MOVING METALLURGY FORWARD

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SAPIENZA UNIVERSITÀ DI ROMA — DIPARTIMENTO INGEGNERIA CHIMICA MATERIALI AMBIENTE

UNIVERSITÀ DI PISA

RINA

Fattori abilitanti per la decarbonizzazione degli stabilimenti siderurgici integrati

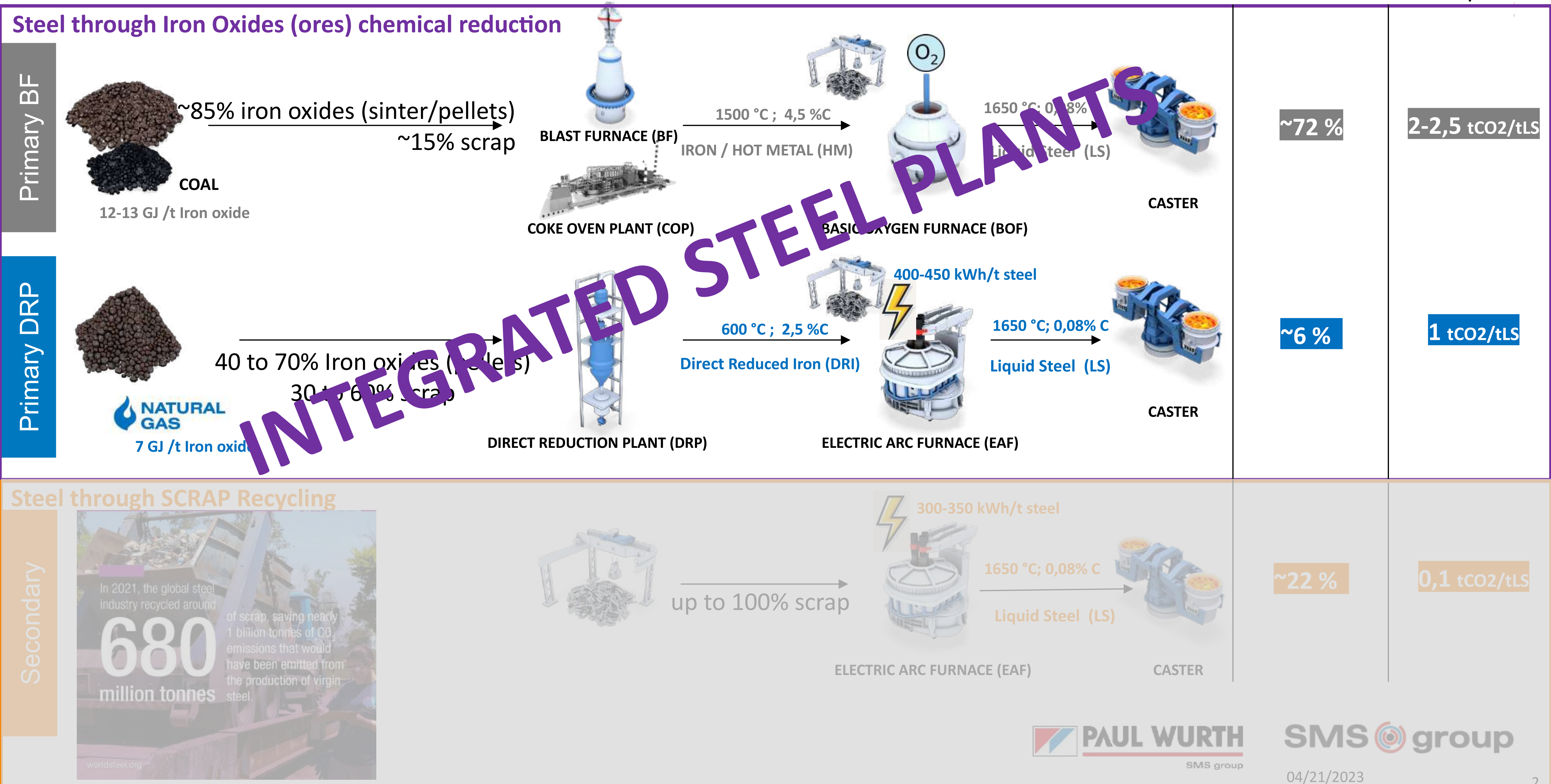
Cristiano Castagnola
Paul Wurth –SMS Group

PAUL WURTH SMS group

How is steel produced today ? How much are the CO2 emissions?

Ratio of world steel production 1,8 Bln t/y

CO_2 Emissions Scope 1



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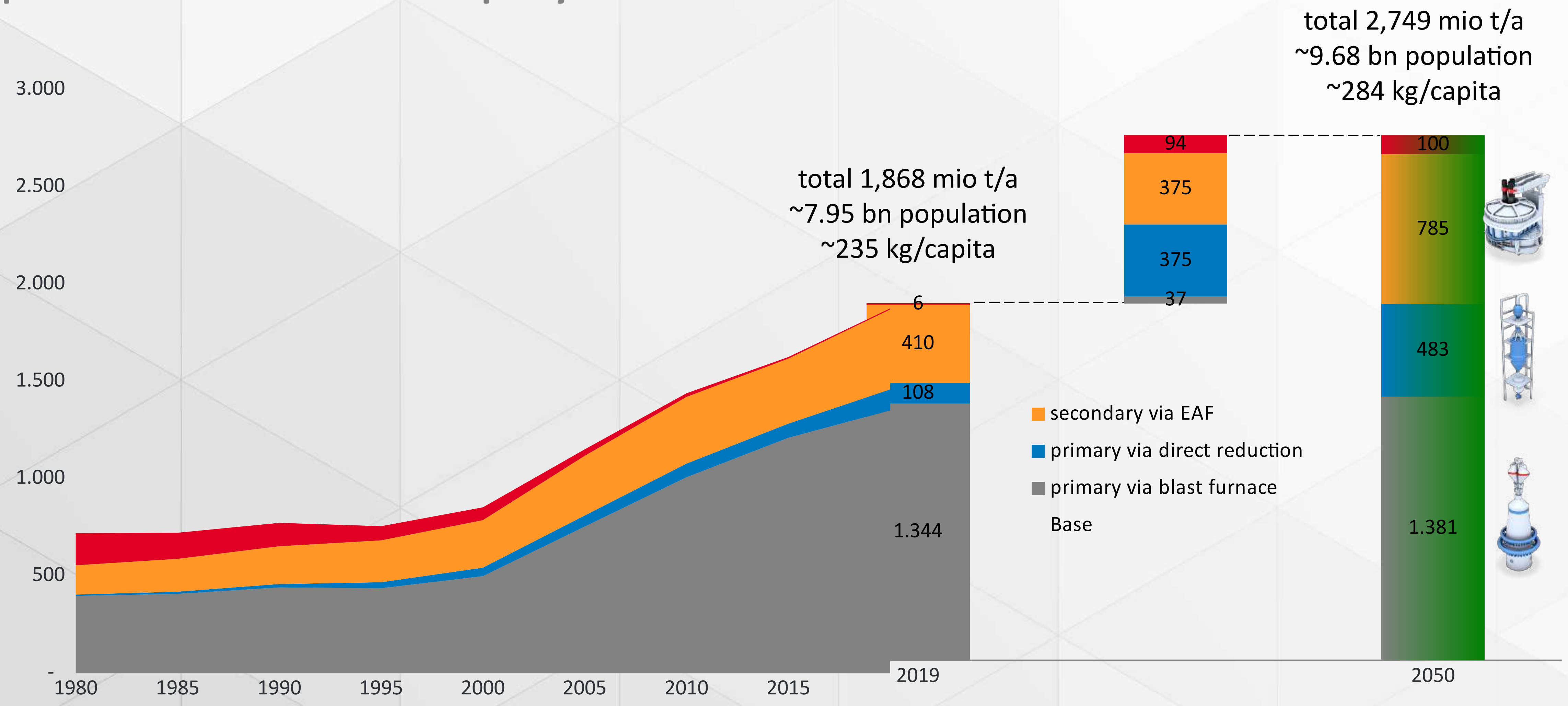
Steelmaking 1980 to 2050

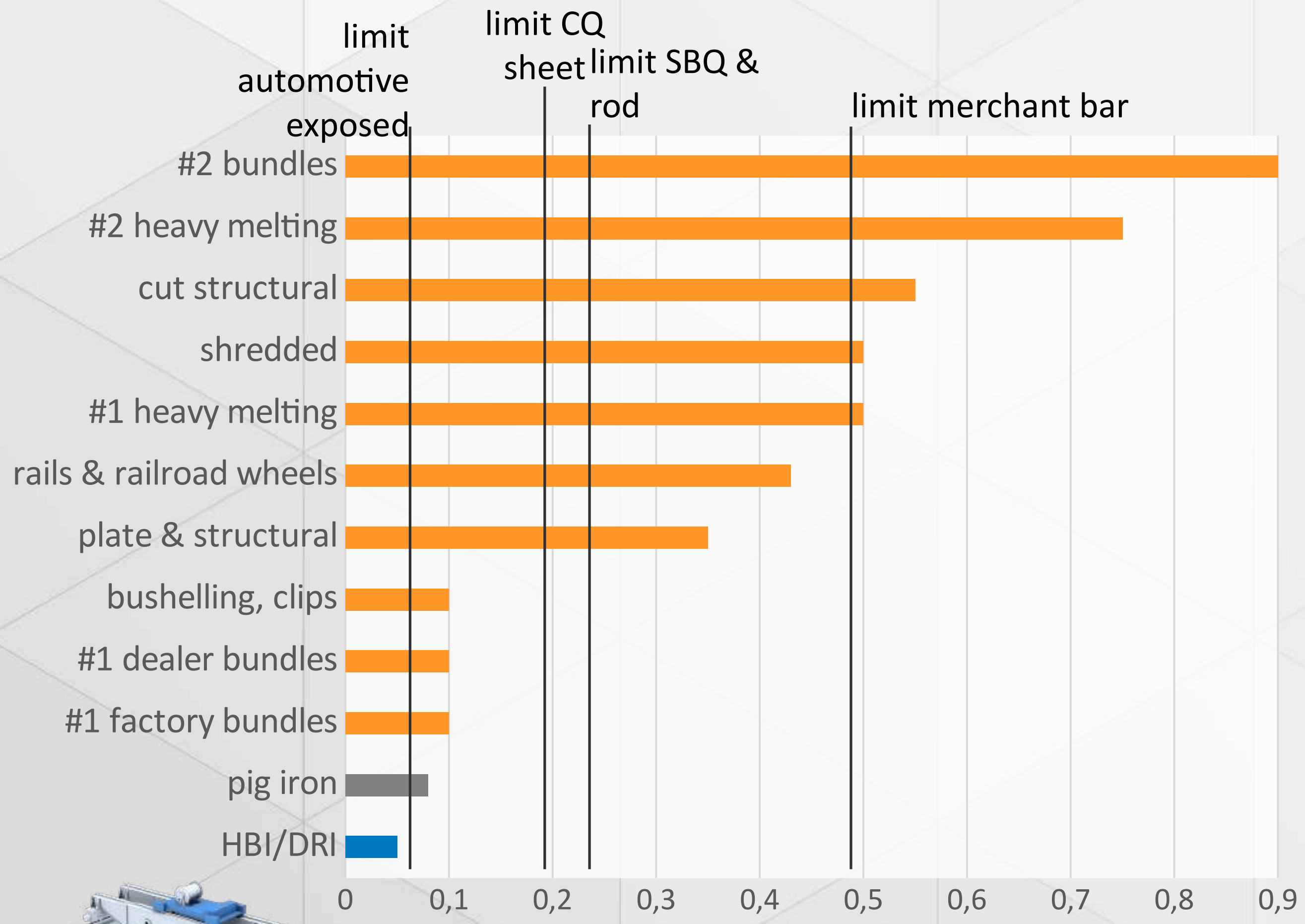
production in million tons per year



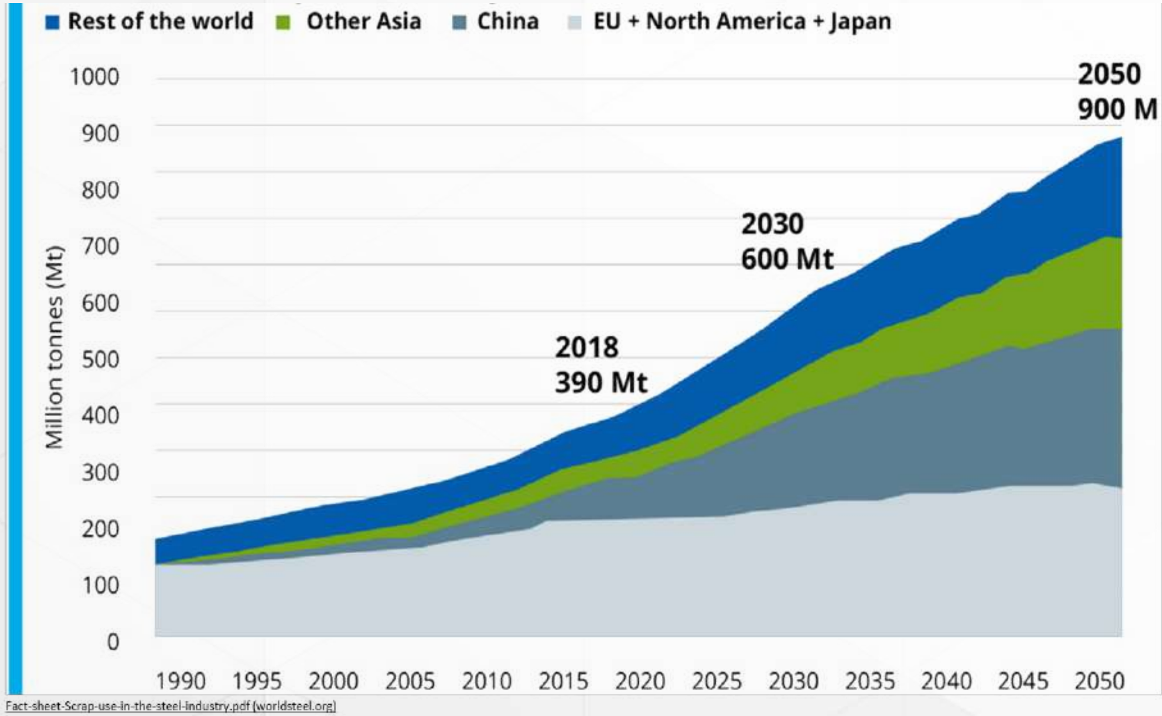
World Steel Association; World Steel in Figures and own analysis

Why Primary steel is so important ? Scrap Quality and Quantity Challenge

Level of residuals found in scrap types (% Cu + Cr + Ni + Mo + Sn)



Forecast of scrap availability

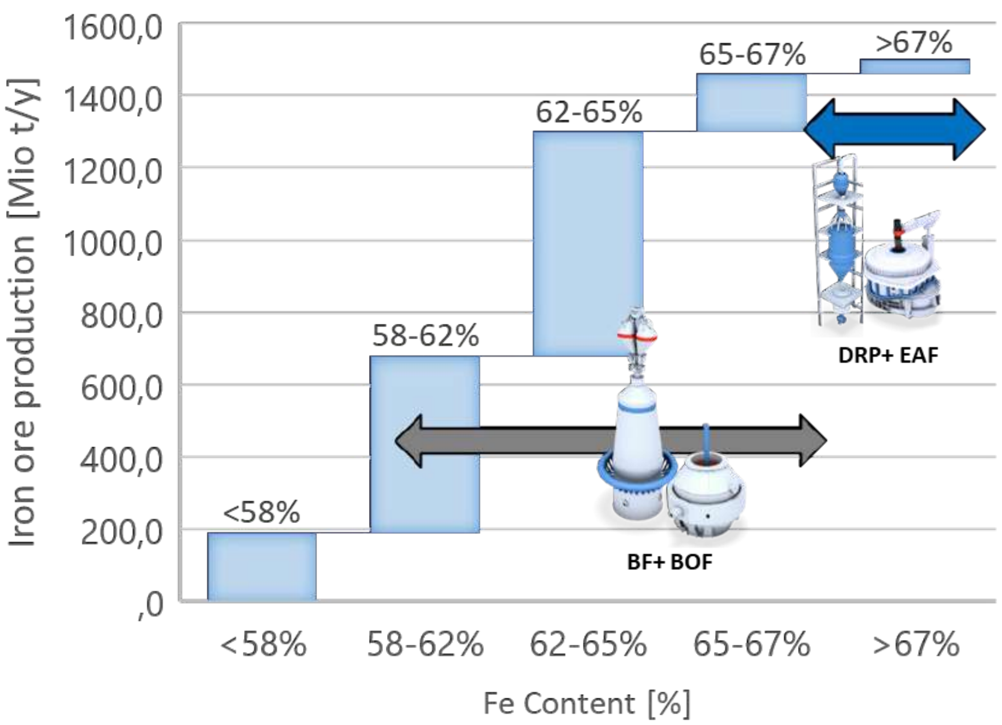


Fact-sheet-Scrap-use-in-the-steel-industry.pdf (worldsteel.org)

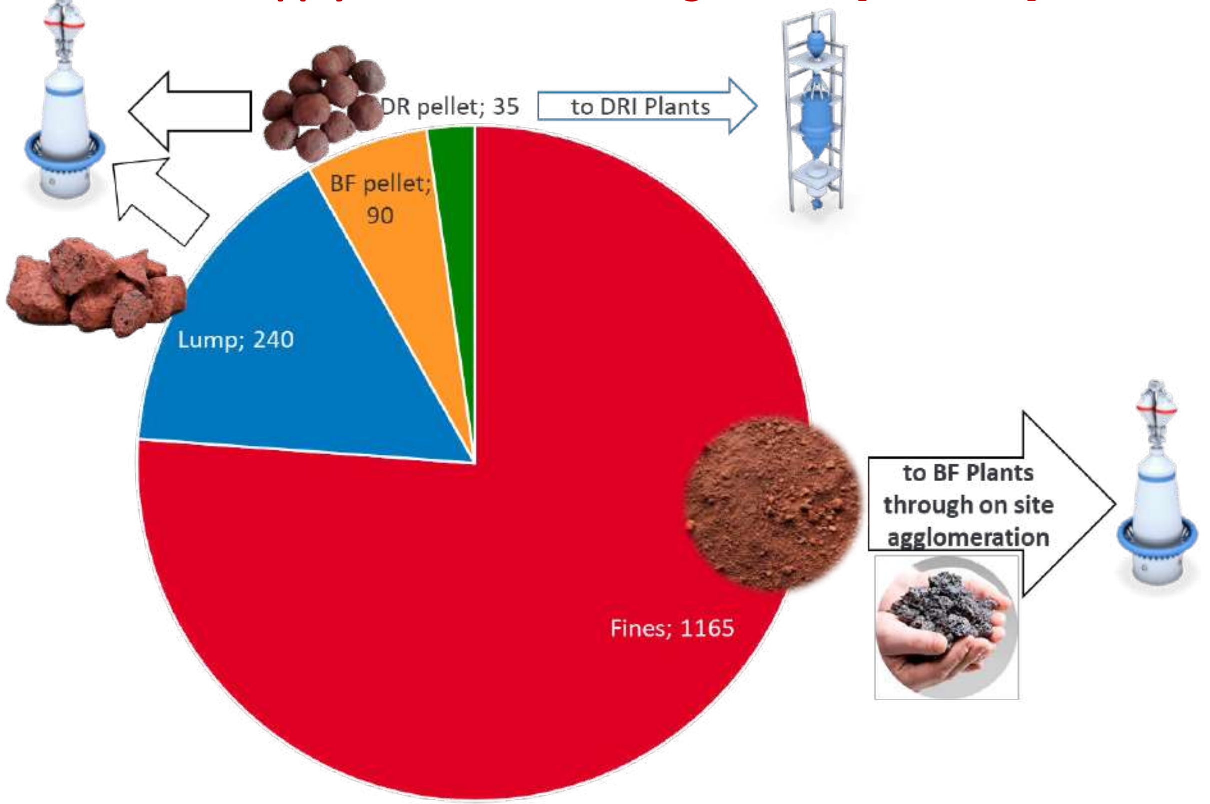
WHY BF COVERS THE MAJORITY OF STEEL PRODUCTION?

+ High **production per unit** (up to 4,5 Mio tpy)
+ Solid fuels allows **independence from energy grids** associated with fluctuating prices and availability issues
+ Very **flexible with respect to input Iron ore features**:
  It can process efficiently lower quality materials (Fe<65%) and fines (with upstream **on site agglomeration**) which are the largest portion of the mined and sea traded iron ores

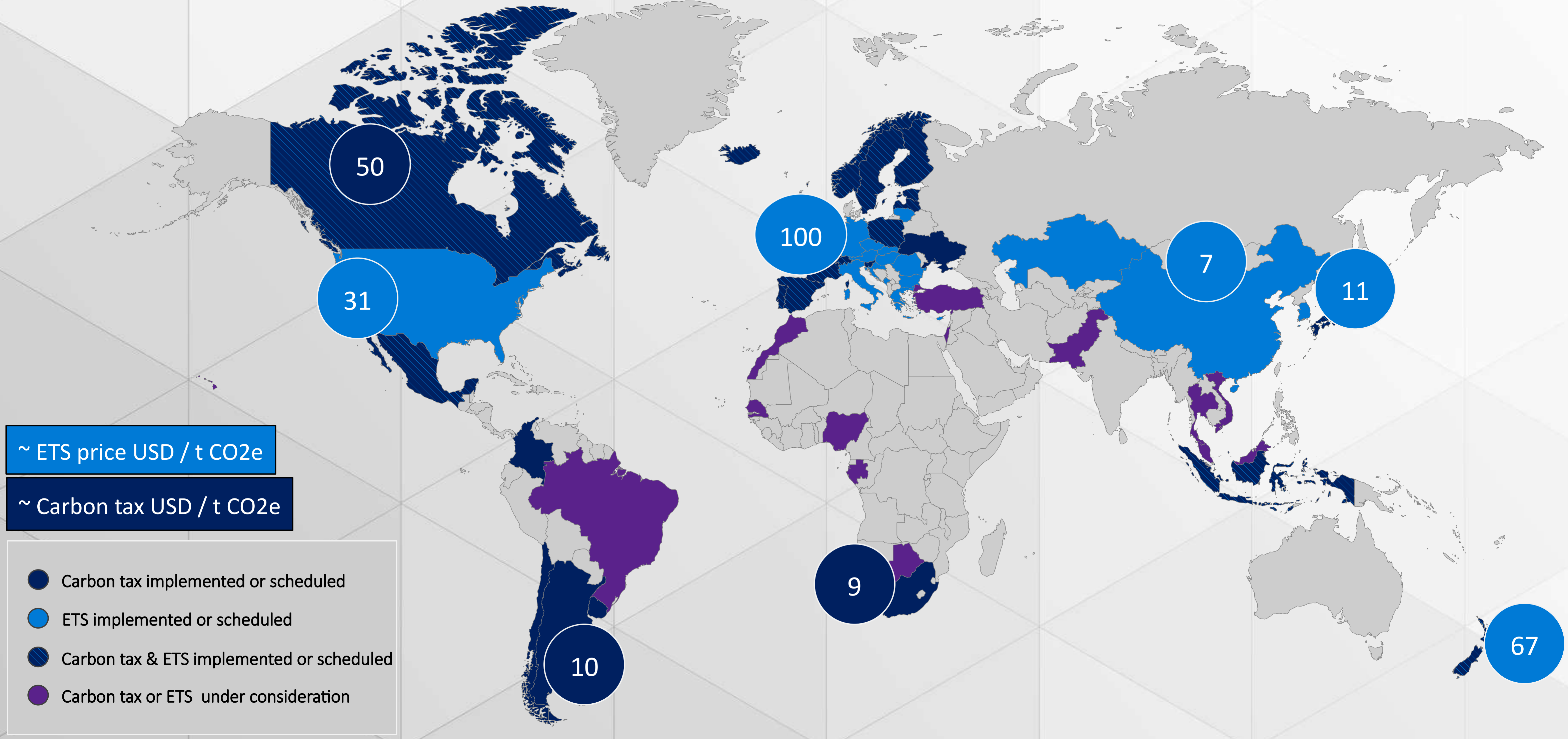
Iron ore production from mines in 2018 vs. Fe % content



Seaborne supply of Iron in 2018 vs grain size [Mio tons]



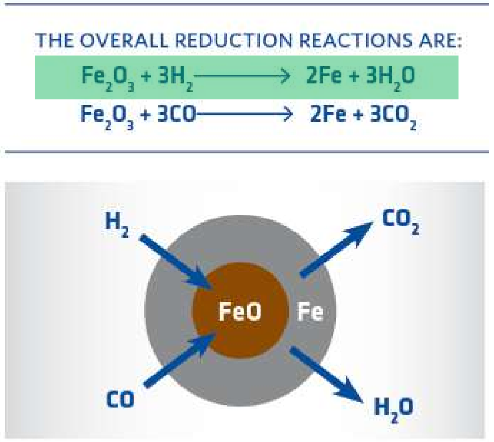
Global CO_2 pricing: different approaches affecting mainly BF based steelmaking

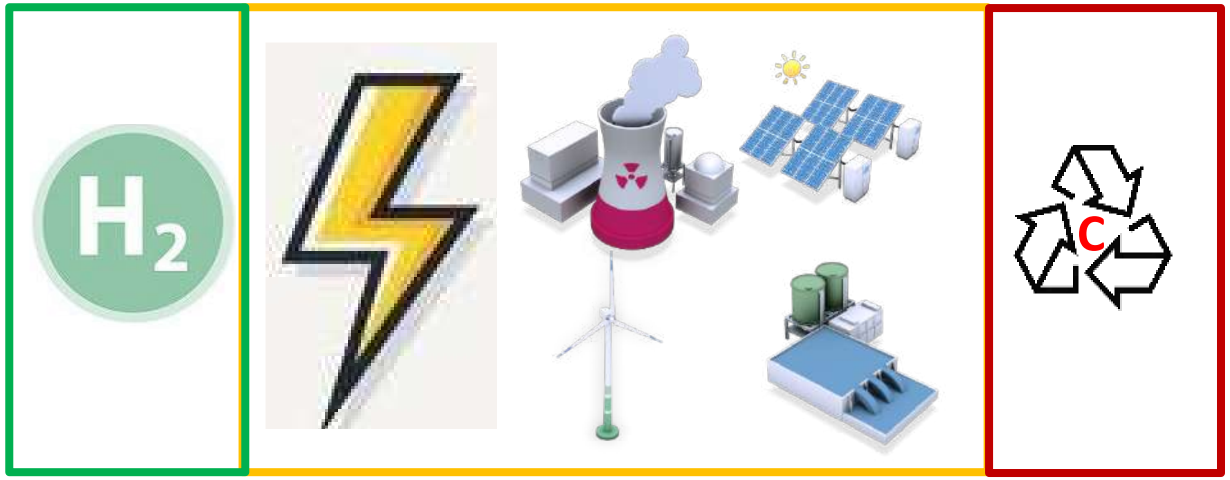


PMI Report 2022 | pmiclimate.org

Why carbon is used in steel production? How can it be replaced?

- **Removal of chemically bounded oxygen** from iron oxides — [Green hydrogen]
- Generation of high **temperature thermal energy** — [Green electricity]
- **Alloy element** : Steel is a solution of C in Fe up to 0,1% — [Circular carbon or Sustainable bio-carbon]
- **Melting process** constraints — [Circular carbon or Sustainable bio-carbon]





For primary steel making, Hydrogen is a chemical reagent, not an energy carrier!

Steel industry without green electrification means de-industrialization !

Circular carbon is needed for the carbon anyhow present in steelmaking

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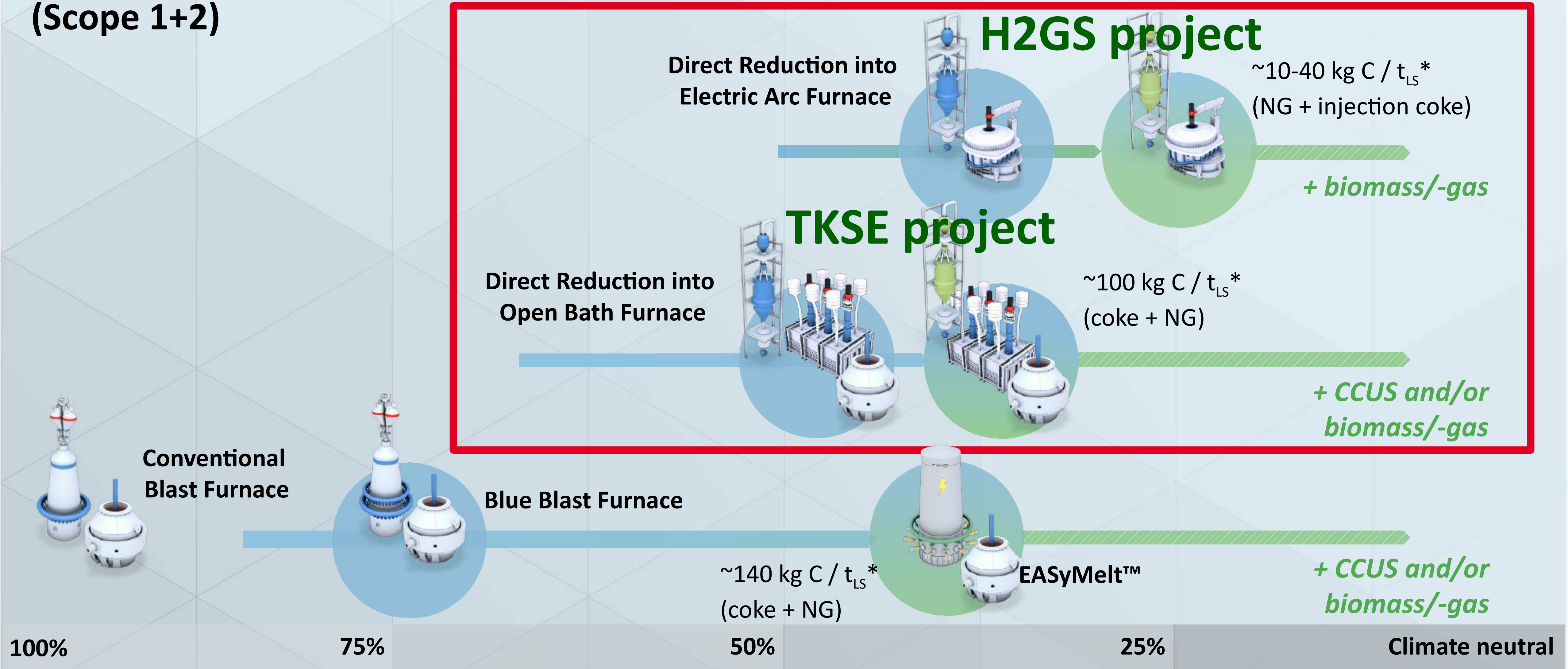
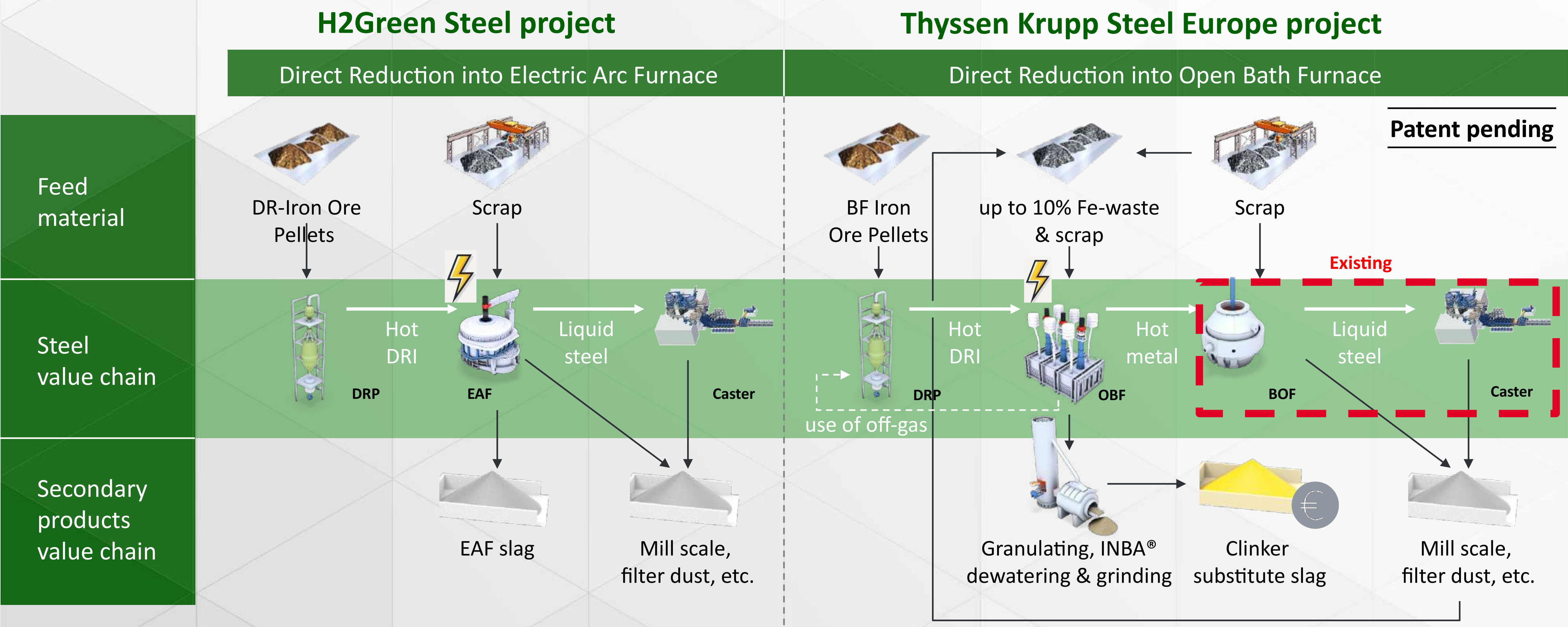
Main decarbonization pathways for primary steel plants-CO_2 emissions mapping (Scope 1+2)



OECD EU-28 emission factor of 80kg CO2/MWh (target 2050)

* corresponds to scope 1 direct carbon input

Direct reduction application to primary steelmaking



DR-IOP: Direct Reduction grade Iron Ore Pellets
BF-IOP: Blast Furnace grade Iron Ore Pellets

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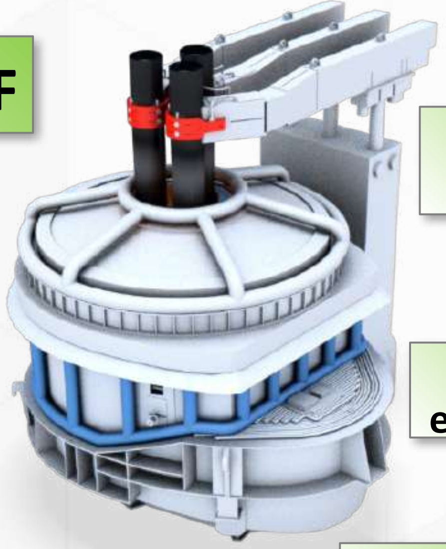
Open Bath Furnace vs Electric Arc Furnace as DRI smelters

Major distinguishing features

EAF

- open to atmosphere → oxidizing environment
- smaller bath surface area → higher power density
- short term vessel and lining philosophy
- concentrated batch feed of materials
- typically graphite electrodes and electrode arms



OBF

- process sealed from surrounding atmosphere → reducing environment
- large bath surface area → lower power density
- long term vessel and lining philosophy
- distributed and continuous material feed
- suspended Söderberg electrode
- continuous "power on"
- simpler secondary power correction
- lower operating resistance

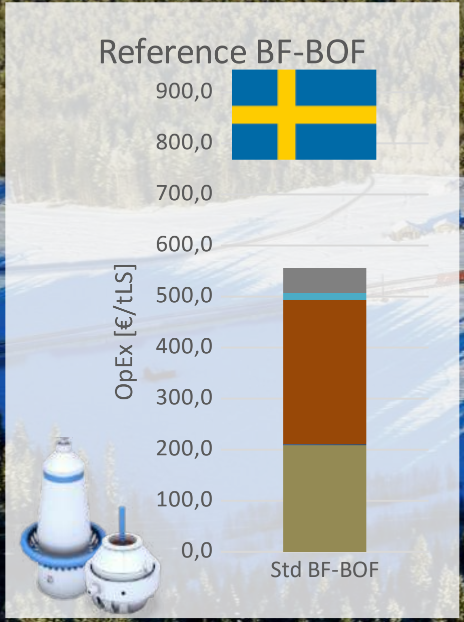
H2 Green Steel

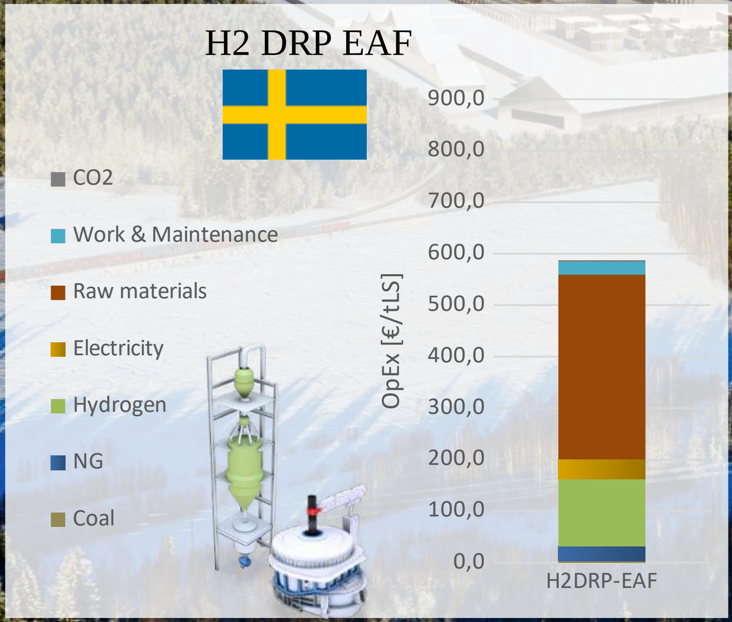
The world's first 100% hydrogen-based integrated steel plant

- **CO_2 emission** reduction up to **95%**
- Based near **Boden, Northern Sweden**
- Start-up of first plant: **2025**
- Capacity of phase 1: **2.5 million t/year,** phase 2**: 5 million t/year**
- **Direct Reduction plant H2 based** supplied by Midrex and Paul Wurth
- SMS group supply from **melt shop to finishing lines**

H2GS project: highlight on OpEx
(internal SMS group evaluation)

Coking coal	€/t	330
BF pellets	€/t	160
DR pellets	€/t	192
Natural Gas	€/MWh	44
Electrical Energy	€/MWh	30
Hydrogen	€/GJ- [€/kg]	23 [2,8]
Sinter Feed	€/t	110
Sized Ore	€/t	150
Fluxes, additivies	€/t	25
Scraps	€/t	550
Workforce	€/h	30
CO_2 price	€/t	100





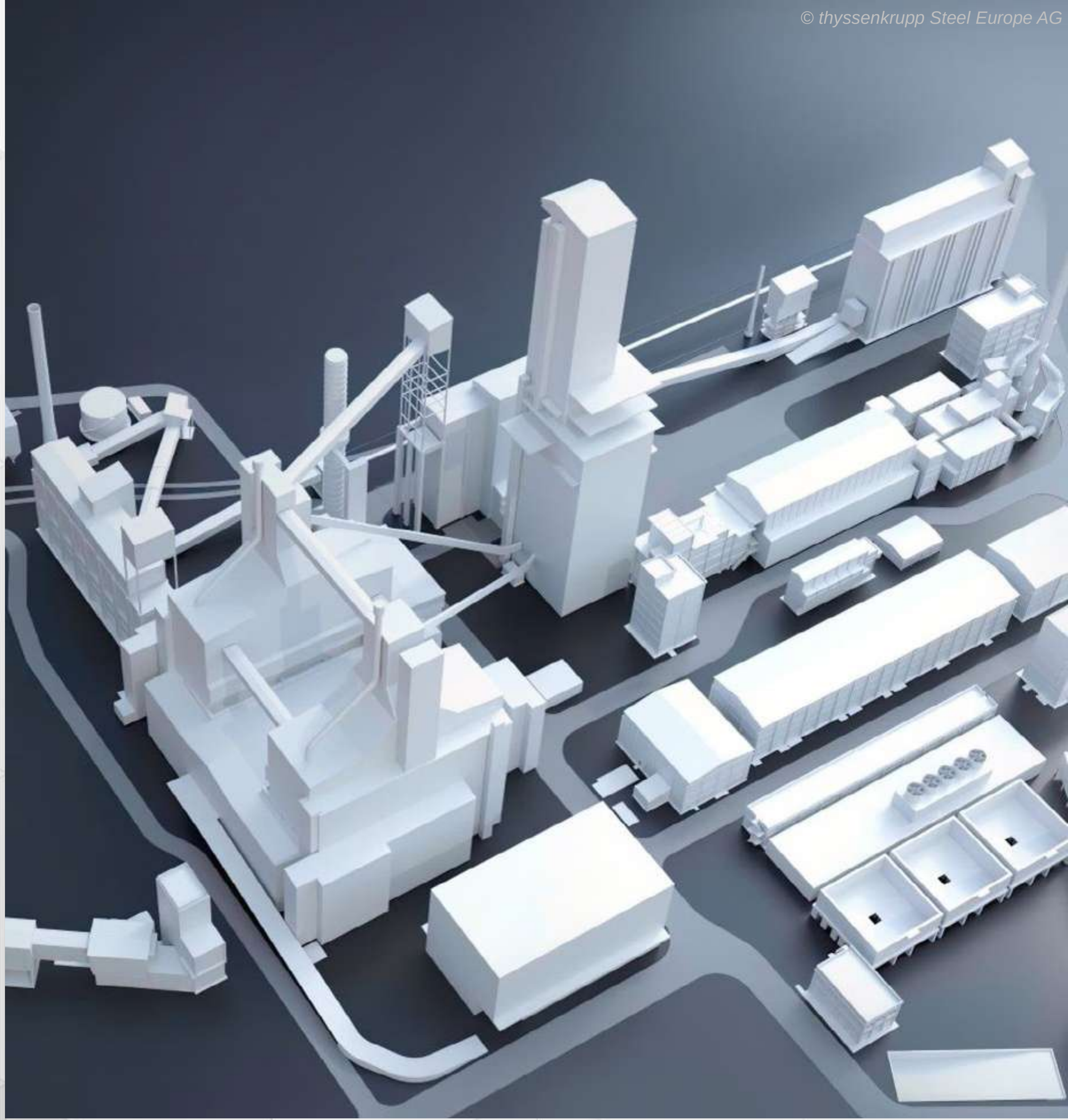
Main Operating data		H2DRP-EAF
Natural Gas	GJ/tls	2,3
Hydrogen	GJ/tls	5,7
Electrical power	kWh/tls	1313
DR grade pellets	t/tls	1,41
EAF Carbon	t/tls	0,01
Scrap	t/tls	0,16
CO_2 emissions	t/tls	0,160
CO_2 free-allocation as per ETS 2025	t/tls	0,138

Pure OpEx considered – no CapEx amortization
tLS= ton of Liquid Steel

ThyssenKrupp Steel Europe Walsum (Germany)
Green Hot Metal project

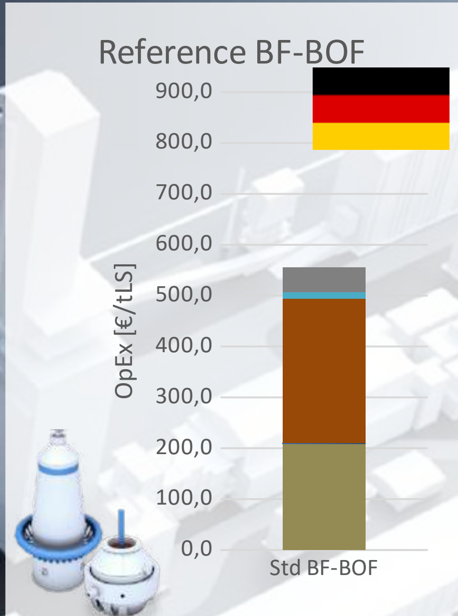
- Annual saving of **over 3.5 million metric tons of CO_2**
- Project CAPEX : >2 billion €
- Location: Duisburg / Germany
- First green Hot Metal: **Q4/2026**
- SMS group covers the **complete process chain** from barges and train unloading until hot iron discharging into torpedo car and until slag sand heap
- Plant designed for up to **100 % H_2 use**

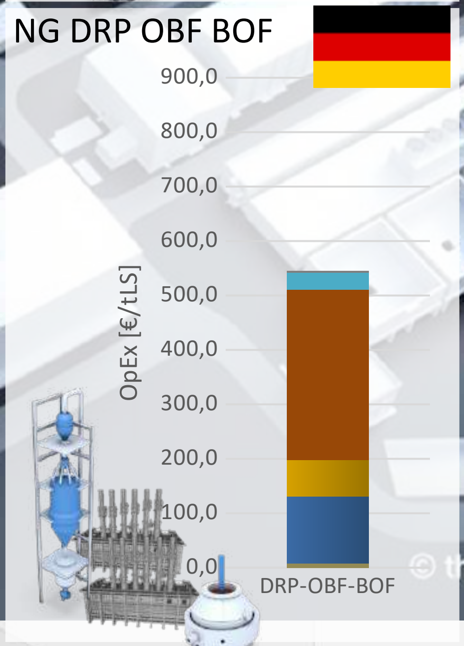
» Paving the way for CO_2-free iron and steel production

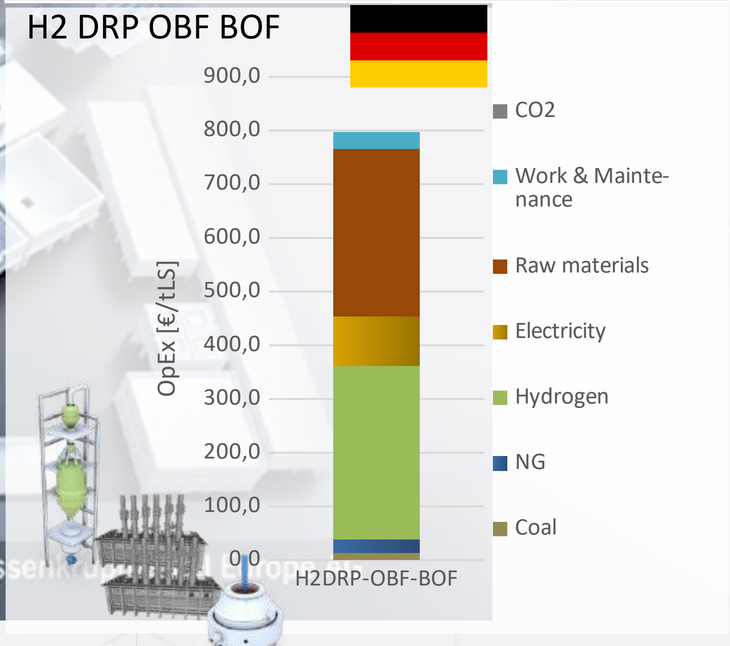


TKSe – DRP OBF highlight on OpEx (internal SMS group evaluation)

LV coking coal	€/t	330
BF pellets premium	€/t	160
DR pellets premium	€/t	192
Natural Gas	€/MWh	44
Electrical Energy	€/MWh	109
Hydrogen (remotely produced)	€/GJ [€/kg]	39 [4,7]
Sinter Feed	€/t	110
Sized Ore	€/t	150
Fluxes, additivies	€/t	25
Scraps	€/t	550
Workforce	€/h	30
CO2 price	€/t	100



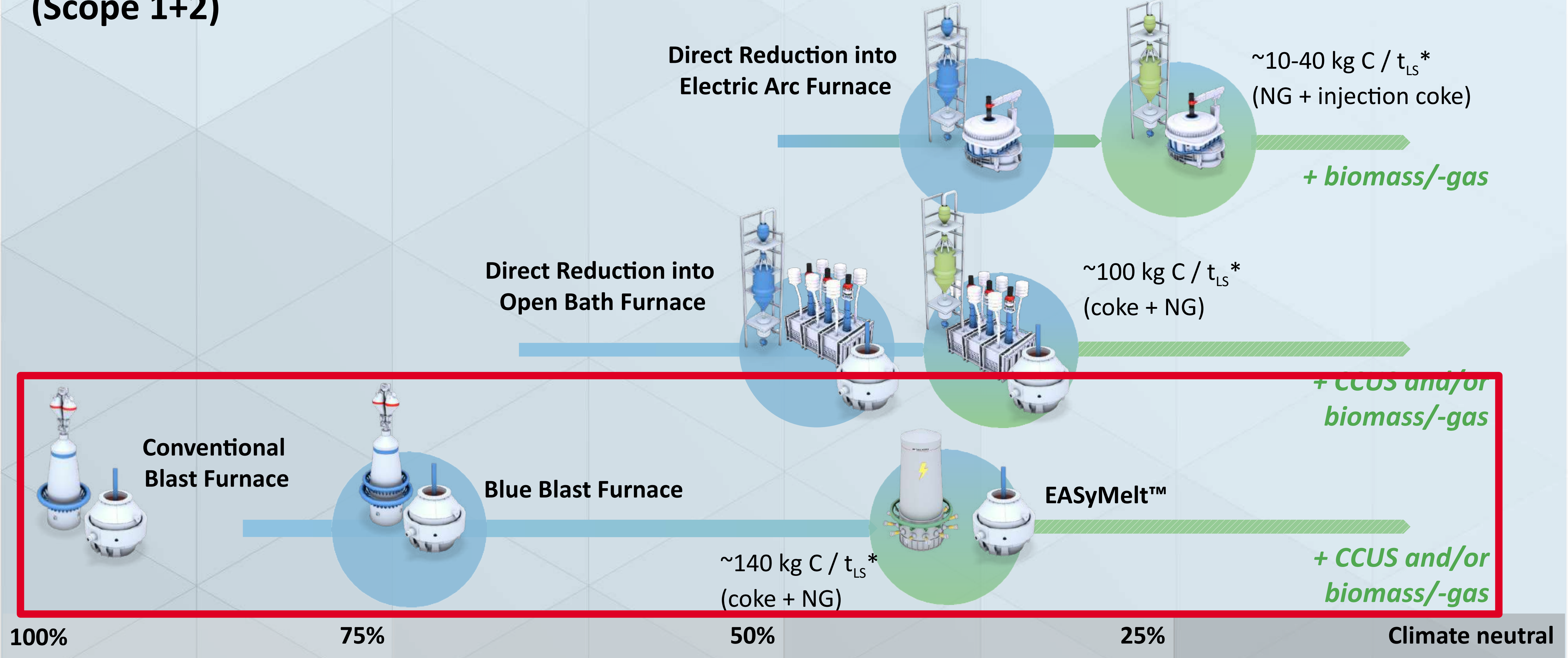




Main Operating data		Ref. BF-BOF	DRP-OBF-BOF	H2 DRP – OBF - BOF
Coal	t/tls	0,630	0	0
Natural Gas	GJ/tls	0,1	10,1	2
Hydrogen	GJ/tls	0	0	8,4
Electrical power	kWh/tls	-90 (export)	830	840
Sinter feed	t/tls	1,06	0	0
Sized Ore	t/ls	0,19	0	0
BF grade pellets	t/tls	0,25	1,39	1,39
Carbon	t/tls	0	0,03	0,045
Scrap	t/tls	0,16	0,16	0,16
CO2 emissions	t/tls	1,931	0,645	0,256
CO2 free-allocation as per ETS 2027	t/tls	1,444	0,611	0,26

Pure OpEx considered – no CapEx amortization
tLS= ton of Liquid Steel

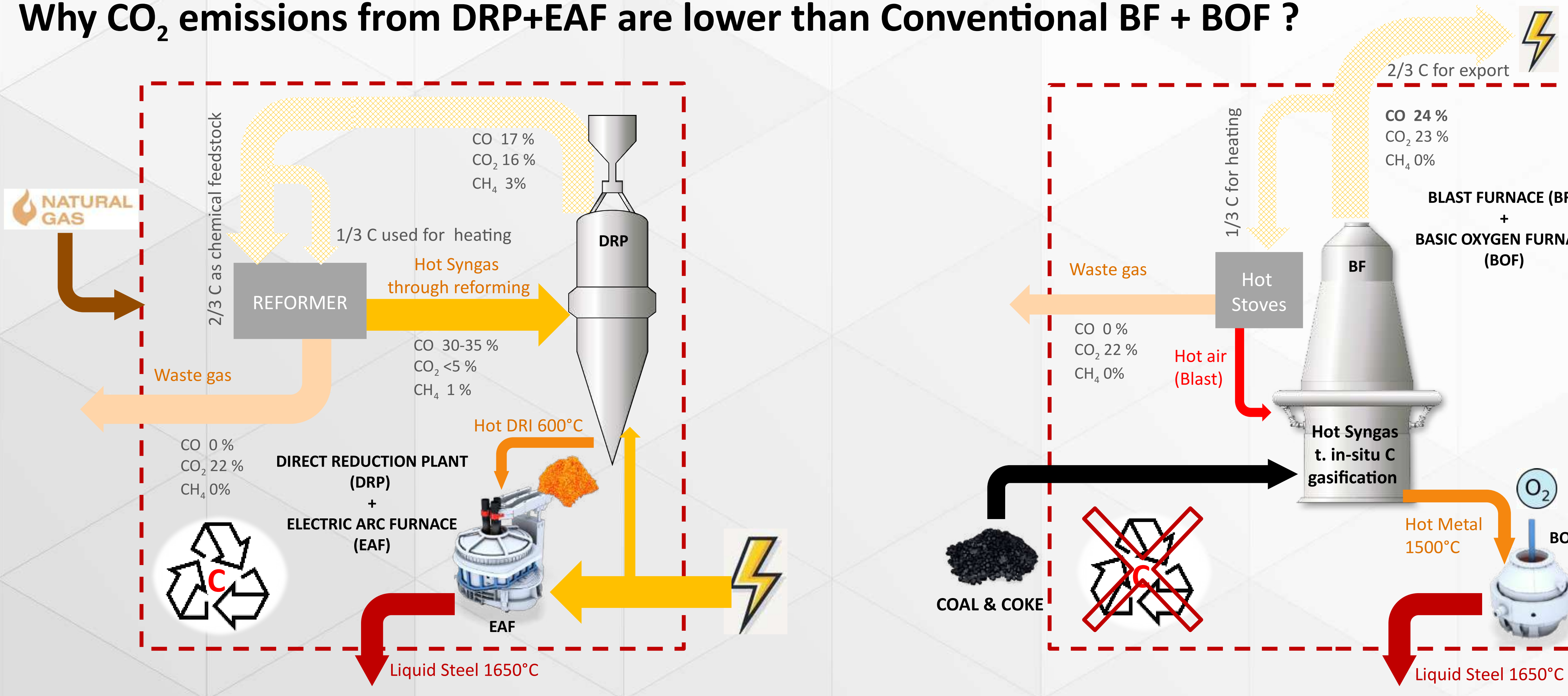
Main decarbonization pathways for primary steel plants-CO_2 emissions mapping (Scope 1+2)



OECD EU-28 emission factor of 80kg CO2/MWh (target 2050)

* corresponds to scope 1 direct carbon input

Why CO_2 emissions from DRP+EAF are lower than Conventional BF + BOF ?



- Circular CARBON concept applied through gas reforming
- All CARBON entering the system exits as CO_2
- External electrical power <u>needed</u> for DRI & smelting

- No circular carbon concept applied
- 40% of the CARBON entering the system is <u>exported as CO</u>
- Iron Ore smelting done through thermal energy
- Credit gas energy [≈ 4 GJ/tLS] used mainly for electricity production

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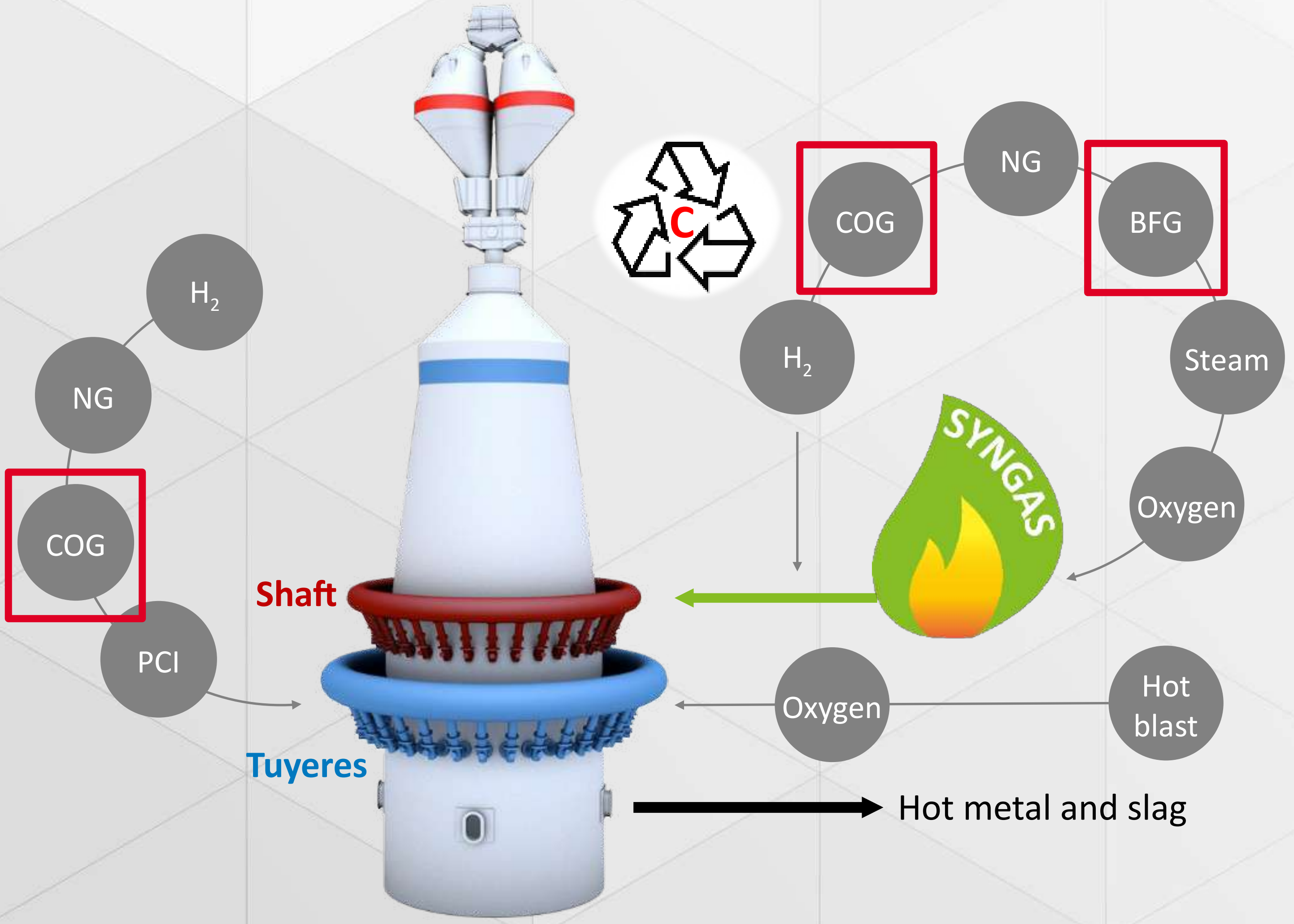
LS= Liquid Steel

Transformation of Blast Furnace Ironmaking

Syngas generated through circular carbon reduces the CO_2 footprint

Patent pending



NG: Natural gas
COG: Coke oven gas
BFG: Blast Furnace gas
PCI : Pulverized coal injection

Blue Blast Furnace

Main feature: Hot syngas shaft injection

- Enabler for higher top gas temperature
- Allows higher amounts of auxiliary fuel injection at tuyere level (e.g. COG, NG, H_2, syngas)
- Efficient H_2 utilization

Main characteristics:

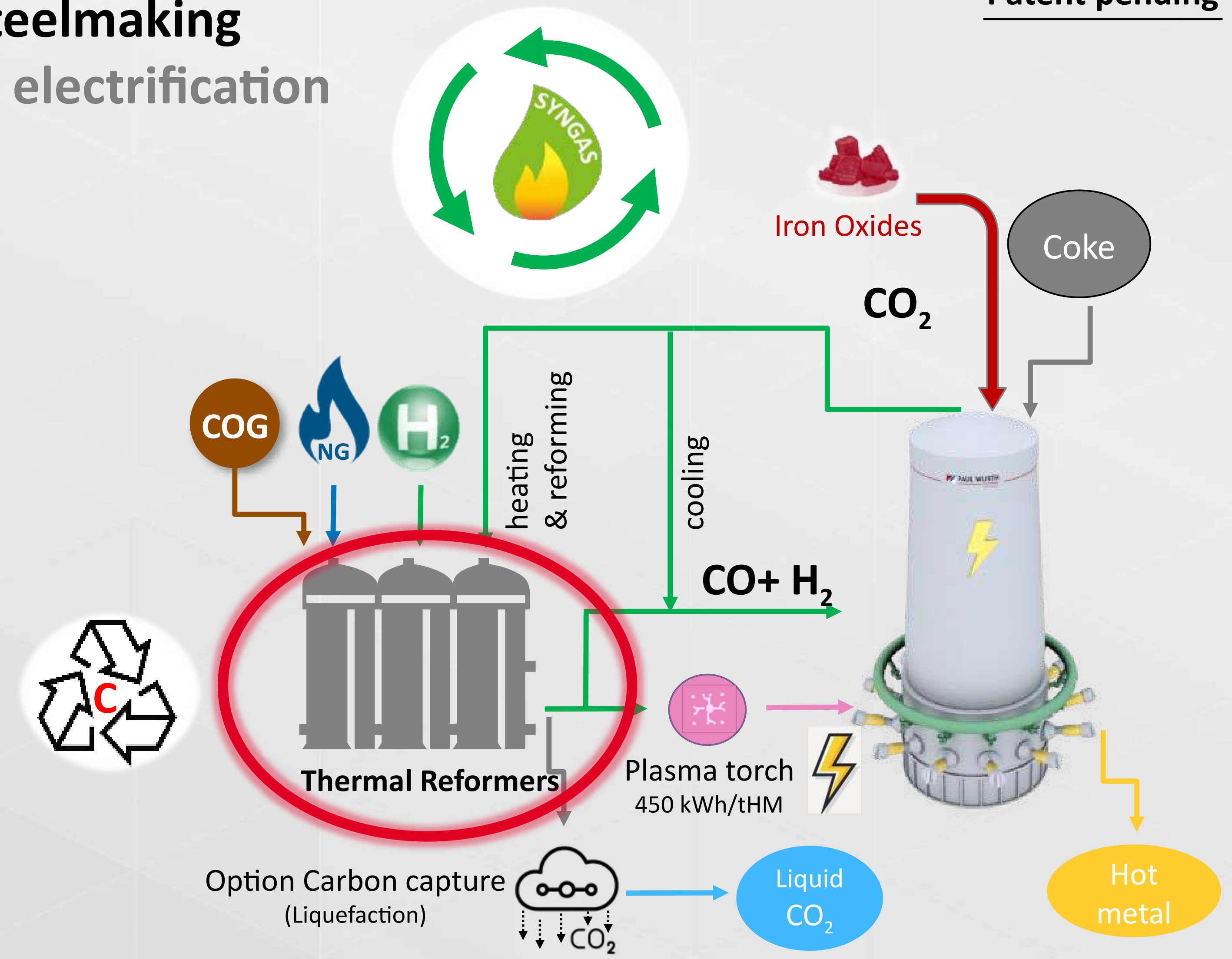
- CO2 emission reduction up to 33% (scope 1)
- Productivity increase due to decreased gas generation at bosh level

Transformation of Blast Furnace based Steelmaking

The next logical step: circular carbon and electrification

EASyMelt™ Electrically Assisted Syngas Smelter

- Novel **technology exploiting existing BF infrastructure**
  - Gas from reactor will be **recycled and valorised** through **reforming** for syngas production with NG and/or COG and/or H_2
  - Hot Syngas injected at lower shaft **and** tuyere level
  - Tuyere level syngas **superheated** to 1750-2200°C by **plasma torch**
  - External reformers **– easy, flexible start-up** (NG/H_2)
- **Minimum CAPEX** to transform existing Blast Furnace plants **(not anymore STRANDED ASSETS!)**



-65% CO_2 emissions vs. standard Blast Furnace without Carbon capture

COG: Coke oven gas
NG : Natural gas

External reformers new technology (Regenerative heat exchangers)

- **Successful pilot plant testing** using **BFG** and **COG**

> Dry reforming **without catalyst**
>
> $\mathbf{CO_2 + CH_4 \longrightarrow 2\,CO + 2\,H_2}$

BFG: Blast Furnace gas
COG: Coke oven gas

- high conversion $\mathbf{X_{CH4} > 98\%}$
- **high syngas quality** obtained

	Input	Output
CH_4	10%	0.2%
CO_2	7.3%	0.5%
H_2	29%	42%
CO	19%	30%
N_2	29%	27%
H_2O	5%	1%
	3.9	**48**

Patent pending

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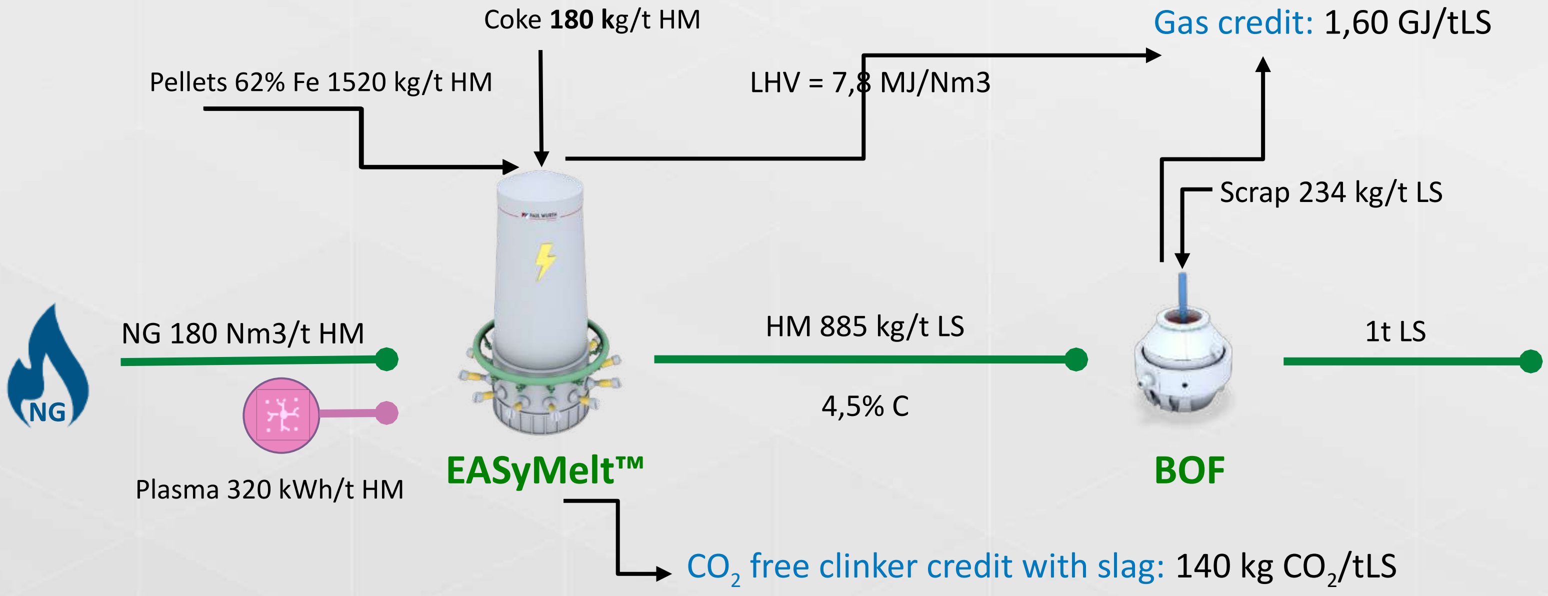
Patent pending

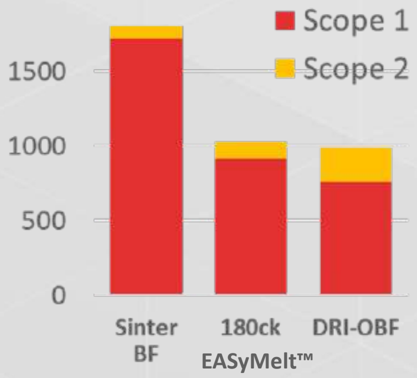
EASyMelt™ 180 kg coke rate without H_2



CO_2 emissions [kg/t LS]

	scope 1	scope 2
coke	54	2
BF	850	95
BOF + sec. met.	8	18
overall	**912**	116

OECD EU-28, emission factor of 300kg/MWh (target 2030)



› **Only 43 kg or 5% higher emissions than NG-DRI/OBF route**

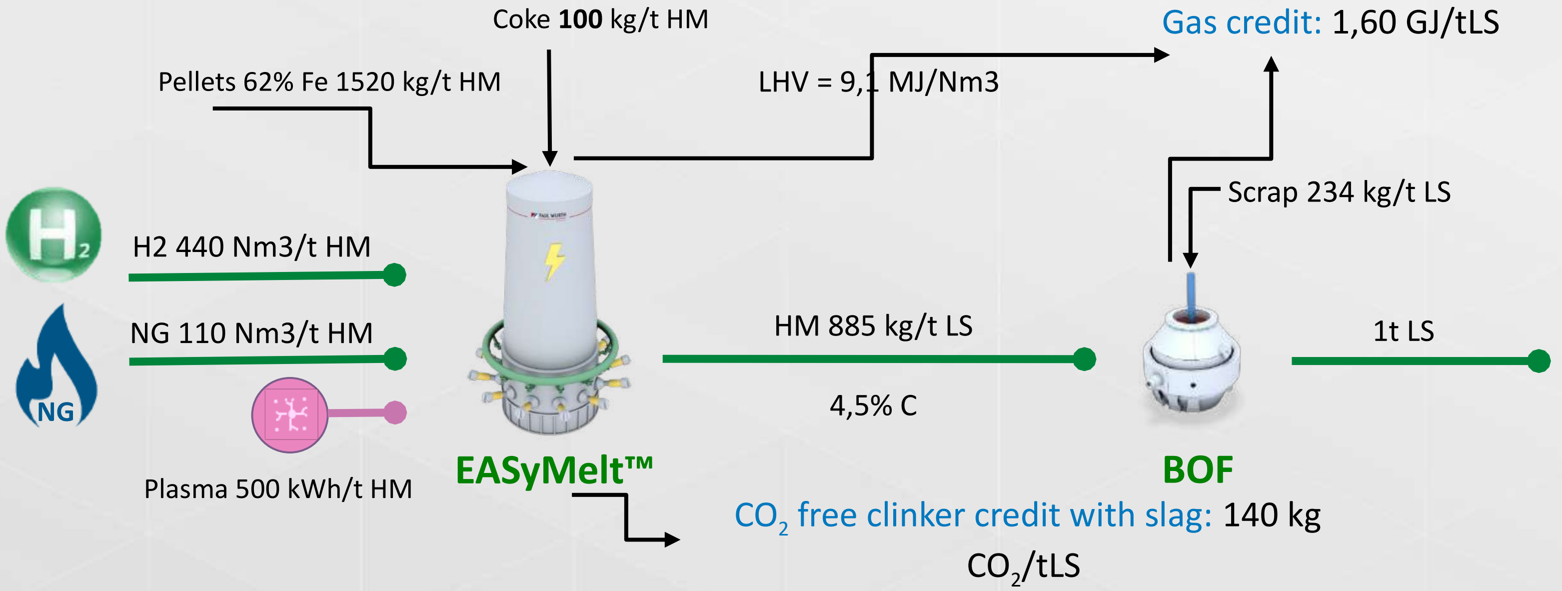
CO_2

1028 kg/t LS
-43%

NG= Natural gas
t HM= ton of Hot Metal
t LS= ton of Liquid Steel

Patent pending

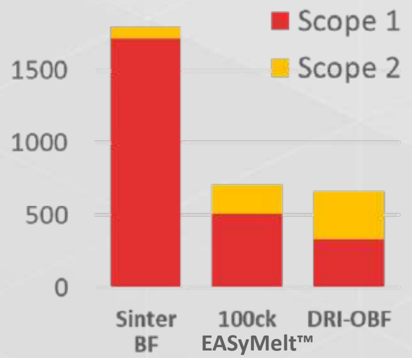
EASyMelt™ 100 kg coke rate with H_2



CO_2 emissions [kg/t LS]

	scope 1	scope 2
coke	30	1
BF	475	193
BOF + sec. met.	7	5
overall	**512**	199

OECD EU-28, emission factor of 80kg/MWh (target 2050)



› **Only 47 kg or 2,5% less reduction in CO_2 compared to H2-DRI/OBF route**

CO_2

711 kg/t LS

-61%

NG= Natural gas
t HM= ton of Hot Metal
t LS= ton of Liquid Steel

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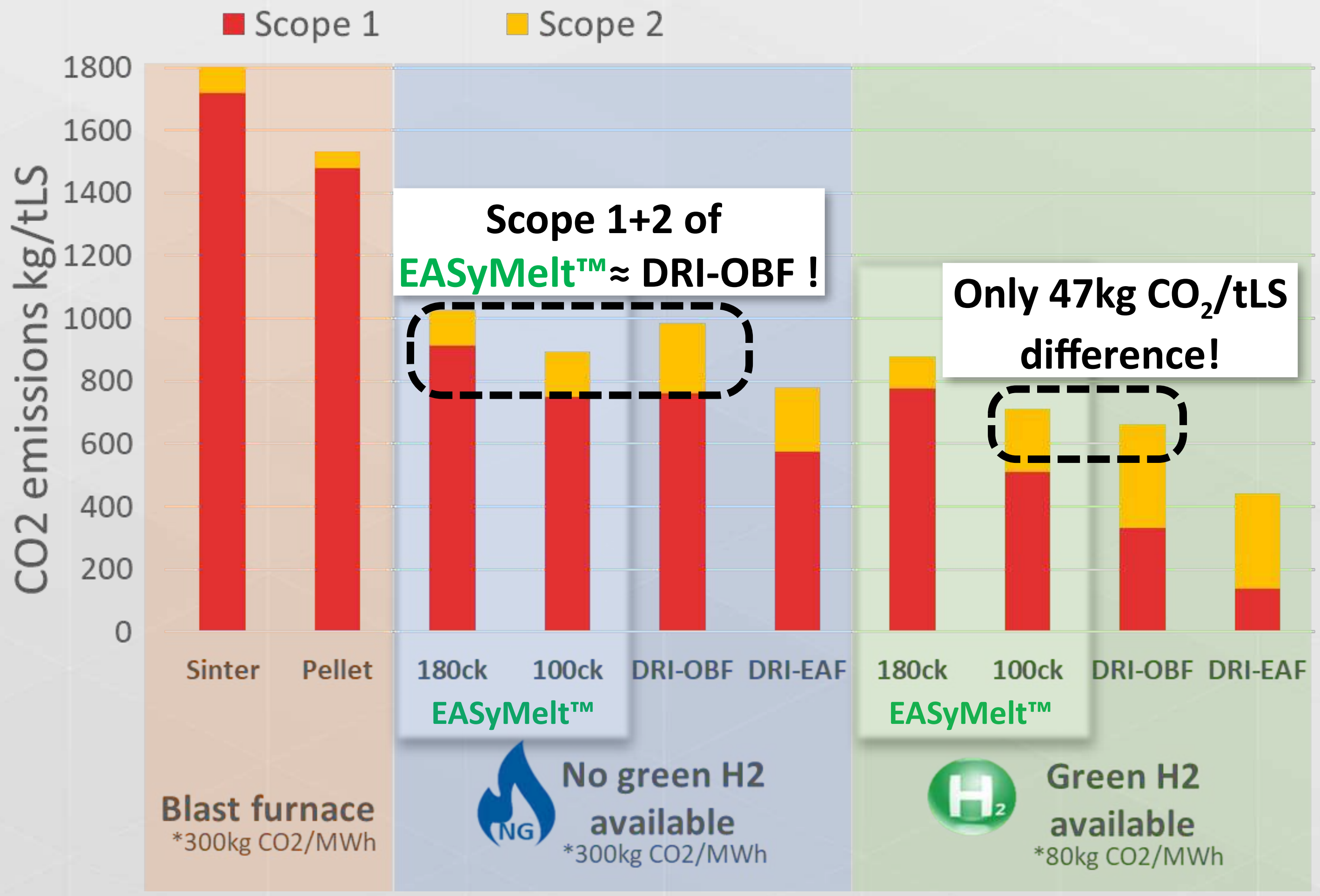
EASyMelt™ : Comparison of specific CO_2 emissions (kg/t LS)



› **EASyMelt™** has a **very similar CO_2** reduction **to DRI-OBF** in both scenarios!

t LS= ton of Liquid Steel

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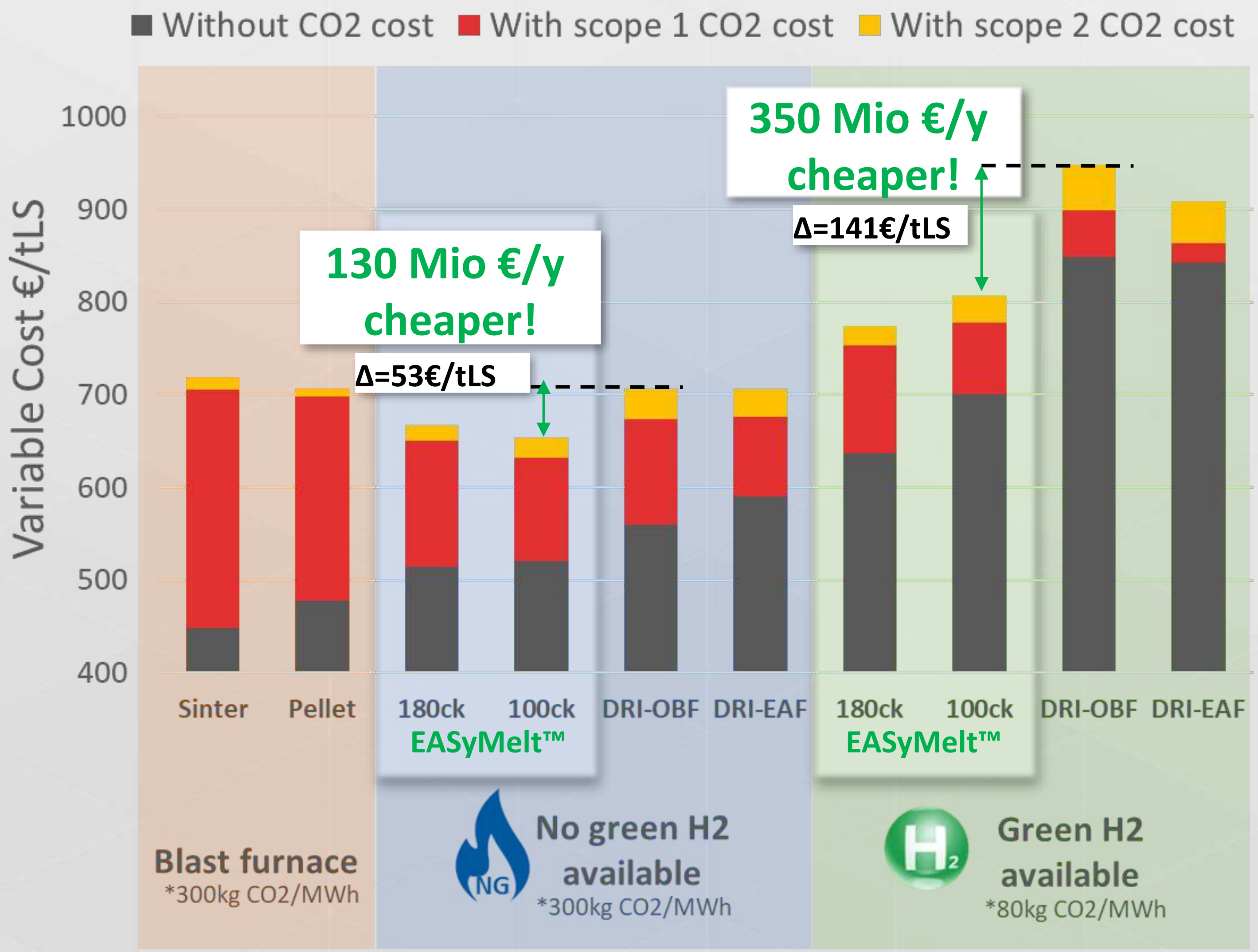
EASyMelt™ : Variable costs (2.5 million t_LS/yr production)



t LS= ton of Liquid Steel

Prices used for cost calculation

CO2 emission electricity*	kg/MWh	300 / 80
Coking coal	$/t	300
Electricity	€/MWh €/GJ	100 28
Hydrogen	€/GJ [€/kg]	50 [4,7]
Natural gas	€/GJ [€/MWh]	12 [44]
BF pellets premium	$/t	75
DR pellets premium	$/t	100
Scrap	€/t	450
CO2 cost	**€/t**	**150**

The EASyMelt™ has the lowest OPEX

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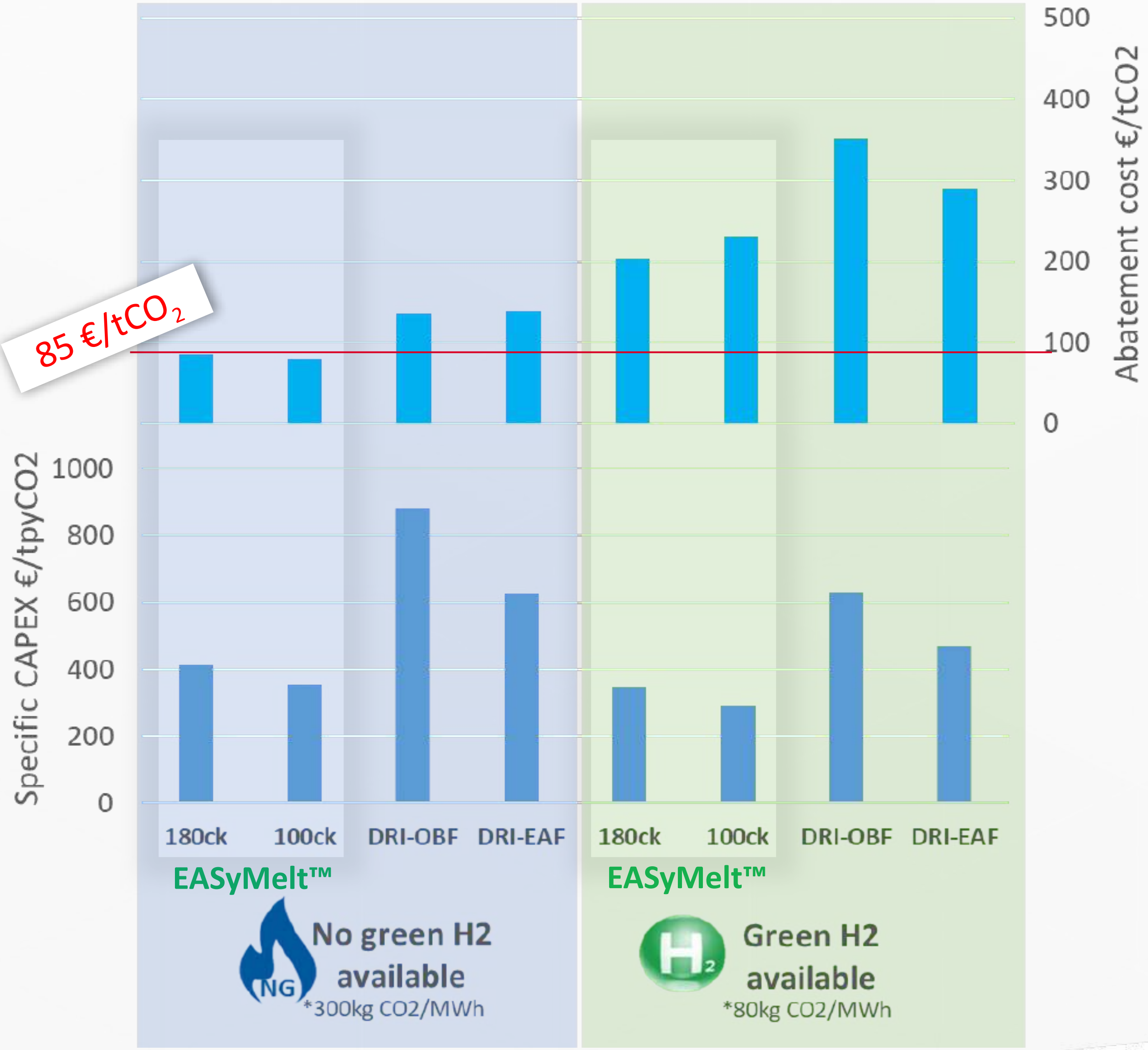
EASyMelt™ : CO_2 abatement cost efficiency

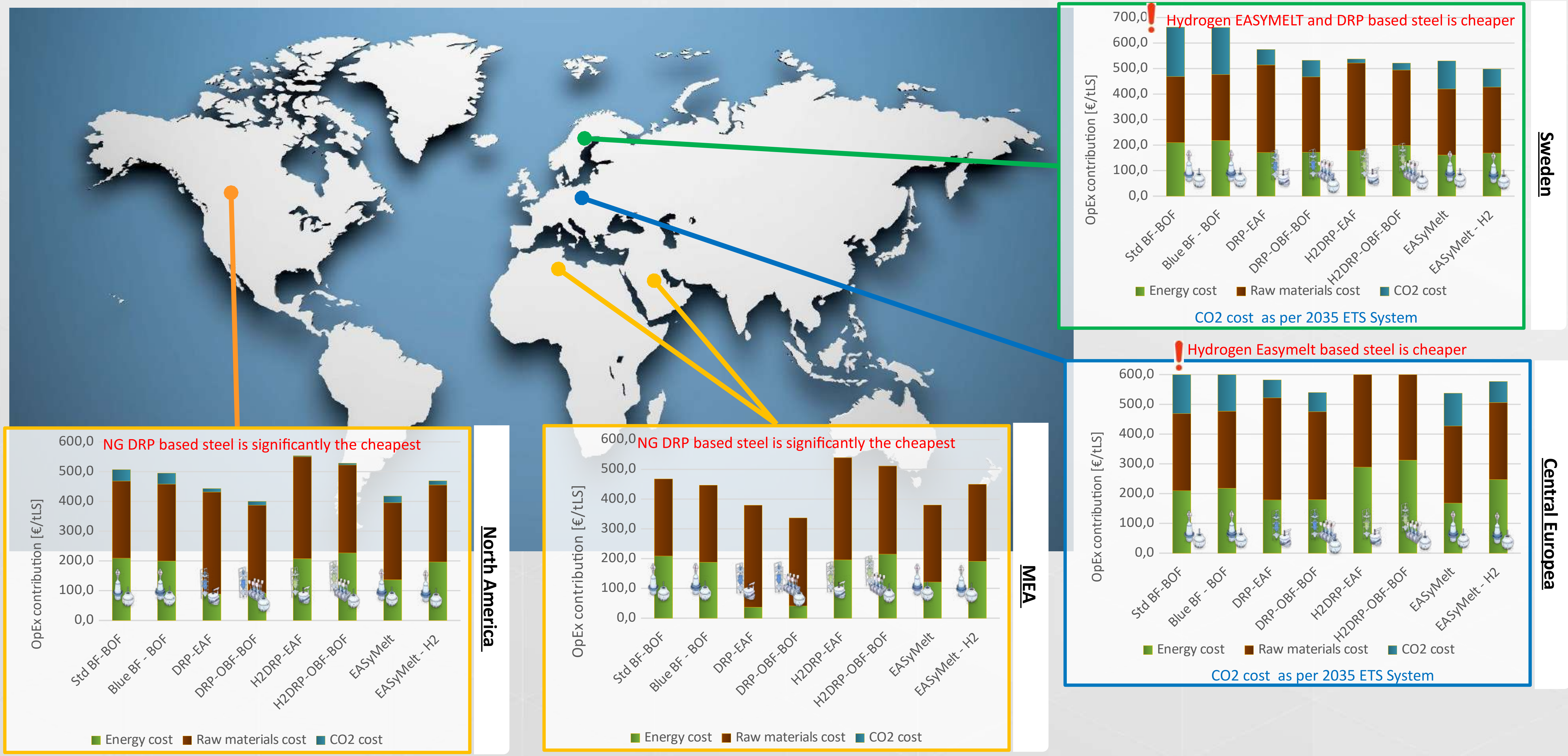


Cost used for OPEX calculation

CO2 emission electricity*	kg/MWh	300 / 80
Coking coal	$/t	300
Electricity	€/MWh €/GJ	100 28
Hydrogen	€/GJ [€/kg]	50 [4,7]
Natural gas	€/GJ [€/MWh]	12 [44]
BF pellets premium	$/t	75
DR pellets premium	$/t	100
Scrap	€/t	450
CO2 cost	**€/t**	**150**

- By far lowest CO_2 abatement cost
- Overall **best financial** option!

OpEx – Overall comparison considering site specific costs and different technologies



Decarbonisation of primary steel: Main Takeaways

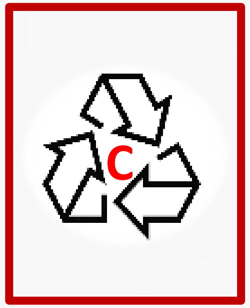
Available technologies

Direct Reduction +EAF/OBF

Blue Blast Furnace + BOF

EASyMelt™ + BOF

Enabling factors



Specific geographical constraints

Raw materials availability

CO2 cost

Energy cost

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