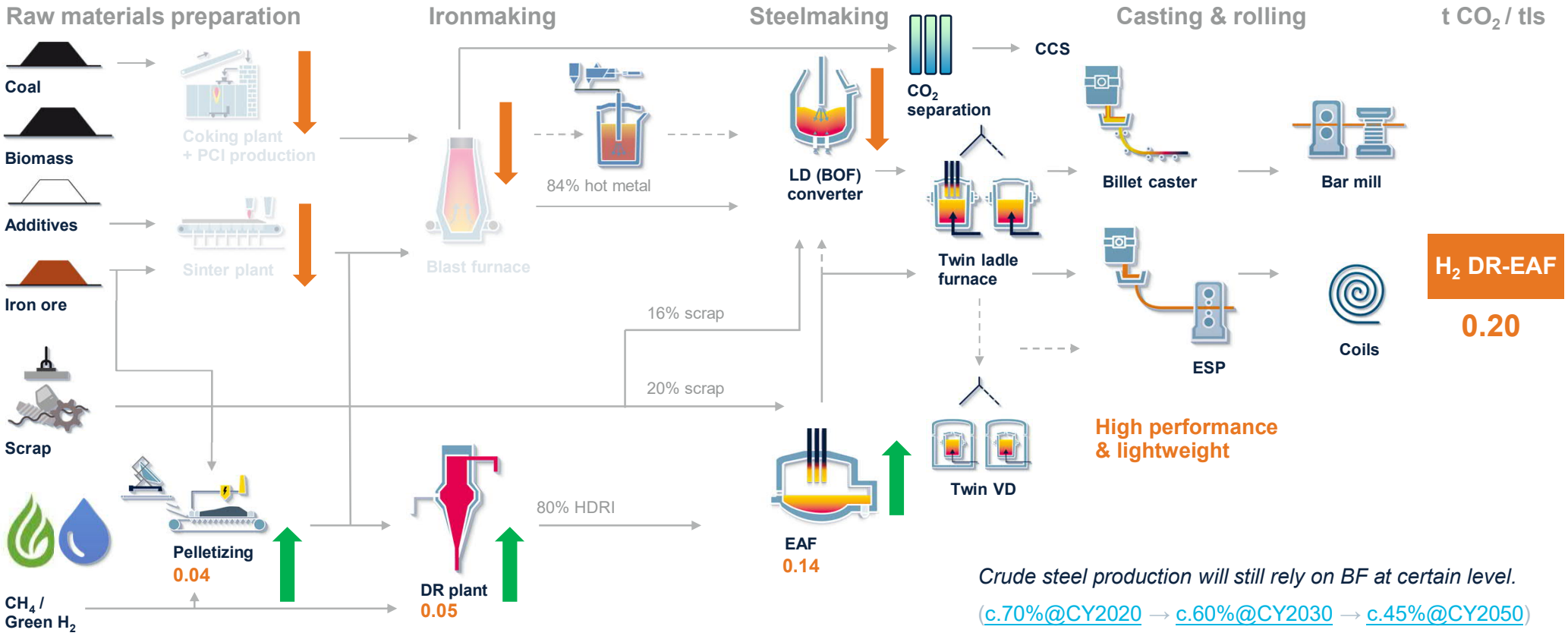
MAIN STEEL PRODUCTION ROUTES — TODAY
(84% HM / 16% SCRAP RESP. 80% HDRI + 20% SCRAP)

PRIMETALS TECHNOLOGIES



CO_2 emissions in tons — considering OECD EU-28 – emission factor of 452 grams CO_2 / kWh and BAT utilization of BF top gas and LD gas in power plant
Scope 3 emissions for raw materials and credits also considered

MAIN STEEL PRODUCTION ROUTES — FUTURE 2050
BASED ON SCRAP AND HBI



Crude steel production will still rely on BF at certain level.

(c.70%@CY2020 → c.60%@CY2030 → c.45%@CY2050)

CO_2 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

DECARBONIZING STEEL: THE CASE OF EUROPE

THE LATEST TRENDS
IN EUROPE

Frans Timmermans
European Commissioner for Climate Action

European Commission

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”

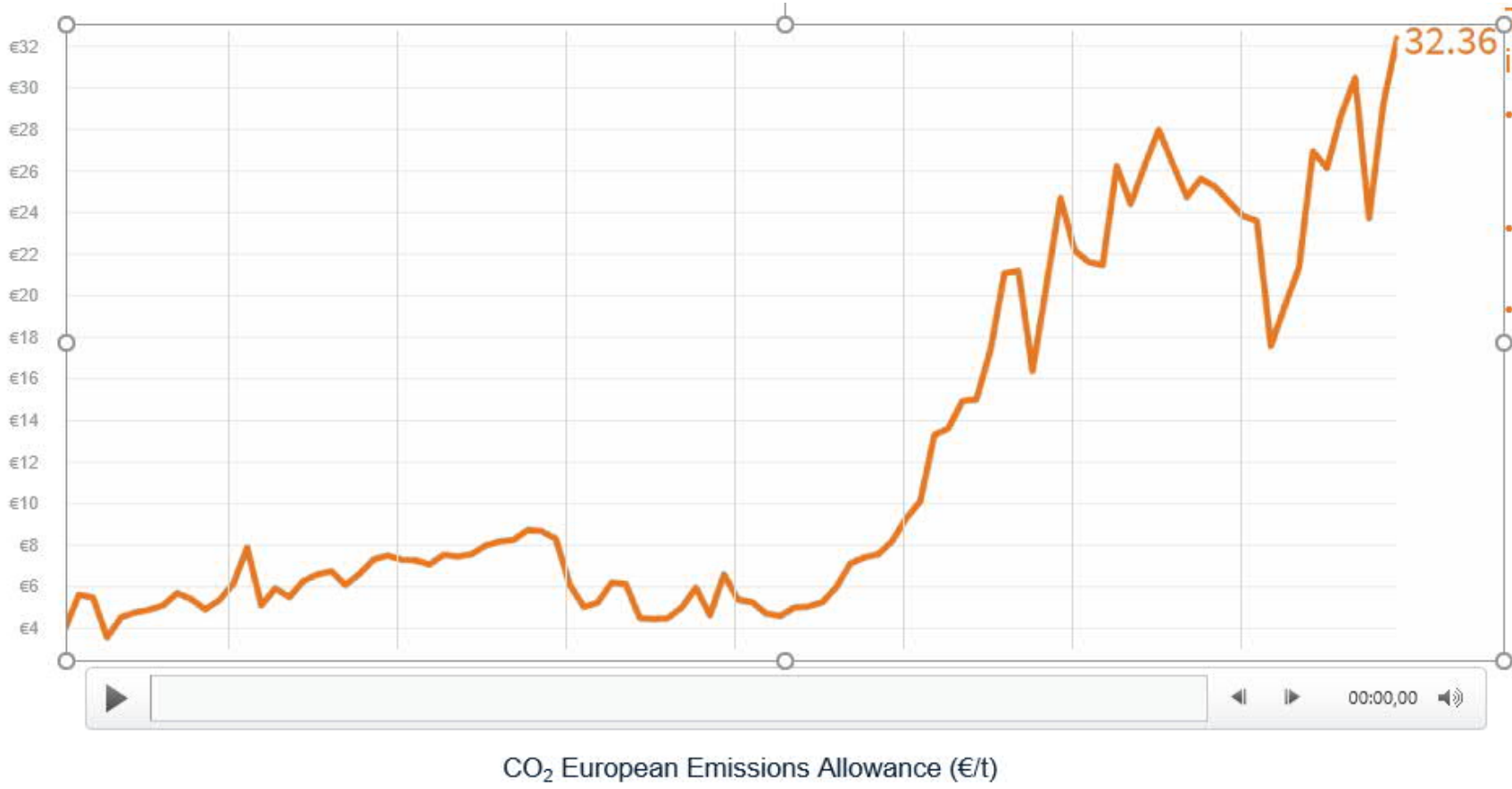
May 2020 “Green (COVID-19) Recovery Plan”

- “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”

DECARBONIZING STEEL —
CARBON PRICING



CO_2 European Emissions Allowance (€/t)

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.

DECARBONIZING STEEL: THE U.S. PERSPECTIVE

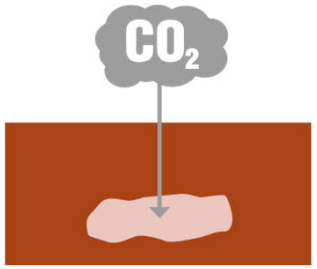
DECARBONIZING STEEL —
U.S. STEEL INDUSTRY HAS A HEADSTART

PRIMETALS TECHNOLOGIES

Large EAF base

Abundance of natural gas through the shale-gas revolution

Low electricity prices, rapidly growing solar + wind capacity, new developments in nuclear



Great potential for carbon capture and storage / utilization

The U.S. steel industry has several starting advantages when it comes to decarbonization.

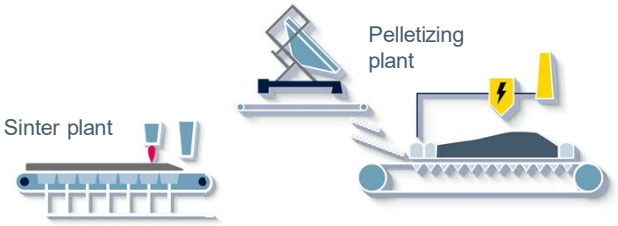
EXISTING TECHNOLOGIES THAT LEAD THE WAY FORWARD

DECARBONIZING YOUR PLANT —
OPTIMIZING INTEGRATED PLANTS (TODAY)

PRIMETALS TECHNOLOGIES

AGGLOMERATION

- BF-gas injection into waste-gas recirculation system (-6–9%)
- (Selective) waste-gas recirculation (-7–10%)
- BF-gas ignition furnace (-0.5–1%)
- Shaft cooler (-6–13%)

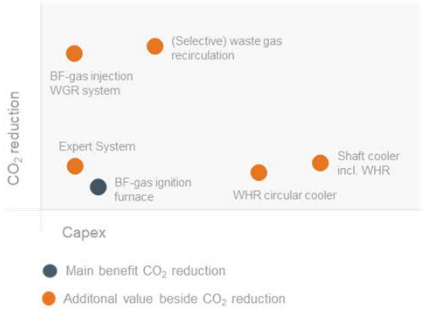


- Waste-heat recovery circular cooler (-5–12%)
- L2 automation (-2–3%)

-25%*

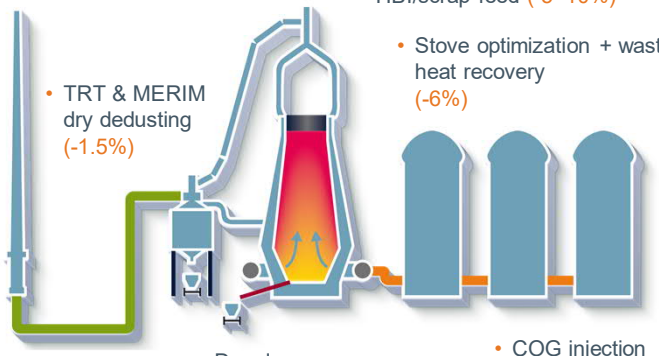
CO_2 equivalents

* (Selective) waste gas recirculation, shaft cooler incl. WHR, BF gas injection WGR, BF gas ignition furnace



BLAST FURNACE

- HBI/scrap feed (-5–10%)
- Stove optimization + waste heat recovery (-6%)
- TRT & MERIM dry dedusting (-1.5%)



- Top gas recovery turbine (TRT) (-1.2%)
- Dry slag granulation + waste heat recovery (-1–2%)
- COG injection (-5–7%)
- H_2 injection (up to -20%)
- L2 automation (-2.5%)

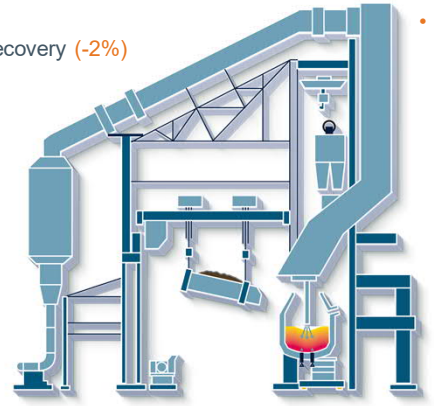
-40%*

CO_2 equivalents

*H_2 injection, HBI feed, advanced stove system, MERIM dry gas cleaning incl. TRT & DSG dry slag granulation

BASIC OXYGEN FURNACE

- Gas recovery (-2%)
- Cooling stack extension & MERCON (-0.7%)

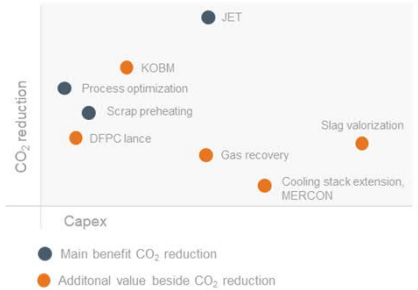


- KOBM / Jet Process (up to -23%)
- Process / heat optimization (up to -9%)
- Scrap preheating (-8%)
- DFPC lance (-4%)
- Slag valorization / ZEWA (-6%)

-25%*

CO_2 equivalents

*Combination of process optimization, scrap pre-heating, DFPC Lance and KOBM without hot blast (JET), gas recovery, MERCON & cooling stack extension

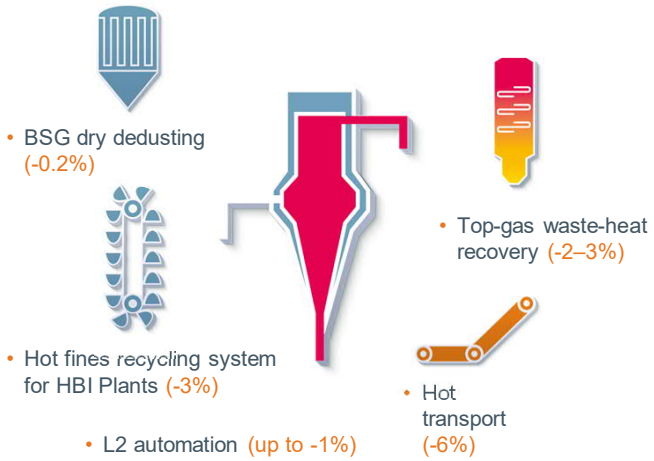


DECARBONIZING YOUR PLANT —
OPTIMIZING DIRECT REDUCTION

PRIMETALS TECHNOLOGIES

Today | **2025** | **2030**

MIDREX — Natural Gas

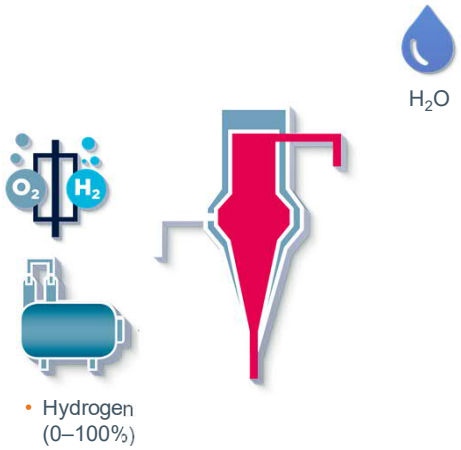


-12%*

CO_2 equivalents

* Hot fines recycling system for HBI plants and L2 automation (DRIPax), WHR, Hot Transport

MIDREX — H_2



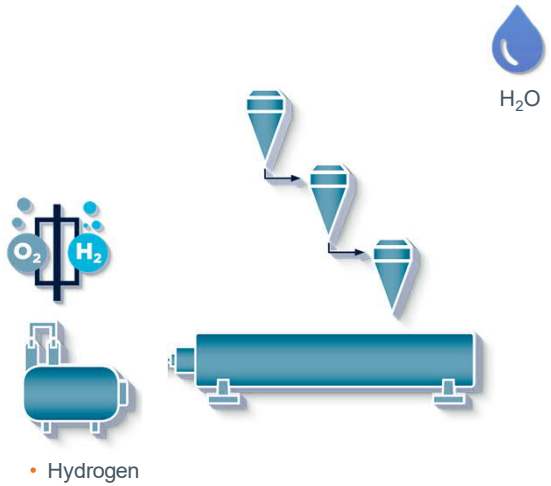
-91%*

CO_2 equivalents

*Use of up to 100% hydrogen,

HYFOR

HYDROGEN-BASED FINE-ORE REDUCTION



-91%*

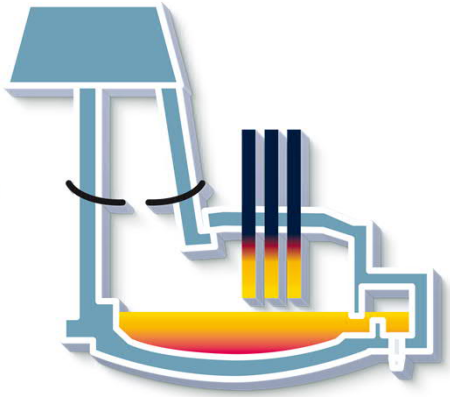
CO_2 equivalents

* Use of 100% hydrogen

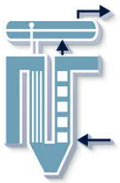
FUTURE

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%*

CO_2 equivalents

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

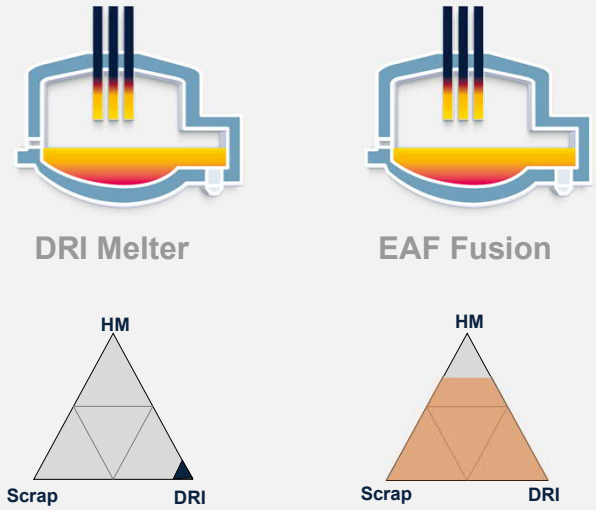
Total CO_2 savings potential
115,200 tons p.a.

- **Energy Saving Assistant (-1%)**
  Improved control of gas cleaning plant

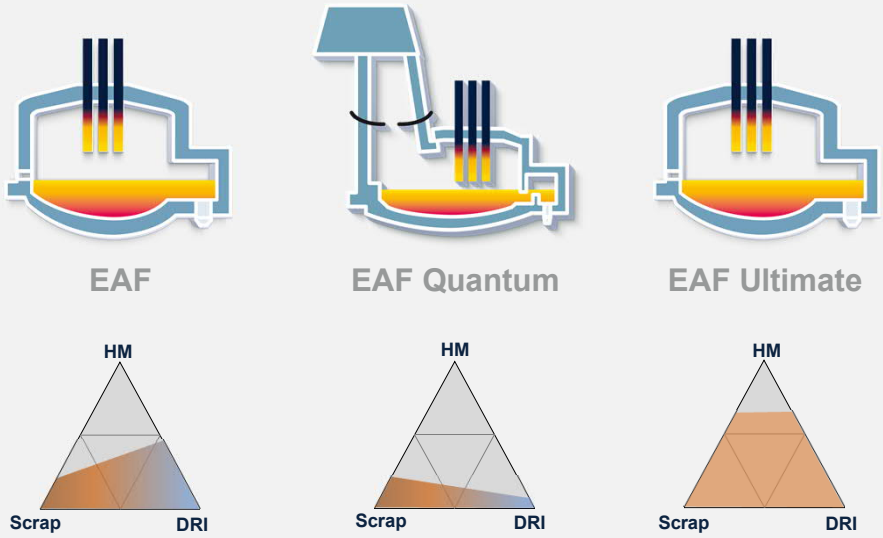
DECARBONIZING YOUR PLANT — FLEXIBLE EAF SOLUTIONS

PRIMETALS TECHNOLOGIES

Integrated plants



Minimills



PRIMETALS TECHNOLOGIES

BREAKTHROUGH TECHNOLOGIES

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

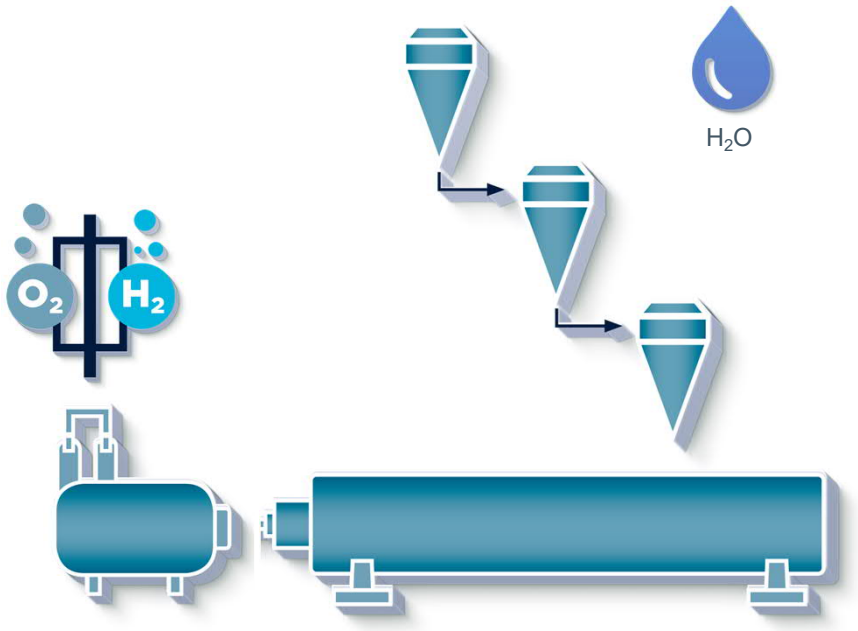
PRIMETALS TECHNOLOGIES

TOTAL

-91%*

CO_2 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**

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

PRIMETALS TECHNOLOGIES

TOTAL

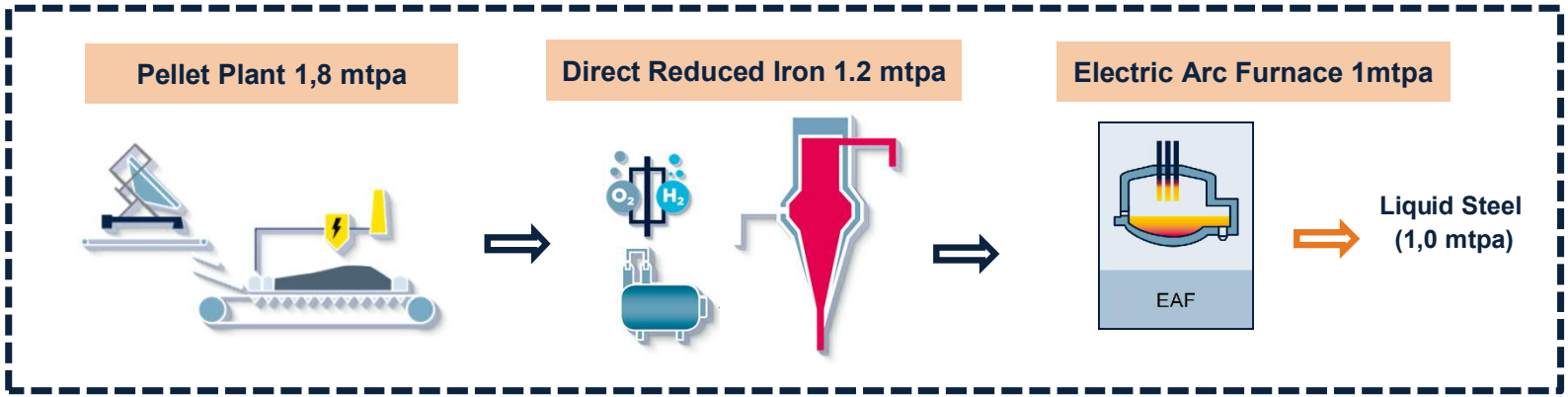
-91%*

CO_2 equivalents

* 100% hydrogen, hot DRI transport into EAF

- **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



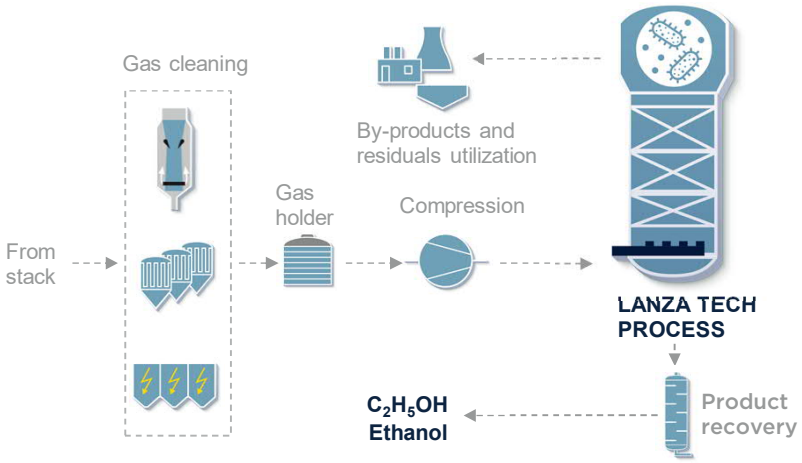
	30% H_2 Use	100% H_2 Use
H_2 amount required for reduction:	29,250 Nm³/h 2,630 kg/h 21,040 tons/annum	97,500 Nm³/h 8,765 kg/h 70,120 tons/annum
H_2 purity:	≥ 99.8 vol%	≥ 99.8 vol%
H_2 pressure (at TOP):	4,5 barg	4,5 barg
Electrolyser Capacity[1] (green electricity):	138 MW[1]	458 MW[1]
Electric Power required for 1 mtpa liquid Steel	~1,75 – 1,82 Twh/a	~5,0 - 5,2 Twh/a
CO_2 Emission[2]	570 kgCO2/tLS	200 $kgCO_2/t_{LS}$

Note : 1) assumed PEM efficiency 52,2 kW/kg : 2) *CO_2 emission factor for grid considered: 80 grm CO_2 / kWh (green electricity);*

DECARBONIZING YOUR PLANT —
CARBON CAPTURE AND UTILIZATION / STORAGE

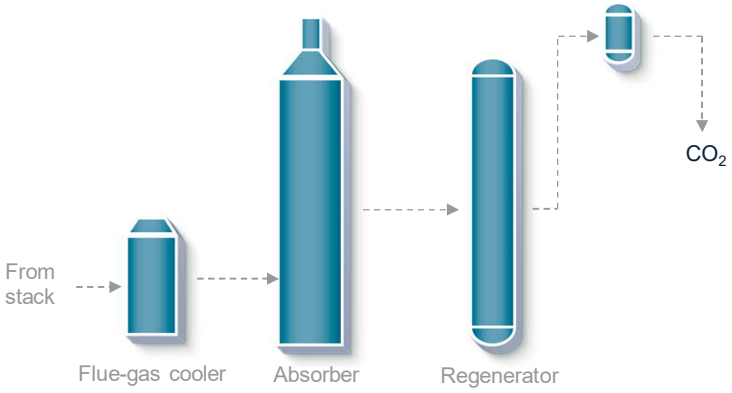
CCU — CARBON CAPTURE AND UTILIZATION

GasFerm*



CCS — CARBON CAPTURE AND STORAGE

Amine Scrubber (KM-CDR 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)

PRIMETALS TECHNOLOGIES

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

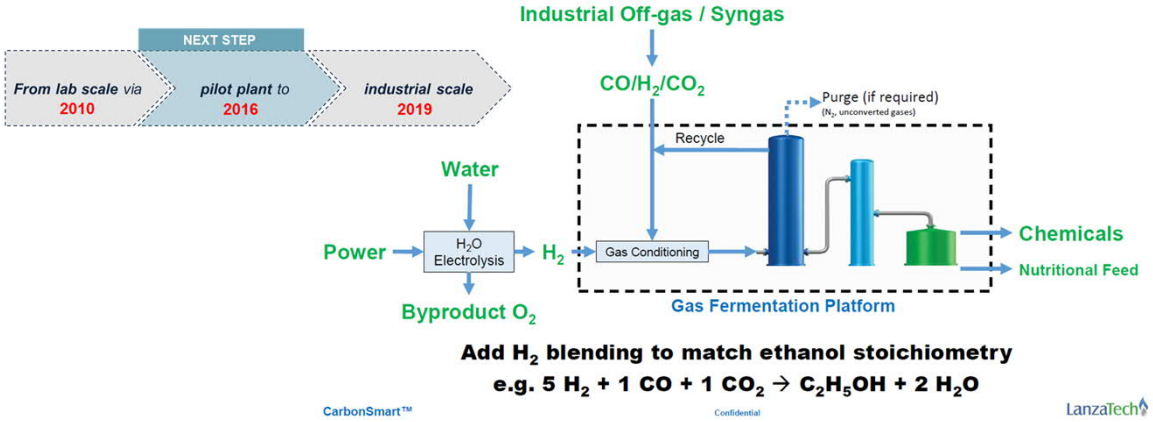
Shougang (SGLT) Summary

首钢朗泽
Shougang LanzaTech

Location	**Caofeidian, China**
Feedstock	**Steel off-gas**
Gas composition	**High-CO**
Capacity	**48K MTA**

Arcelor Mittal / Gent, Belgium

Flexible Gas Fermentation Platform for Conversion of CO_2 and H_2 into Products



Add H_2 blending to match ethanol stoichiometry

e.g. 5 H_2 + 1 CO + 1 CO_2 → C_2H_5OH + 2 H_2O

CarbonSmart™ Confidential LanzaTech

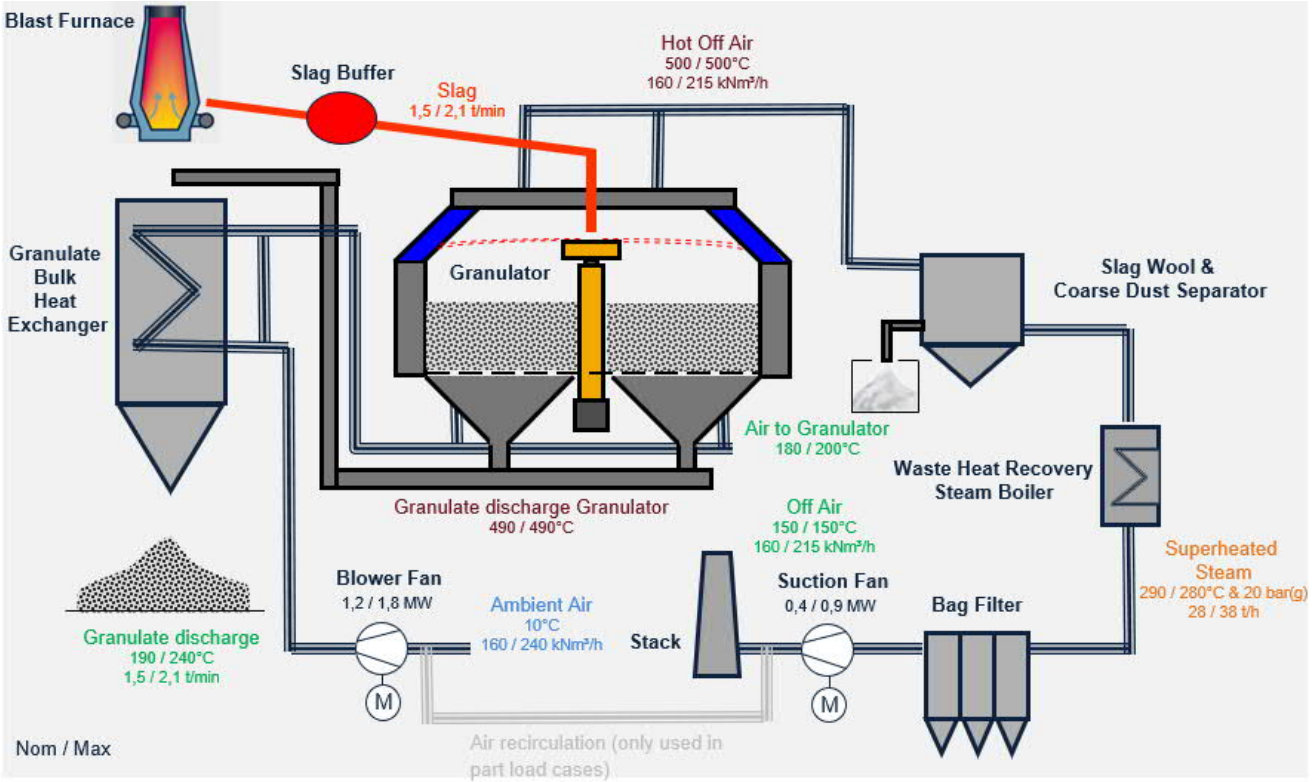
Consumption and production figures:	
Gas Flow	100.000 Nm³/h
Composition	20 Vol% BOF-Gas + 80 % BF-Gas
Ethanol Production	8 t/h / 64.000 t/a

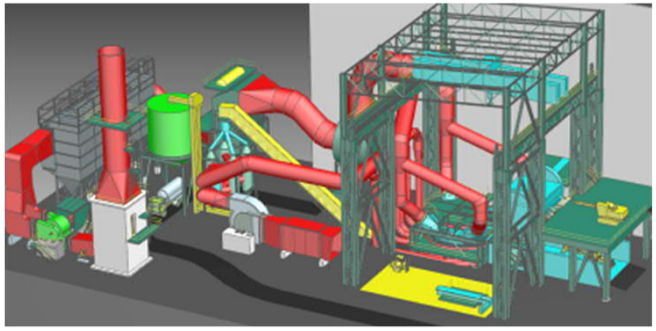
		H_2:CO Ratio	$\Delta G°_{rxn}$ (kJ/rxn_mol)	Carbon Efficiency	Energy Efficiency
CO	6 CO + 3 H_2O → C_2H_5OH + 4 CO_2	0:1	-216	33.3%	72.8%
CO + H_2	3 H_2 + 3 CO → C_2H_5OH + CO_2	1:1	-156	66.7%	78.5%
CO + H_2	4 H_2 + 2 CO → C_2H_5OH + H_2O	2:1	-135	100%	80.6%
CO + H_2 + CO_2	5 H_2 + 1 CO + 1 CO_2 → C_2H_5OH + 2 H_2O	5:1	-115	100%	82.9%

BY-PRODUCT UTILIZATION

DRY SLAG GRANULATION

BY-PRODUCT UTILIZATION
DRY BF SLAG GRANULATION





DECARBONIZATION: THE DIGITAL ANGLE

AUTOMATIC SCRAP CLASSIFICATION AND AUTOMATIC OPERATION

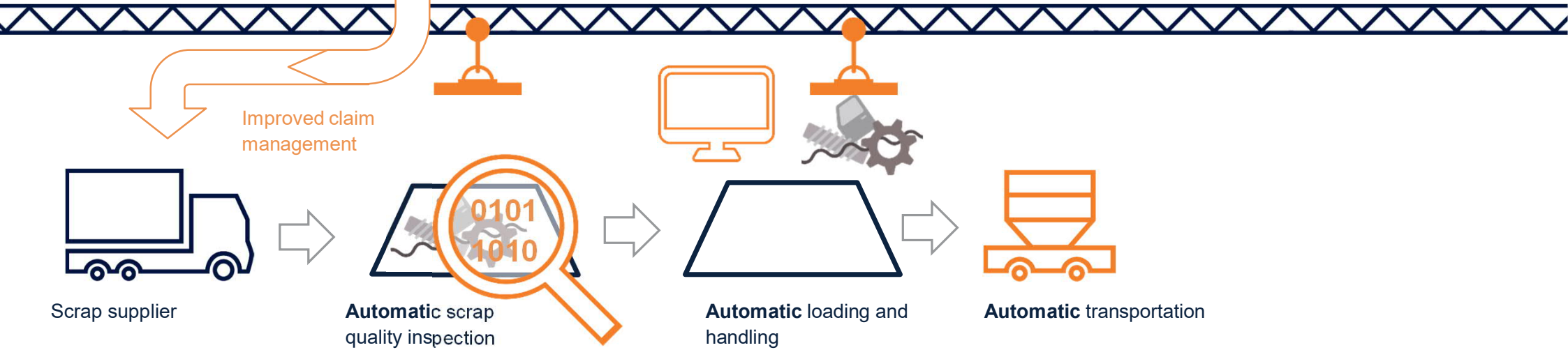
PRIMETALS TECHNOLOGIES

Scrap order with defined scrap quality

Assured scrap quality

Increased yield through better charging materials

Reproducible quality in steel production



Improved claim management

Scrap supplier

Automatic scrap quality inspection

Automatic loading and handling

Automatic transportation

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 H_2 based on Electrolysis/Pyrolysis must rise, and prices must fall substantially.*
- *Storage of Hydrogen / Captured CO_2 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 CO_2 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*

PRIMETALS
TECHNOLOGIES

THANK YOU