TATA STEEL
#WeAlsoMakeTomorrow

IIM Metallurgy Materials Engineering

tenova

International Conference on
GREEN & SUSTAINABLE IRON MAKING
January 17 - 18, 2024

Direct Reduced Iron and its future in Steelmaking: Tenova iBlue®

The use of Hydrogen for Green Steel Production

Praveen Chaturvedi
TENOVA

S7: H2 / CCU

17th-18th January 2024 at United Club, Jamshedpur

Techint Group

OUR FAMILY

USD **33.6** billion
Annual Revenues

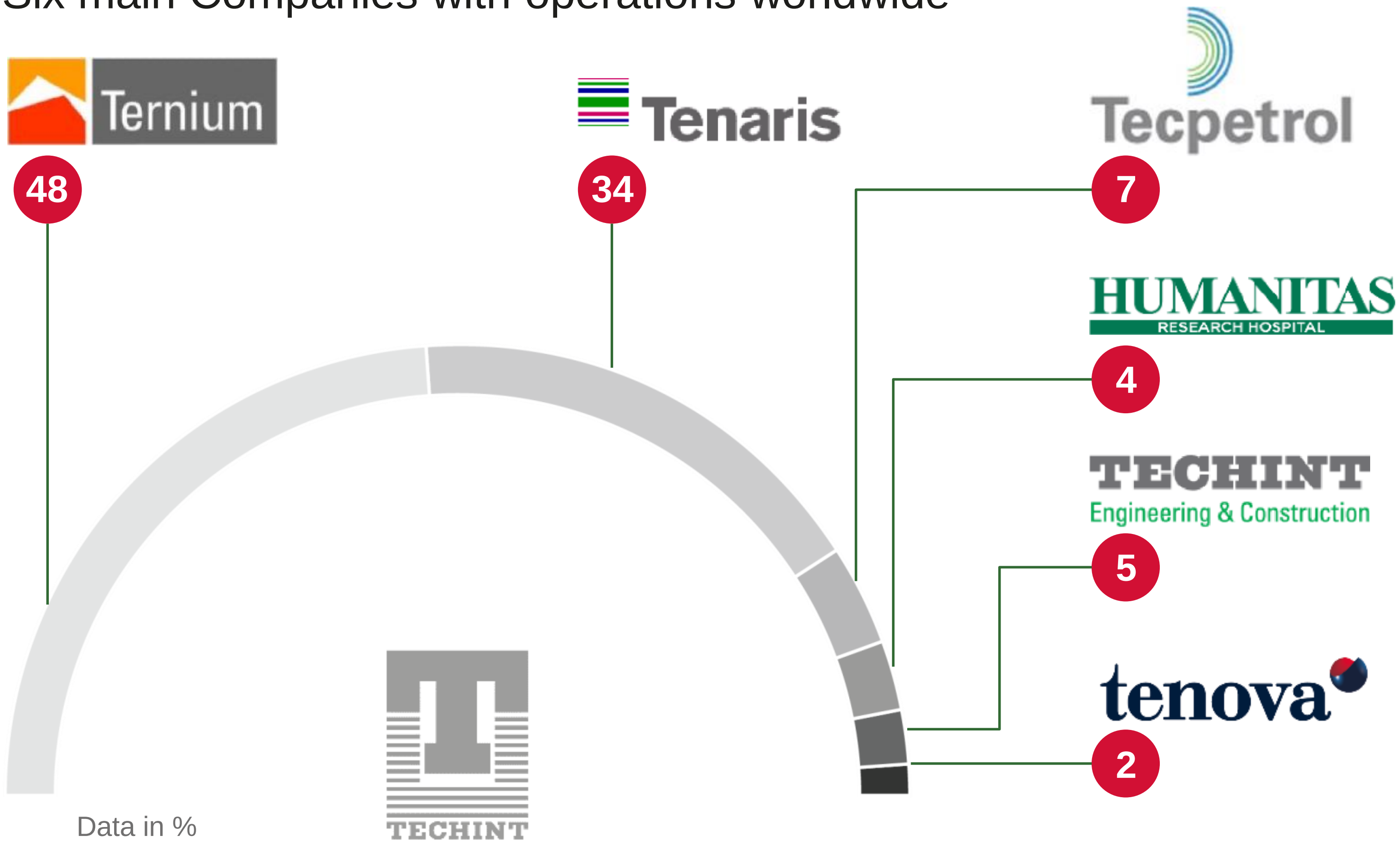
60,000
Permanent Employees

79,300
Total Employees

5
Continents

Revenues as of December 31, 2022

Six main Companies with operations worldwide



Top 50 steel-producing companies 2022

tenova

million tonnes, crude steel production

Rank	Company	Tonnage
1	China Baowu Group [1]	131.84
2	ArcelorMittal [2]	68.89
3	Ansteel Group [3]	55.65
4	Nippon Steel Corporation [4]	44.37
5	Shagang Group	41.45
6	HBIS Group	41.00
7	POSCO Holdings	38.64
8	Jianlong Group	36.56
9	Shougang Group	33.82
10	Tata Steel	30.18
11	Shandong Steel Group	29.42
12	Delong Steel	27.90
13	Hunan Steel Group [5]	26.43
14	JFE Steel Corporation	26.20
15	JSW Steel Limited	23.38
16	Nucor Corporation	20.60
17	Fangda Steel	19.70
18	Hyundai Steel	18.77
19	Liuzhou Steel	18.21
20	IMIDRO [6]	18.00 [e]
21	SAIL	17.93
22	Cleveland-Cliffs	16.80
23	NLMK	16.00 [e]
24	Rizhao Steel	15.63
25	CITIC Pacific	15.03
26	Techint Group	14.86
27	U. S. Steel	14.49
28	Shenglong Metallurgical	14.21
29	Baotou Steel	14.18
30	Jingye Group	13.97
31	China Steel Corporation	13.96
32	Sinogiant Group	13.95
33	Tsingshan Holding	13.92
34	Gerdau S.A.	13.90
35	EVRAZ	12.50 [e]
36	Zenith Steel	12.23
37	Shaanxi Steel	12.17
38	MMK	11.69
39	Anyang Steel	11.18
40	Sanming Steel	11.03
41	Nanjing Steel	11.00
42	Severstal	10.69
43	thyssenkrupp	9.93
44	Steel Dynamics, Inc.	9.73
45	Donghai Special Steel	9.65
46	Jiuquan Steel	9.01
47	Jindal Steel and Power	8.01
48	Erdemir Group	7.79
49	Jinxi Steel	7.43
50	voestalpine Group	7.42

worldsteel ASSOCIATION

Sustainability CHAMPIONS

worldsteel ASSOCIATION

The ten steel-producing companies recognised as the 2023 Steel Sustainability Champions for their work in 2022 are:

ArcelorMittal	HBIS Group Co., Ltd.	HYUNDAI Steel Company	JFE Steel Corporation
JSW Steel Limited	Nippon Steel Corporation	POSCO Holdings	Tata Steel
Tenaris	Ternium		

Sustainable Solutions for Metals and Mining

WHO WE ARE

Tenova, a Techint Group Company, is your worldwide partner for **sustainable, innovative and reliable solutions in the metals and** – also through the well-known TAKRAF and DELKOR brands – in the **mining** industries. We design and develop solutions that help companies to:

REDUCE COSTS

SAVE ENERGY

LIMIT ENVIRONMENTAL IMPACT

IMPROVE WORKING CONDITIONS

Global Footprint

tenova

OUR WORLD PRESENCE

19
COUNTRIES

34
LOCATIONS

Sustenovability

OUR APPROACH

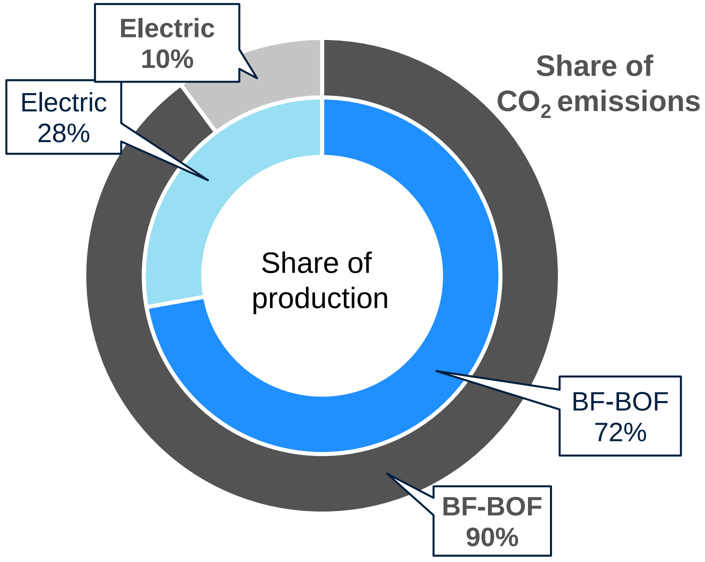
Sustenovability is a neologism that embodies the perfect blend between the Tenova Brand, its eco-friendly values and its capacity to **deliver sustainable solutions**

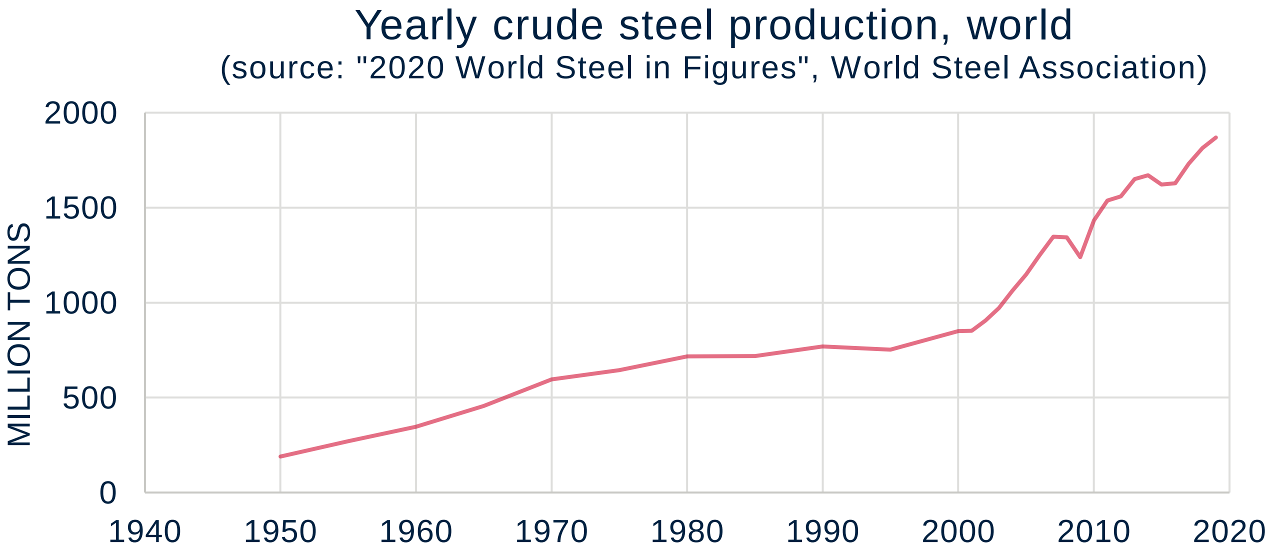
sustenovability.

sustenovability.tenova.com
is a new web platform featuring stories, best practices and case studies that highlight how Tenova is living up to its commitment towards sustainability

Different routes, different CO_2 footprint

STEELMAKING ACCOUNTS FOR 31% OF TOTAL CO_2 INDUSTRIAL EMISSIONS.



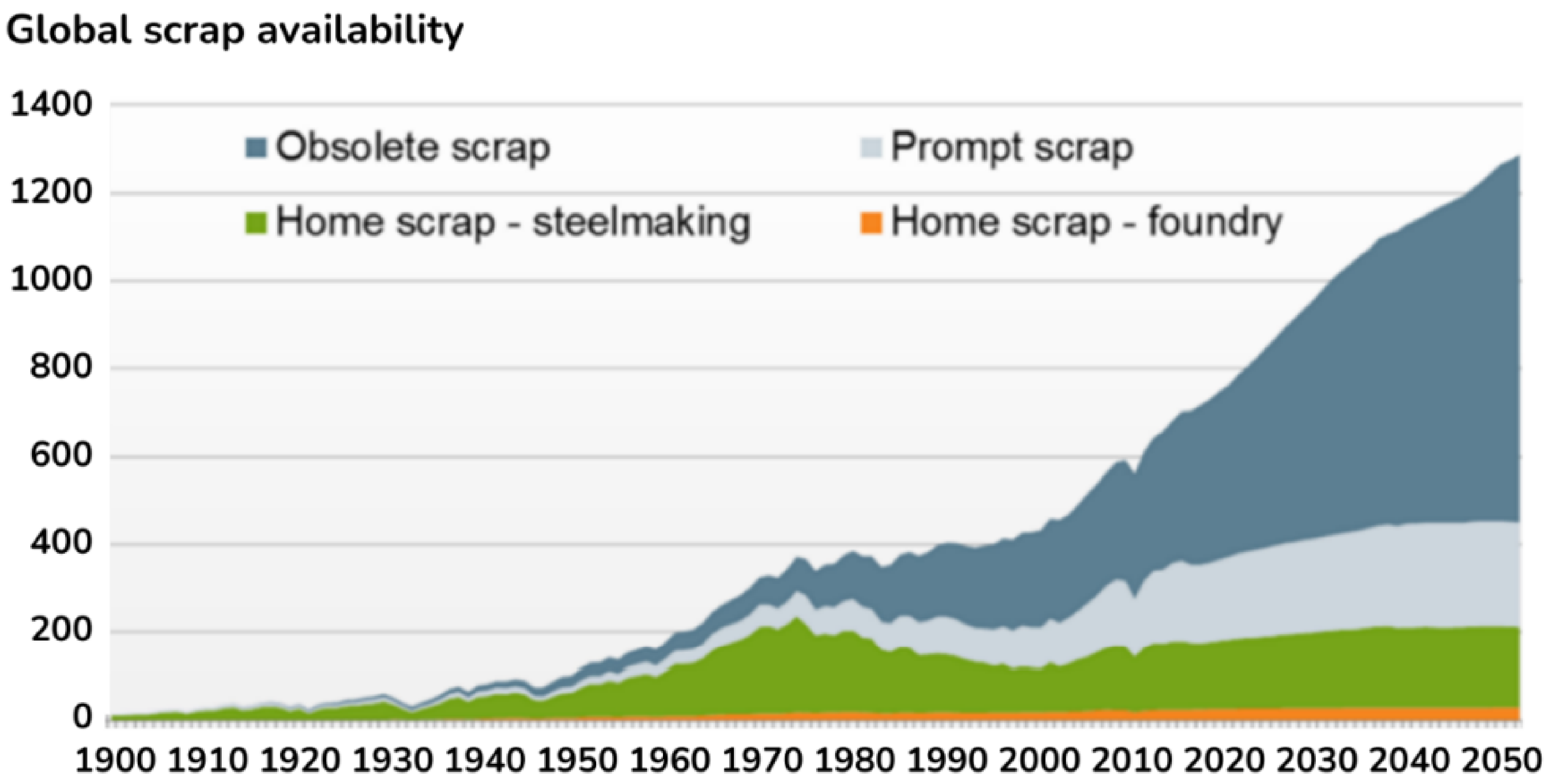


tCO_2/ton (tot. crude steel)	BF/BOF min	BF/BOF max	EAF min	EAF max
IEA 2003	1.62	2.2	0.56	0.91
Carbon Trust 2011	1.8	3	0.2	0.4
EUROFER 2015	1,876		0,410	

Source: author's own elaboration of data from Carbon Trust. (May 2011). Steel. London, UK: International Carbon Flows and de Beer, J., Harnisch, J., & Kressemeeckers, M. (Oct 2003). Greenhouse Gas Emissions from Steel Production. Greenhouse Gas R&D Programme: International Energy Agency - Greenhouse Gas R&D Programme

Global scrap availability

Increase of volumes, but lower qualities



Source: World Steel Association

Cannot do without virgin iron units

LIMITATIONS ON CONTENT OF TRAMP ELEMENTS IN LIQUID STEEL FOR SOME PRODUCTS

Concentration of tramp elements in scrap is increasing, and incompatible with many high-quality steel grades, so dilution with virgin iron (HBI, DRI, Hot Metal, Pig Iron) is needed.

			Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Cu content range (liquid steel)	**ppm**		<500	700-1000	1000-1500	1500-2000	2500-3000
Cu content target (liquid steel)	**ppm**		450	850	1250	1750	2750
Design charge mix		**Cu content**	**Grade 1**	**Grade 2**	**Grade 3**	**Grade 4**	**Grade 5**
Bushelling (E2, E8)	%	1000ppm	12%	7%	18%	25%	0%
Obsolete scrap, heavy melting (HMS1)	%	2500ppm	0%	0%	0%	0%	0%
Obsolete scrap (E1)	%	3500ppm	5%	18%	13%	19%	50%
Obsolete scrap, heavy melting (HMS2)	%	4000ppm	1%	1%	1%	1%	1%
Collected scrap(EHRB)	%	4500ppm	0%	0%	9%	14%	15%
Internal return	%	1500ppm	4%	4%	4%	4%	4%
HBI	%	0	48%	41%	25%	8%	0%
Pig Iron	%	0	30%	30%	30%	30%	30%
EAF output data			**Grade 1**	**Grade 2**	**Grade 3**	**Grade 4**	**Grade 5**
Tap to tap	[min]		46	46	46	46	46
Electrical consumption	[kwh/ton]		404	398	387	377	368
Electrode consumption	[Kg/ton]		1,18	1,16	1,14	1,11	1,10
Oxygen consumption	[Nm3/ton]		39,2	38,8	36,9	35,1	35,6
Carbon consumption	[Kg/ton]		12	12	12	12	12
Natural gas consumption	[Nm3/ton]		2,5	2,5	2,4	2,3	2,3
Lime	[kg/tls]		33,8	32,5	28,8	28,8	28,1
Dololime	[kg/tls]		13,8	15,6	15,6	15,0	12,5

Technological innovations

tenova

IRON AND STEELMAKING EVOLUTION TRENDS

- Energy sources
- Technologies in use (in EU)
- Technologies available (word wide)
- Technologies under development

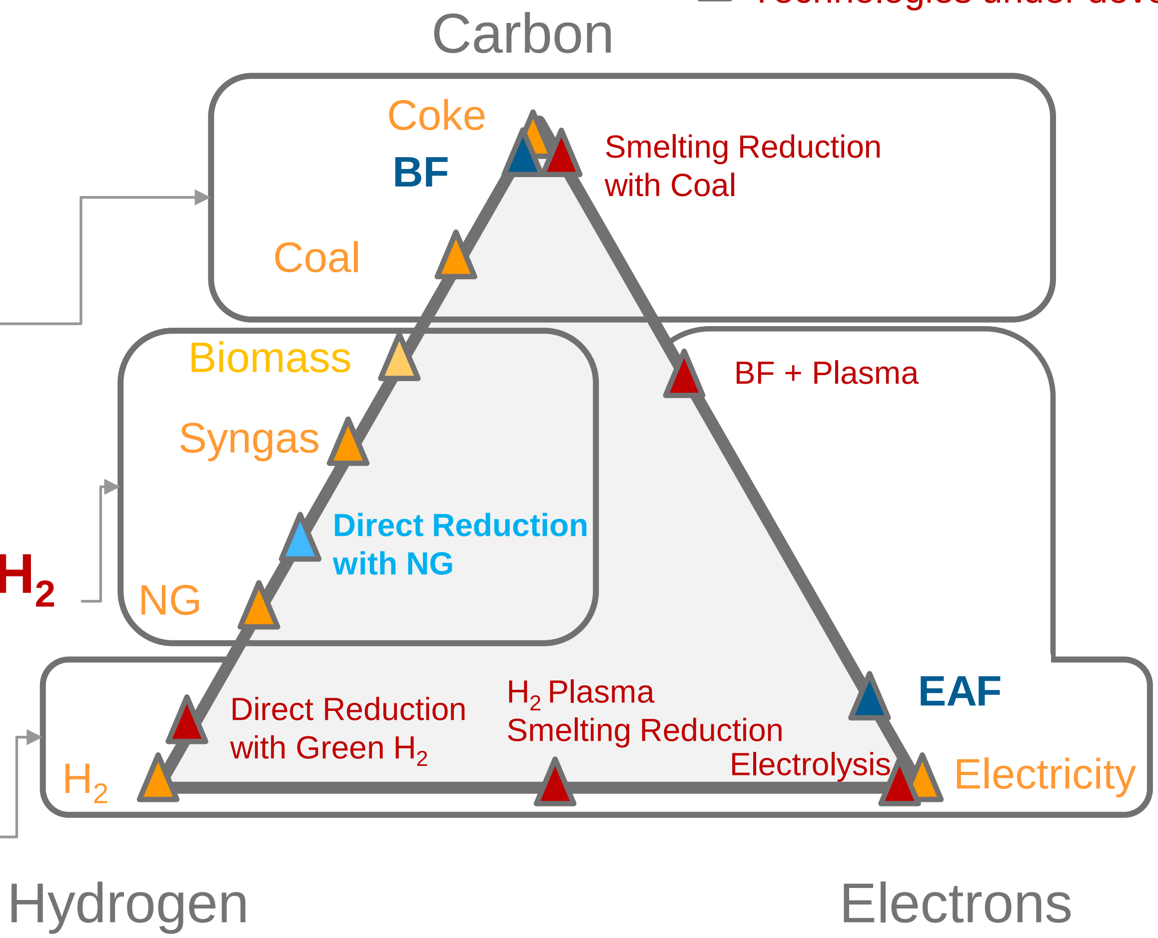
SCU
Smart Carbon Use

COAL (biomass)
+ CCS/CCU
Carbon capture and utilization/
Carbon capture and storage

CDA
Carbon Direct Avoidance

NG/Syngas (biogas)/H_2
+ CC embedded

ELETRIC ENERGY
Renewables / GreenH_2



The unique features that make ENERGIRON® the preferred **DRI technology** towards **sustainability**

DRI Technology Characteristics for Green Steel

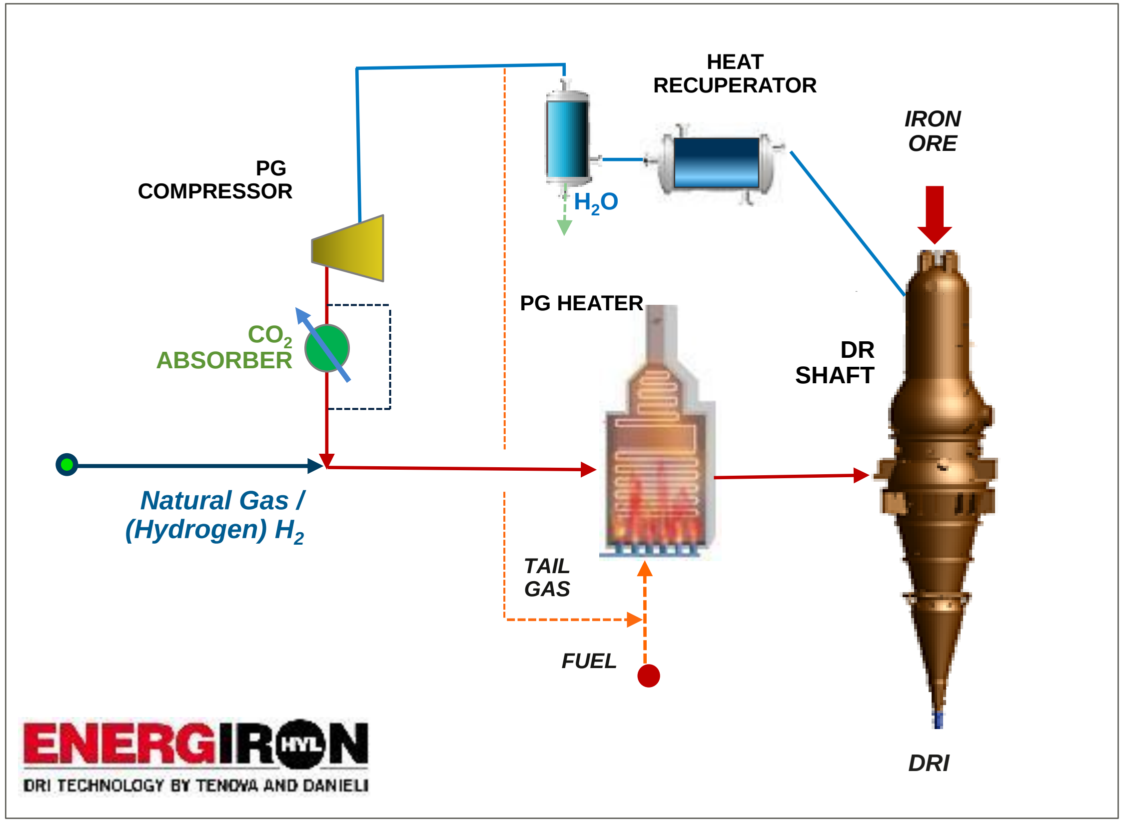
tenova

BASIC REQUIREMENTS FOR DECARBONIZING IRONMAKING/STEELMAKING INDUSTRY

- ✓ Possibility for inherent **CCU/CCS.**
  ENERGIRON DR technology has an inherent selective CO_2 removal as part of its standard and unique scheme.

- ✓ **Hydrogen Ready!** Flexibility to operate with NG/H_2 from 0-100%:
  ENERGIRON is the only DR technology available capable to operate from 100%NG - 100%H_2 in **reversible operating mode** at any moment with no need to modify the process configuration.

- ✓ Flexibility for **high %C DRI** for HM production
  ENERGIRON is the only proven technology to produce >4%C DRI with 100%NG. Even with 30%H_2 (energy), %C >3.3% can be achieved.

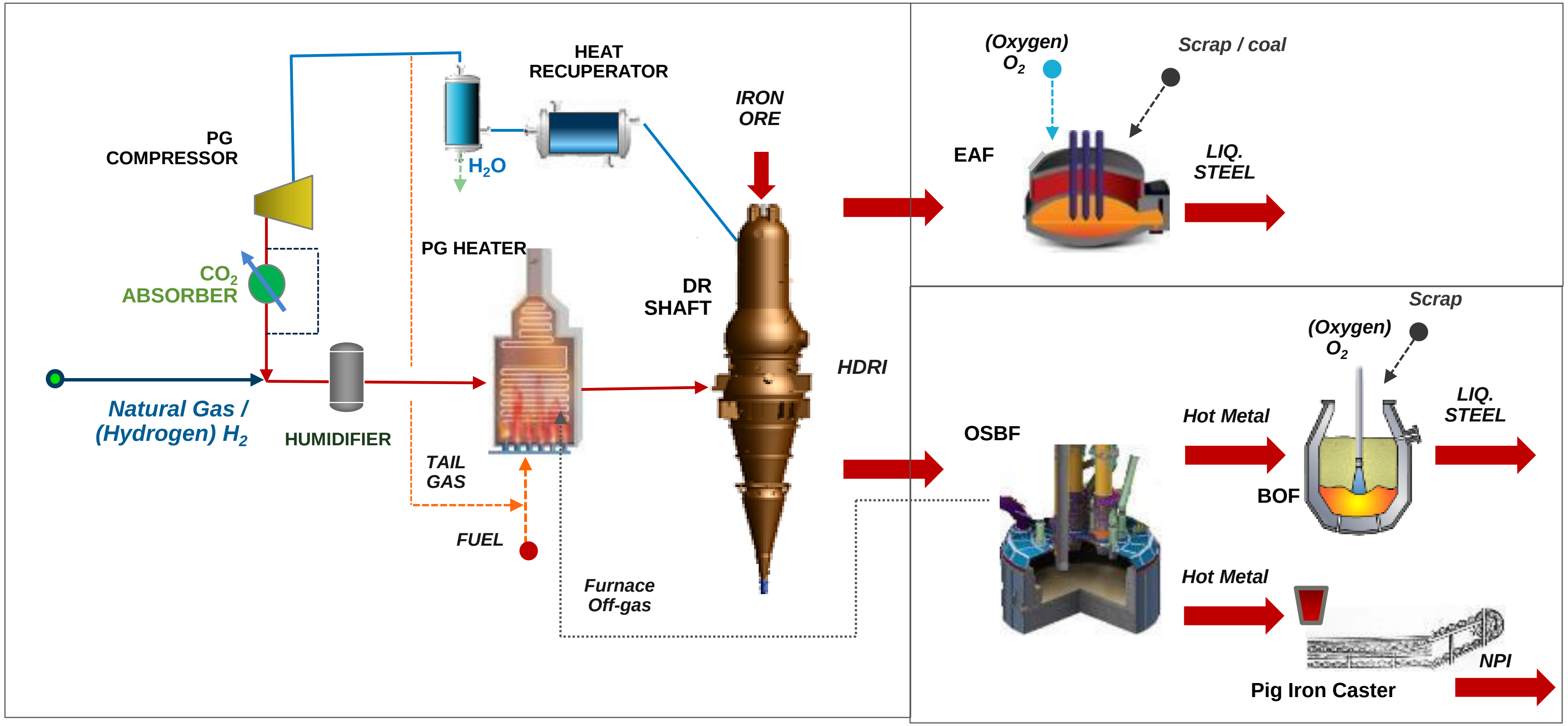


ENERGIRON® DRI Standard ZR Process Scheme

Routes for Low-C Footprint Steelmaking

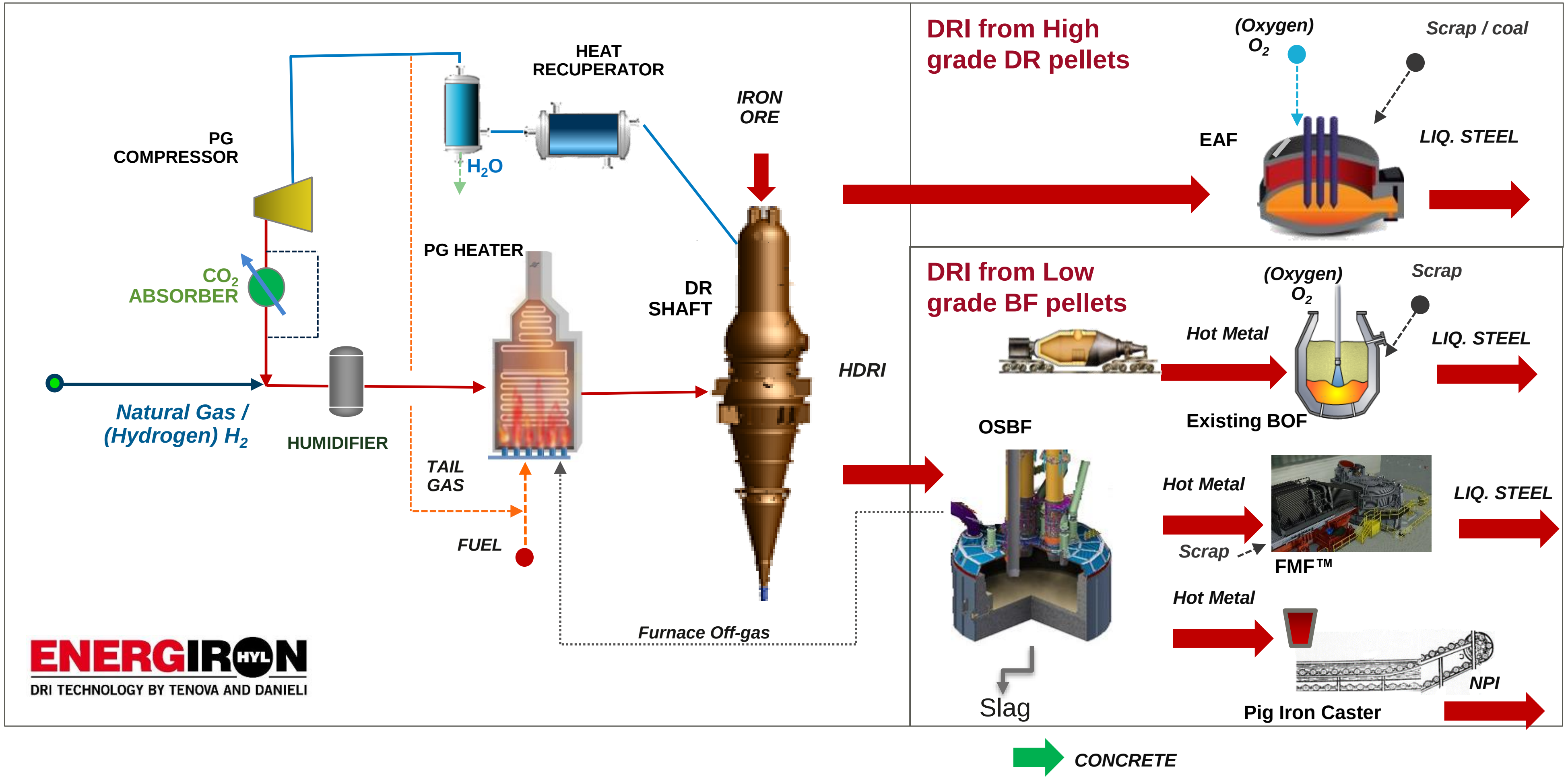
BASIC REQUIREMENTS FOR DECARBONIZING IRONMAKING/STEELMAKING INDUSTRY

1. Steel production by DRI-EAF
2. Replacement of BF by ENERGIRON DRI-Tenova OSBF **(iBLUE)** for Hot Metal production to existing BOF-downstream facilities
3. Production of PI/NPI by DRI-Tenova OSBF **(iBLUE)**



Routes for low-C footprint steelmaking

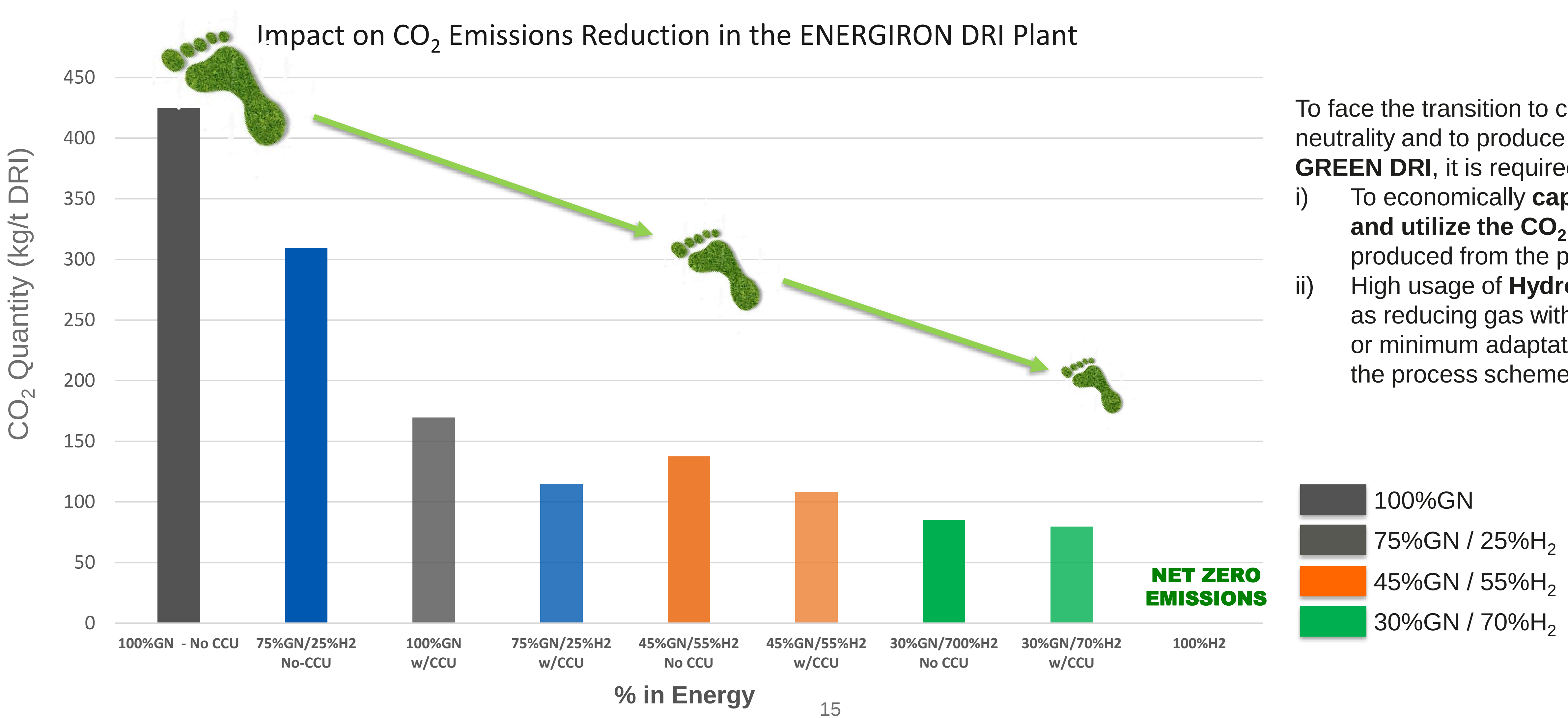
GENERAL APPROACH



Carbon Footprint by Using Hydrogen and CCU

tenova

CARBON FOOTPRINT REDUCTION FROM H_2 TRANSITION



To face the transition to carbon neutrality and to produce **GREEN DRI**, it is required to:

i) To economically **capture and utilize the CO_2** produced from the process

ii) High usage of **Hydrogen** as reducing gas with none or minimum adaptations to the process scheme.

Current DRI Projects for Decarbonization

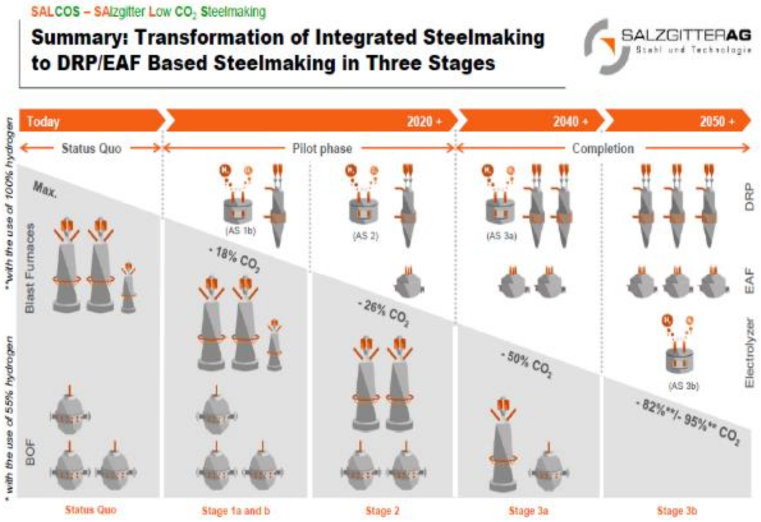
PROJECTS WITH THE LOWEST-C EMISSIONS FOR STEELMAKING BASED ON ENERGIRON® TECHNOLOGY

In Europe…

HYBRIT
FOSSIL-FREE STEEL
SSAB LKAB VATTENFALL

H_2-based DRI Pilot Plant

SALCOS
Steelmaking. Reinvented.



2,1 Mtpy ENERGIRON DRI Plant as part of the SALCOS initiative

µDRAL Plant operating with NG/H_2

TATA STEEL

H_2-ready ENERGIRON DRI Plant for Ijmuiden steelworks

Current DRI Projects for Decarbonization

PROJECTS WITH THE LOWEST-C EMISSIONS FOR STEELMAKING BASED ON ENERGIRON® TECHNOLOGY

…and outside Europe…

HBIS GROUP 河钢集团 HBIS GROUP

First DRI Plant in China
550,000 tpy DRI
70%H_2 in makeup gases

BAOWU

Second DRI Plant in China
1,000,000 tpy DRI
Flexible to use diff. gases, including H_2

ArcelorMittal DOFASCO | HAMILTON

2,5 Mtpy ENERGIRON DRI Plant
Hydrogen-ready

Current DRI Projects for Decarbonization

PROJECTS WITH THE LOWEST-C EMISSIONS FOR STEELMAKING BASED ON ENERGIRON® TECHNOLOGY

…and outside Europe…

Ternium

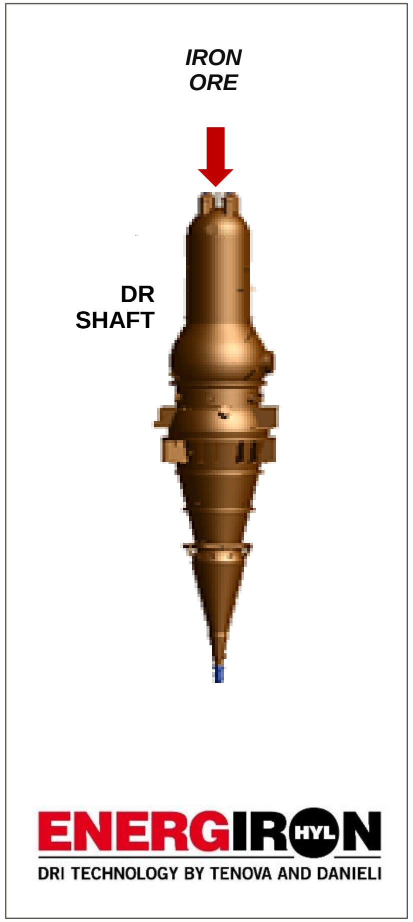
Largest steelmaking facility in Latin America
2.1 MTPY DRI
100% NG up to 100%H_2 in makeup gases

VULCAN GREEN STEEL
PART OF JINDAL STEEL GROUP

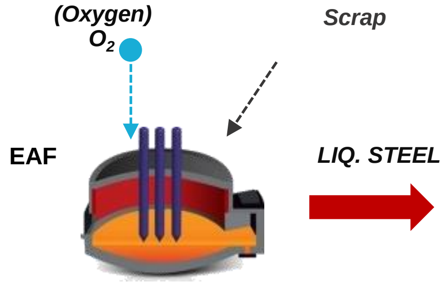
Most recent DRP-EAF facility in Oman
2.5 MTPY DRI
100% NG up to 100%H_2 in makeup gases

The “Classic” Solution is Always Mainstream

CLASSIC SOLUTION TO MEET SUSTAINABILITY GOALS



DRI from High grade DR pellets

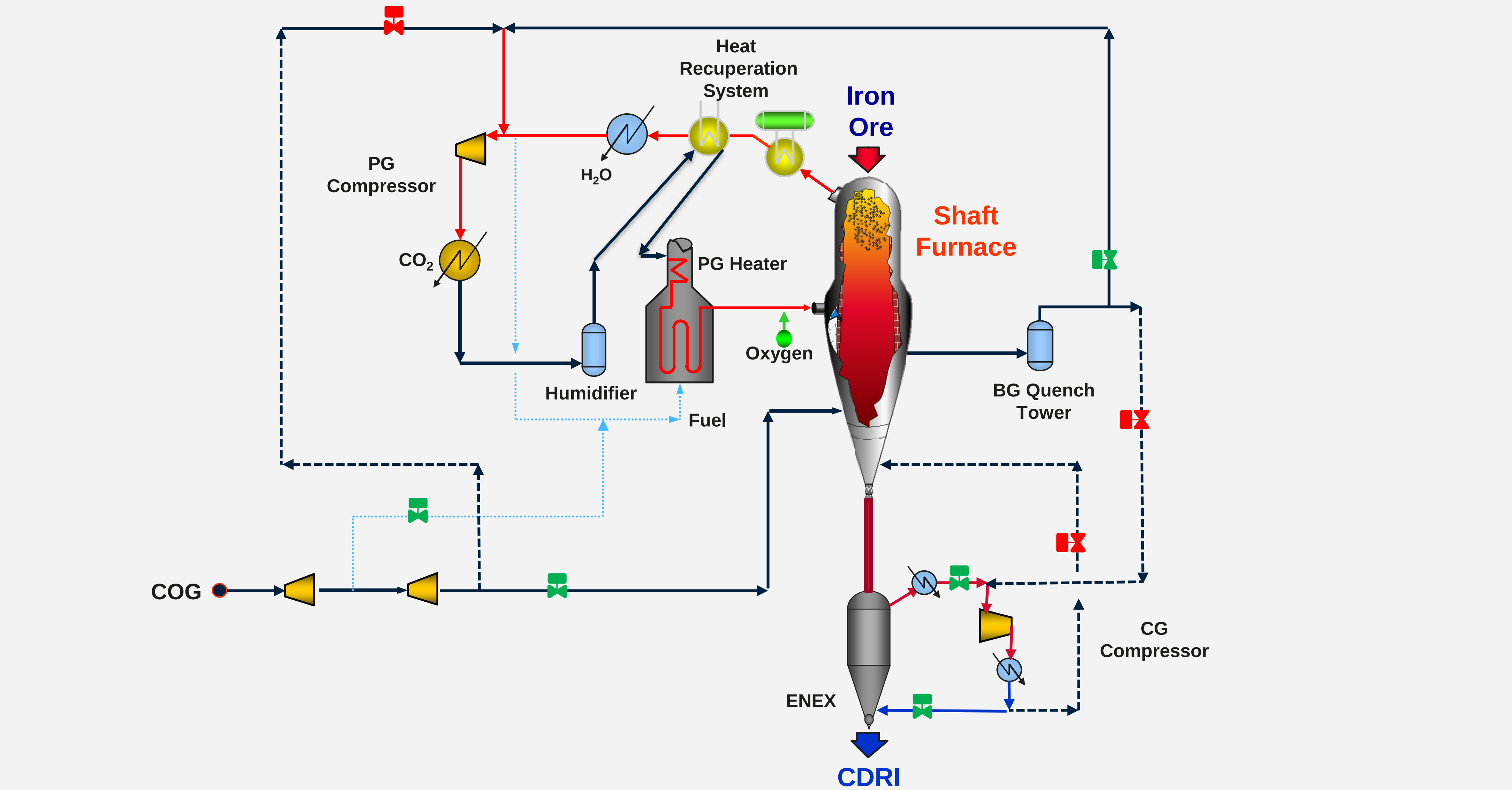


Most of the plants sold nowadays are designed based upon the “classic” concept of DRI being fed (with different percentages) in one or more EAFs.

This year in October the **HBIS project**: “Unique coke oven gas zero-reforming DRI process combined with EAF” won the **WSA award** for “Excellence in low-carbon steel production”

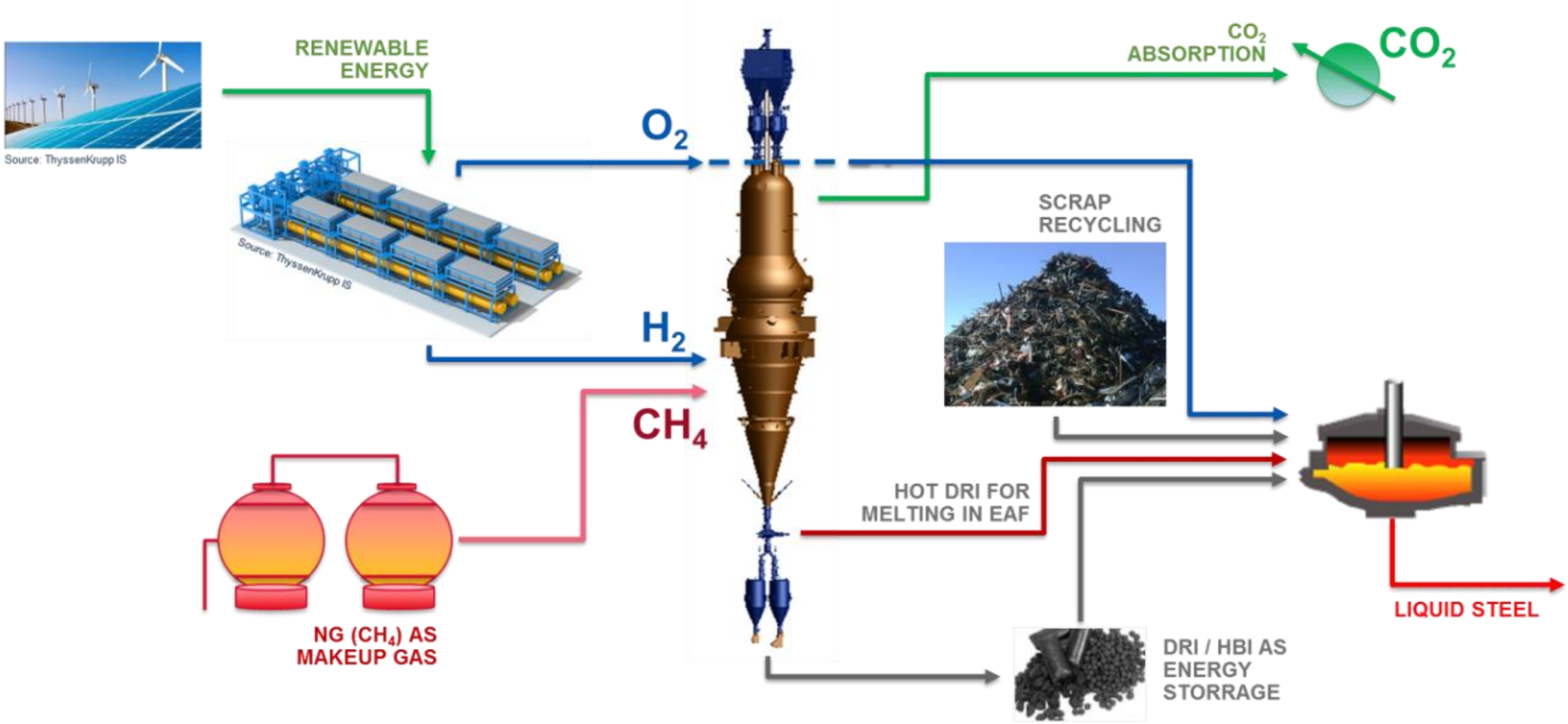
The “Classic” Solution is Always Mainstream

CLASSIC SOLUTION TO MEET SUSTAINABILITY GOALS



Ironmaking via Direct Reduction

TENOVA HYDROGEN-BASED DIRECT REDUCTION



Tenova HYL leading process for DRI

tenova

UNIQUE FEATURES OF THE ENERGIRON TECHNOLOGY

ENERGIRON HYL
DRI TECHNOLOGY BY TENOVA AND DANIELI

Removal of CO_2

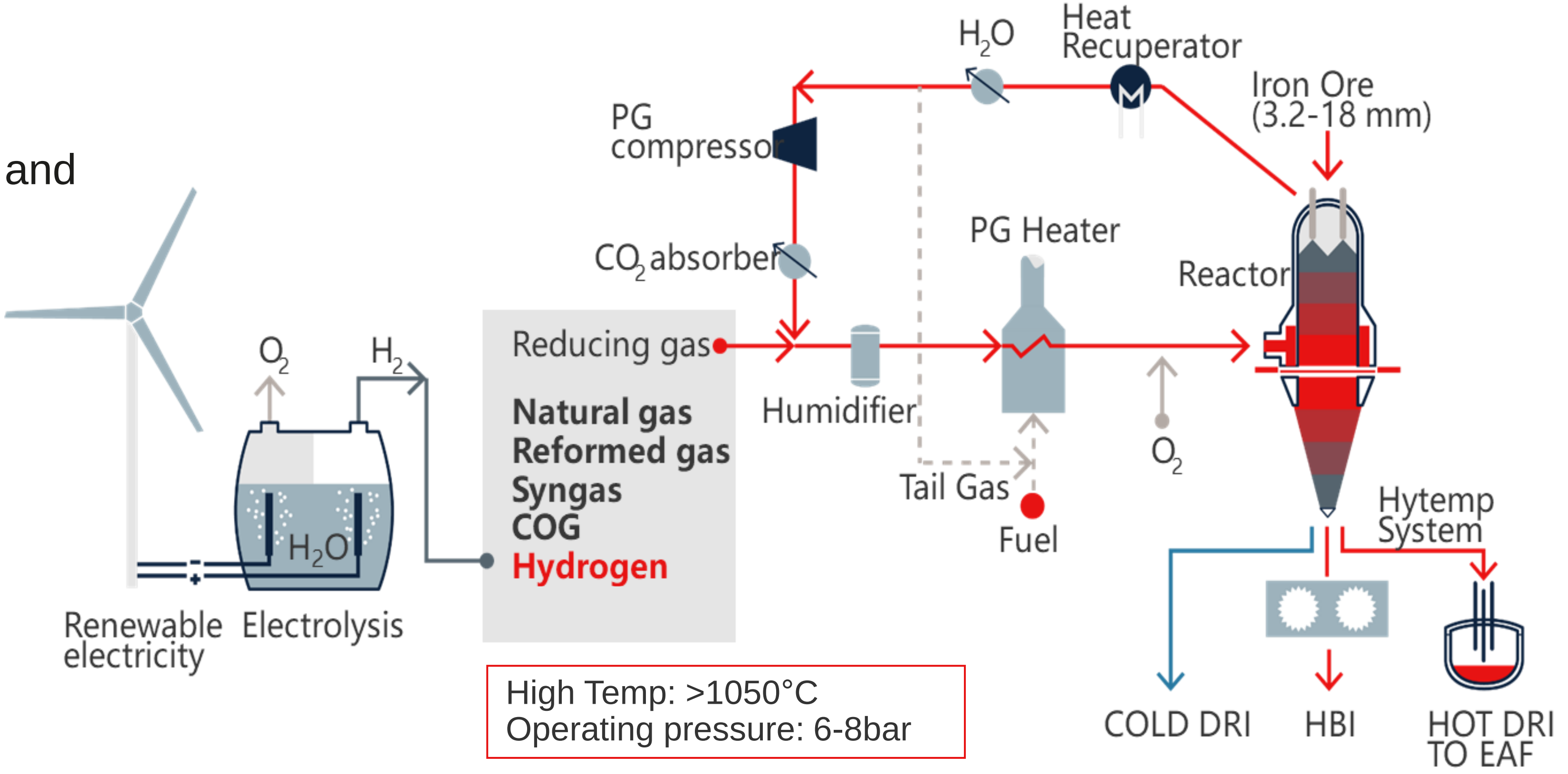
- Selective removal of CO_2
- Intrinsic capability for CCU and CCS

Flexibility

- Same process scheme for any energy source

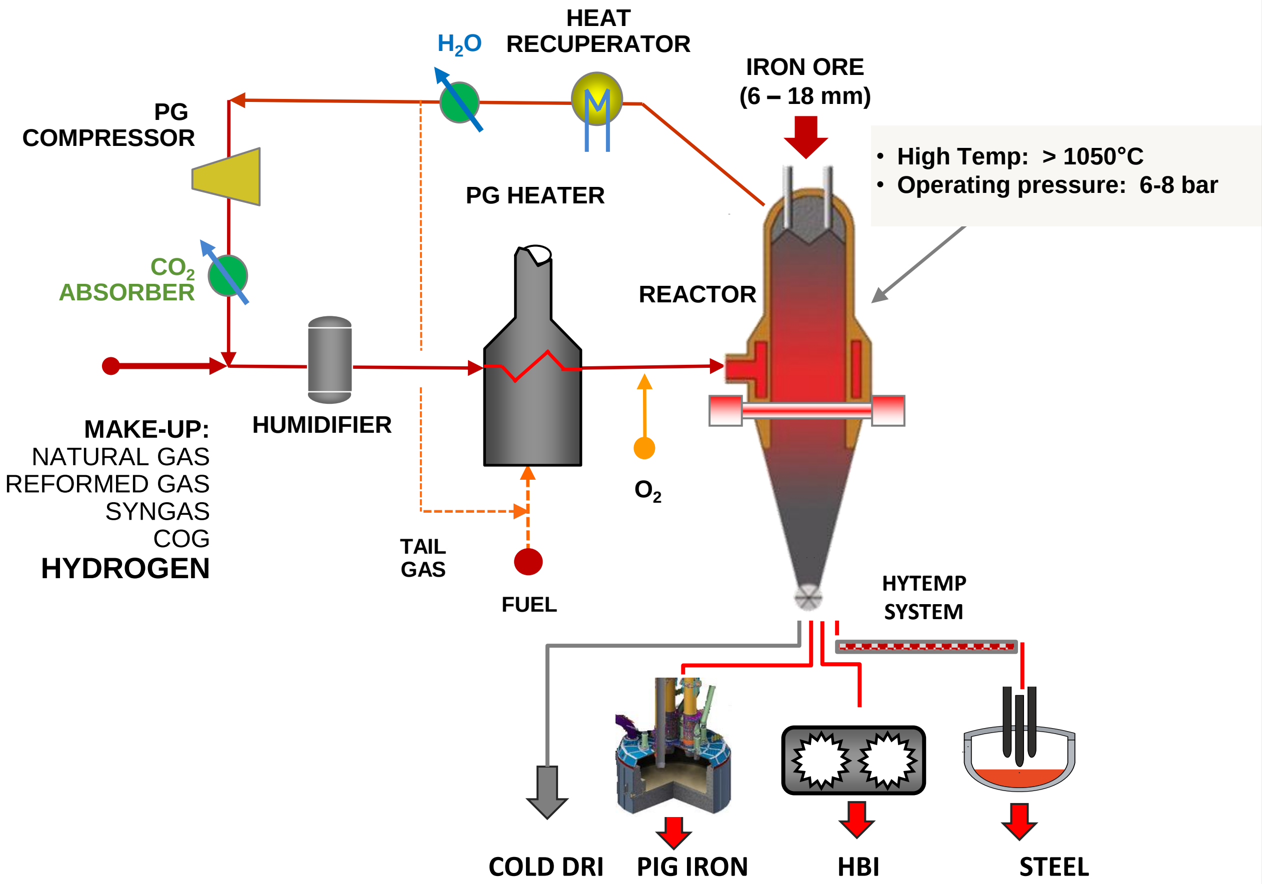
DRI Quality

- 94% to 96% metallization 1,5% to 5,0% Carbon
- Carbon as Fe_3C



High Temp: >1050°C
Operating pressure: 6-8bar

ENERGIRON ZR: THE MOST SIMPLE AND FLEXIBLE PROCESS SCHEME



FLEXIBILITY:

- Same scheme for ANY energy source

ENVIRONMENTAL:

- Selective removal of iron ore reduction's by-products: H_2O & CO_2 for CCU
- Direct use of reducing gases from different sources replacing carbon/coke of BF
- lowest NOx emissions w/o additional equipment

DRI QUALITY:

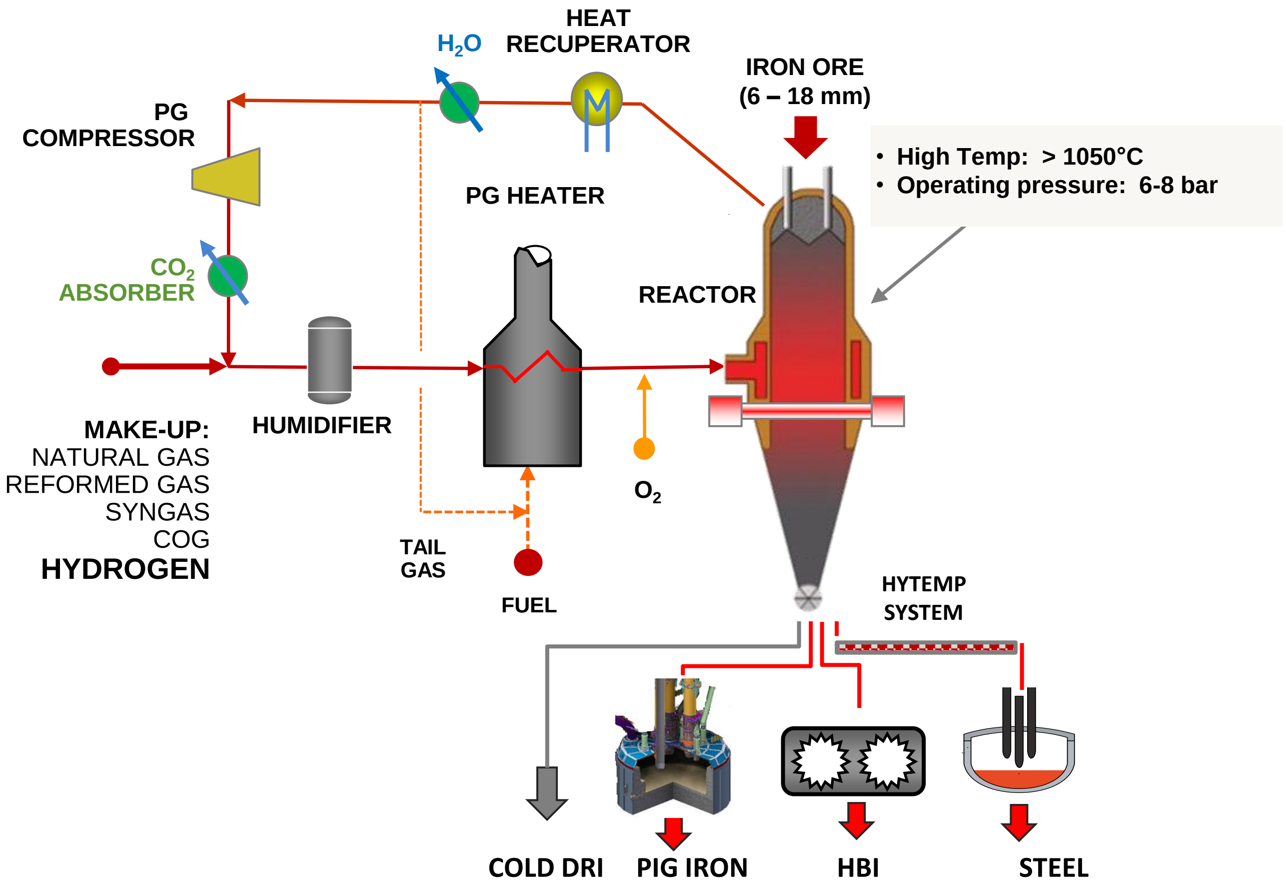
High-C CDRI, High-C HDRI, High-C Briquettes

- ≥94% Mtz; 1,5%- 4,6% Carbon (as Fe_3C)

OPEX:

- Highest overall Energy efficiency
  - ~10,0 GJ/t; < 80 kWh/t
  - high yield: <1,4 t IO/t

ENERGIRON ZR: THE MOST SIMPLE AND FLEXIBLE PROCESS SCHEME

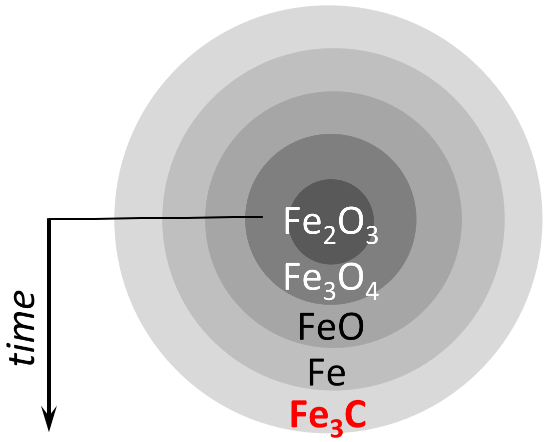


PROCESS SCHEME	BENEFITS
Direct recycling to DR shaft through CO_2 removal system and heater. No External Reformer: All processes inside the DR shaft (reforming, reduction, carburization) Same scheme for ANY energy source	✓Flexibility; Higher efficiency, ✓Selective CO_2 absorption for CCU as by-product
In-situ Reforming of hydrocarbons	✓No need for catalyst-based reformer; ➢Less maintenance; less OPEX; Less CAPEX
High Reducing gas temperature: > *1050°C.*	✓Higher flexibility for carburization via CH_4 for higher Fe_3C formation.
▪ Top gas is recycled to the shaft. Any sulphur is eliminated in the CO_2 removal system. ▪ No restriction, for processing iron ores with high sulphur content. ➢*AMLC uses local, cheaper high-sulphur content iron ore pellets.*	✓Higher flexibility for use of lower cost raw materials and different energy sources.

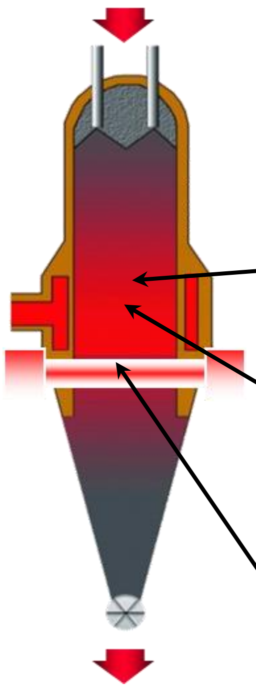
MAIN CHARACTERISTICS:

- NG Reforming, iron ore Reduction and DRI Carburization take place in the SAME Reactor.
- Catalyst is the SAME iron (Fe) in DRI being produced and always renewed.
- High temperature to comply with *in-situ* reforming & reduction (>1050°C)
- Production of UNIQUE High-C DRI.
- Most efficient DR process.

STEPS IN DRI FORMATION



IRON ORE



HIGH-C DRI

REDUCTION ⇄ REFORMING

REDUCTION

$Fe_2O_3 + 3H_2 \Rightarrow 2Fe^\circ + 3H_2O$

$3Fe_2O_3 + 2CO \Rightarrow 2Fe^\circ + 3CO_2$

REFORMING

$CH_4 + H_2O \Rightarrow CO + 3H_2$

$Fe_2O_3 + 3H_2 \Rightarrow 2Fe^\circ + 3H_2O$

METHANE CRACKING

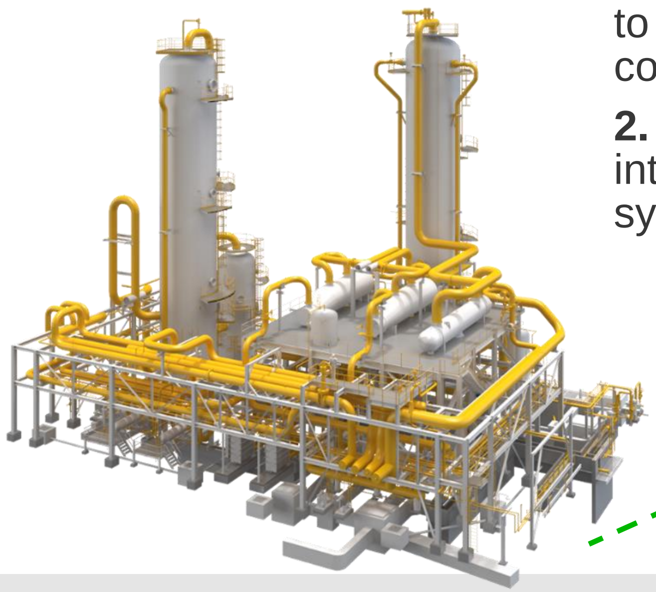
$CH_4 \Leftrightarrow C + 2H_2$

CARBURIZATION

$3Fe^\circ + CH_4 \Rightarrow Fe_3C + 2H_2$

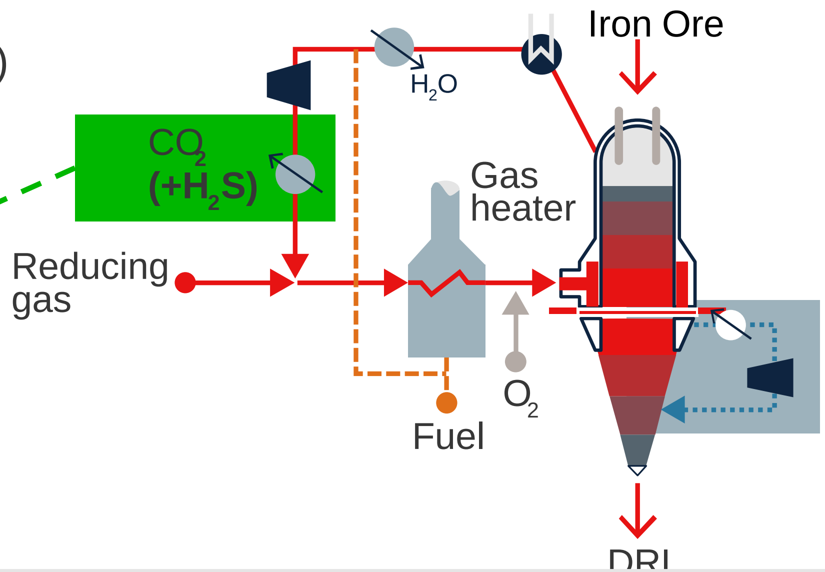
Carbon Capture & Utilization (CCU)

CO_2 ABSORPTION SYSTEM



1. In a DRP, CO_2 emissions are related to iron ore reduction and carbon content of the fuel used (Coal, NG, etc)

2. ENERGIRON DR process intrinsically includes a CO_2 absorption system for selective elimination of CO_2



For **Mass Conservation Principle**, total Carbon feeding the **ENERGIRON** DRP is ultimately found as CO_2 at the battery limit as:

- **Sequestrated Emissions**
- **Free Emission to Atmosphere (mainly from PG Heater)**
- **Carbon in Product (DRI/HBI)**

Carbon Capture & Utilization (CCU)

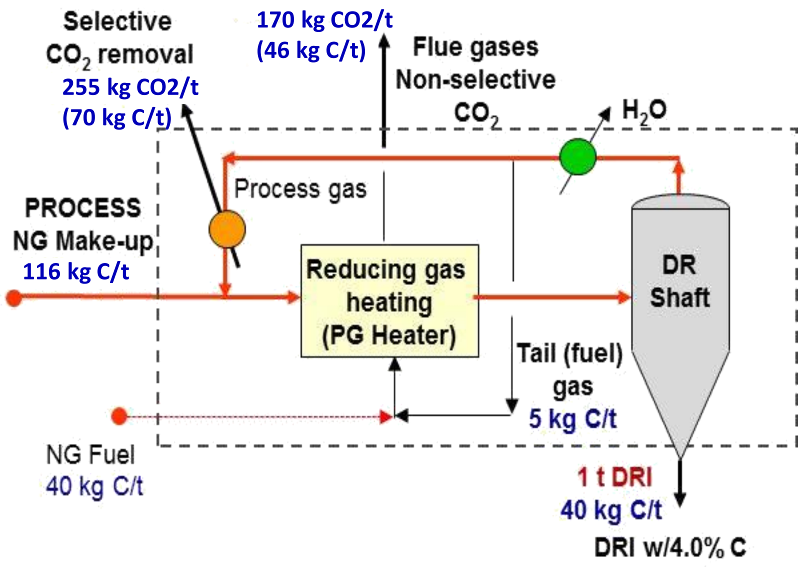
CO_2 ABSORPTION SYSTEM

In ENERGIRON ZR:

From total Carbon input:

- ~ 45% of total carbon (as CO_2) is selectively removed.
- ~30% through flue gases and
- ~ 25% as C in the DRI

Selective CO_2	255 kg/t	60%
Non-Selective CO_2	170 kg/t	40%
Total CO_2	425 kg/t	



Carbon balance for Nucor Plant

Selective CO_2: What to do with it?:

Since 1998, CO_2 gas, from the CO_2 absorption system of ENERGIRON plants has been used as byproducts by different off-takers

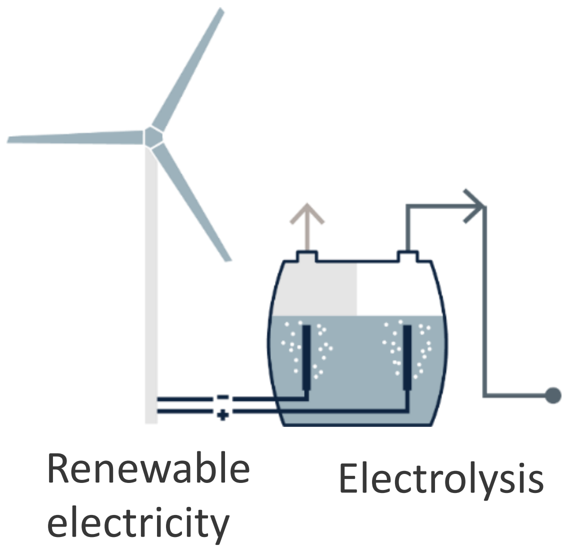
HyL/ENERGIRON DR Plant	Off-taking company	Use
Ternium; Monterrey, Mexico	Praxair	Food and beverages industries
Ternium; Puebla, Mexico	Infra	Beverages industries
PTKS; Indonesia	Janator	Food industry
PSSB; Malaysia	Air Liquid/MOQ	Food industry
JSW Salav; India	Air Liquid	Dry Ice
Emirates Steel; UAE(1)	Masdar/ADNOC	Enhanced Oil Recovery (EOR)

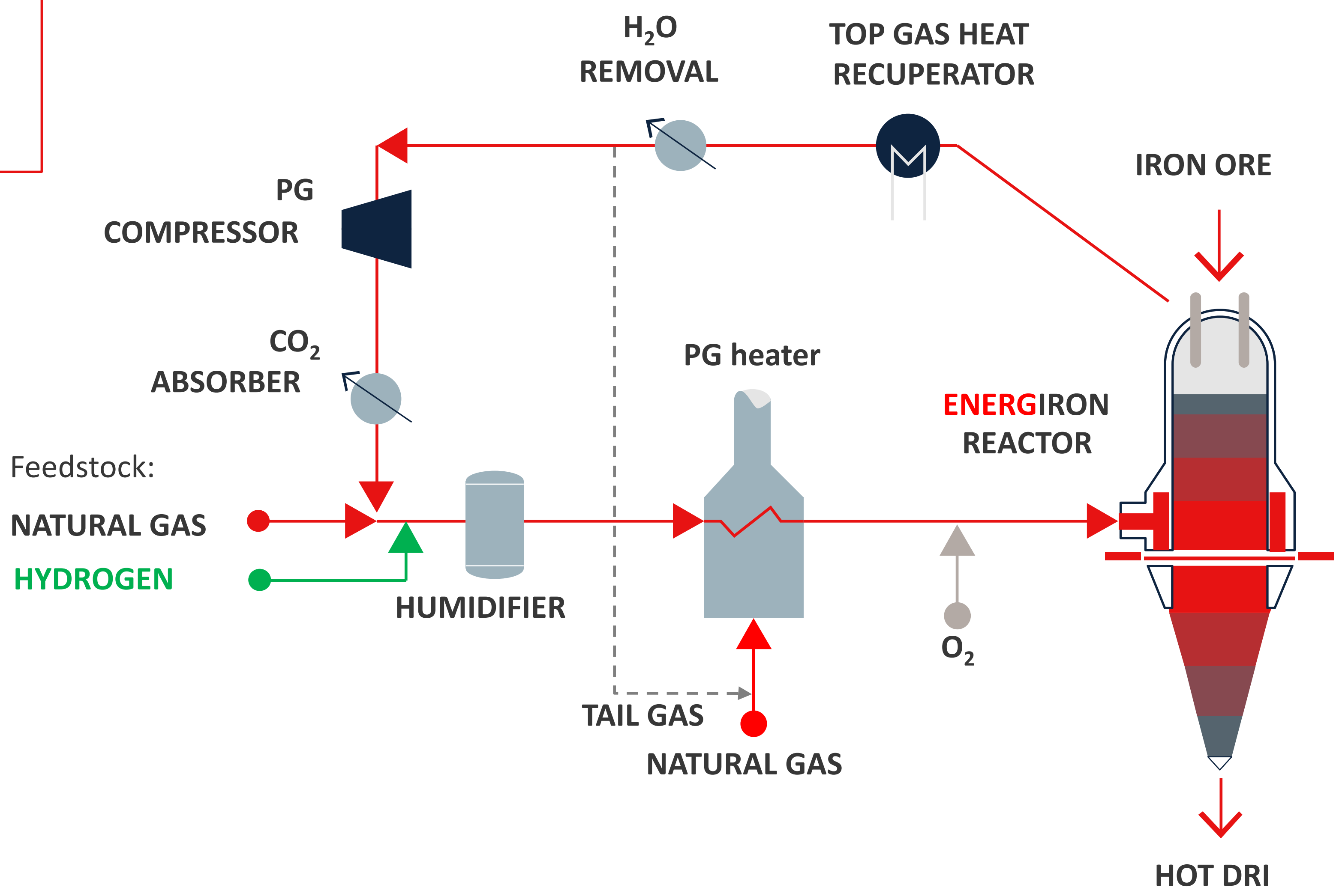
> Hydrogen based Direct Reduction

HYDROGEN-READY TECHNOLOGY

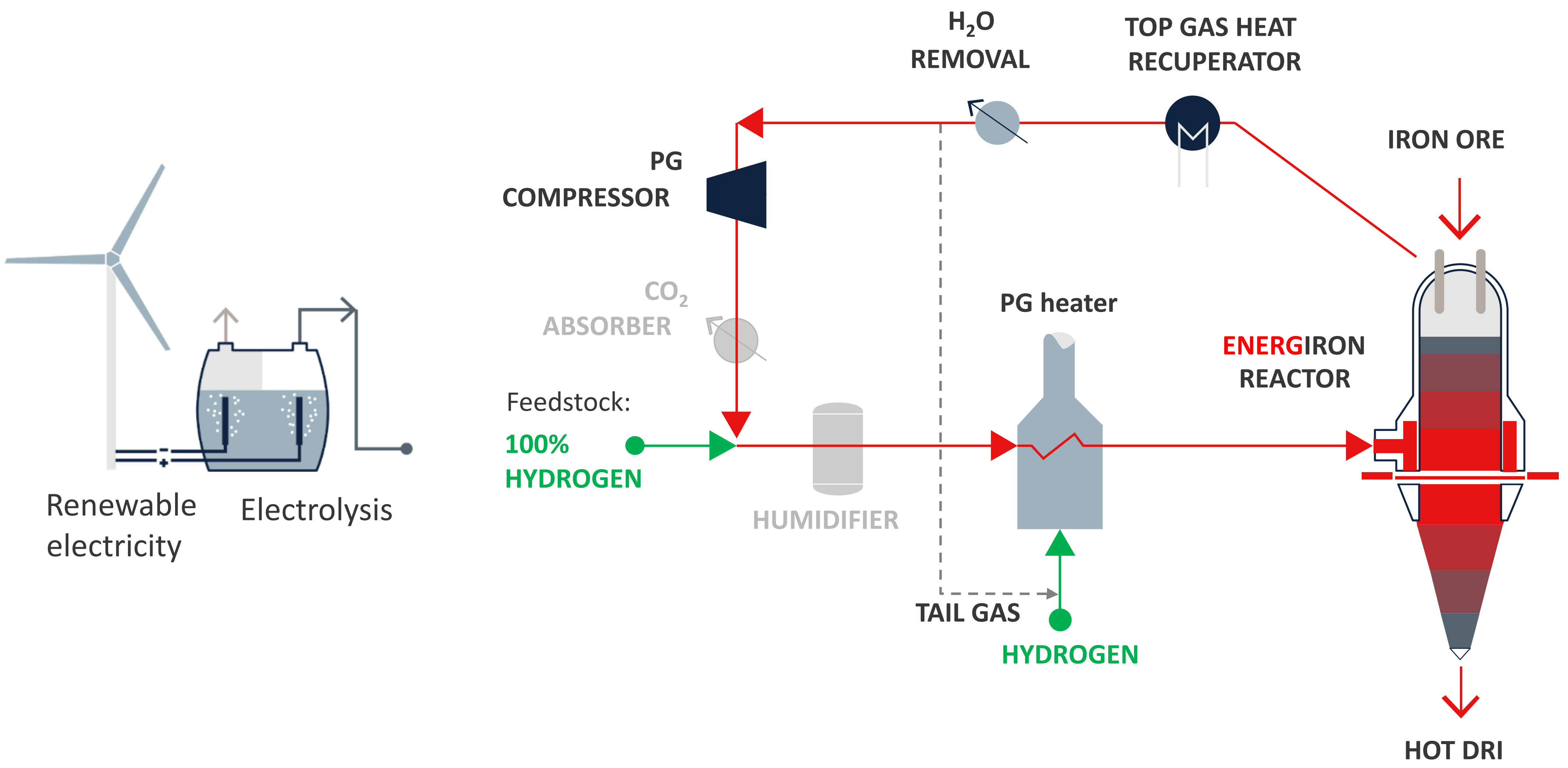
ENERGIRON HYL

New technologies are being developed to produce **H_2** from renewable energy sources





FROM CARBON CAPTURE AND USE (CCU) TO CARBON DIRECT AVOIDANCE (CDA)

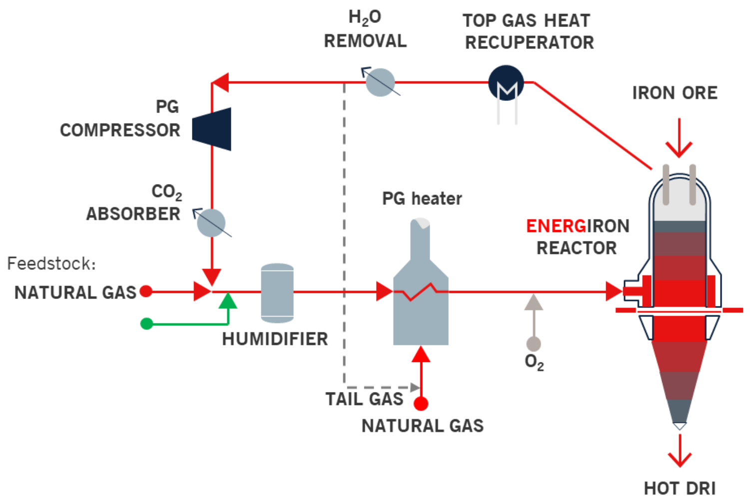


NG TRANSITION UP TO 100% H2

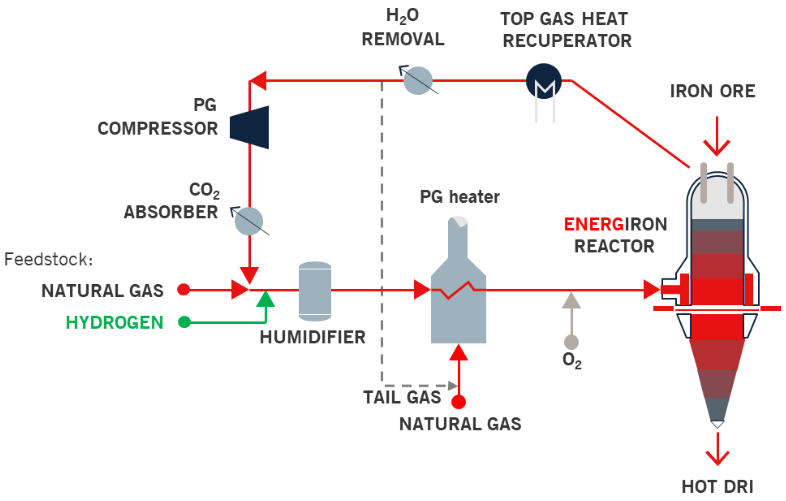
ENERGIRON HYL

SAME SCHEME FOR PRESENT, NEAR AND FAR FUTURE

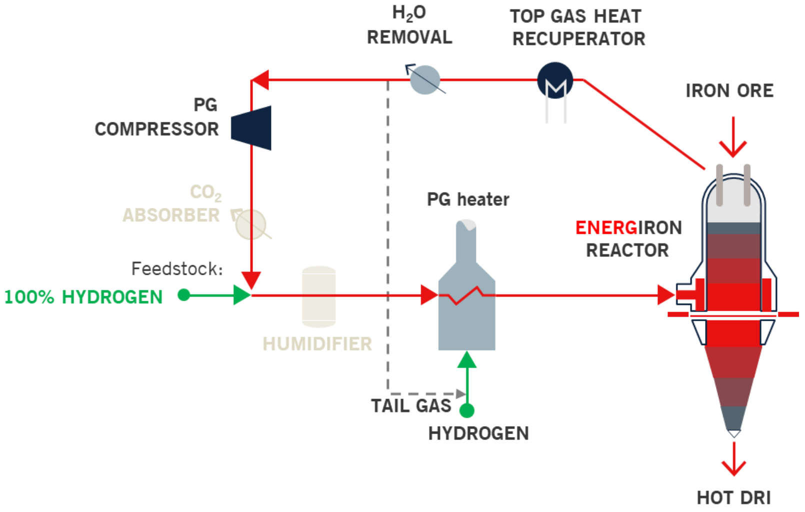
NOW | BY 2030 | BY 2050



100% Natural Gas



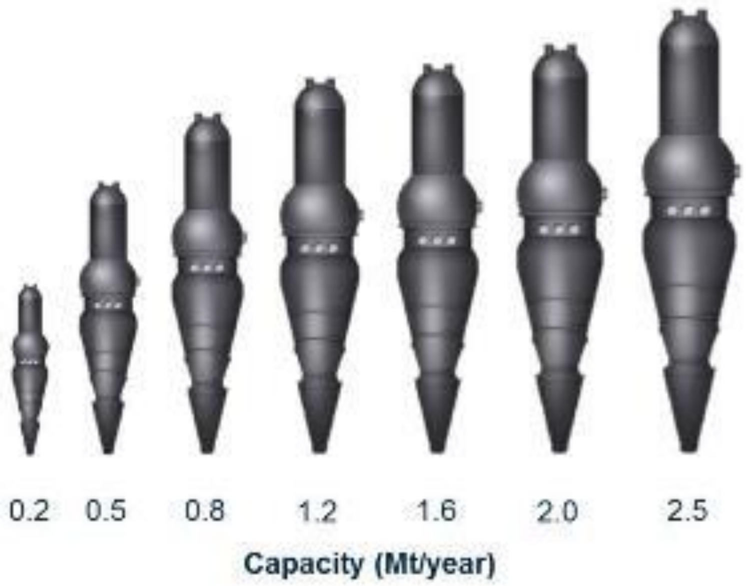
any % Natural Gas
any % Hydrogen



100% Hydrogen

ENERGIRON: DR MODULES SIZES

0,20 MTPY CDRI
Carbon 3.0% - 4%
Metallization 94%



2,5 MTPY
Carbon 3.0% - 4.5%
Metallization 95% - 96.5%

2.5 – 5 million tpa Blast Furnace

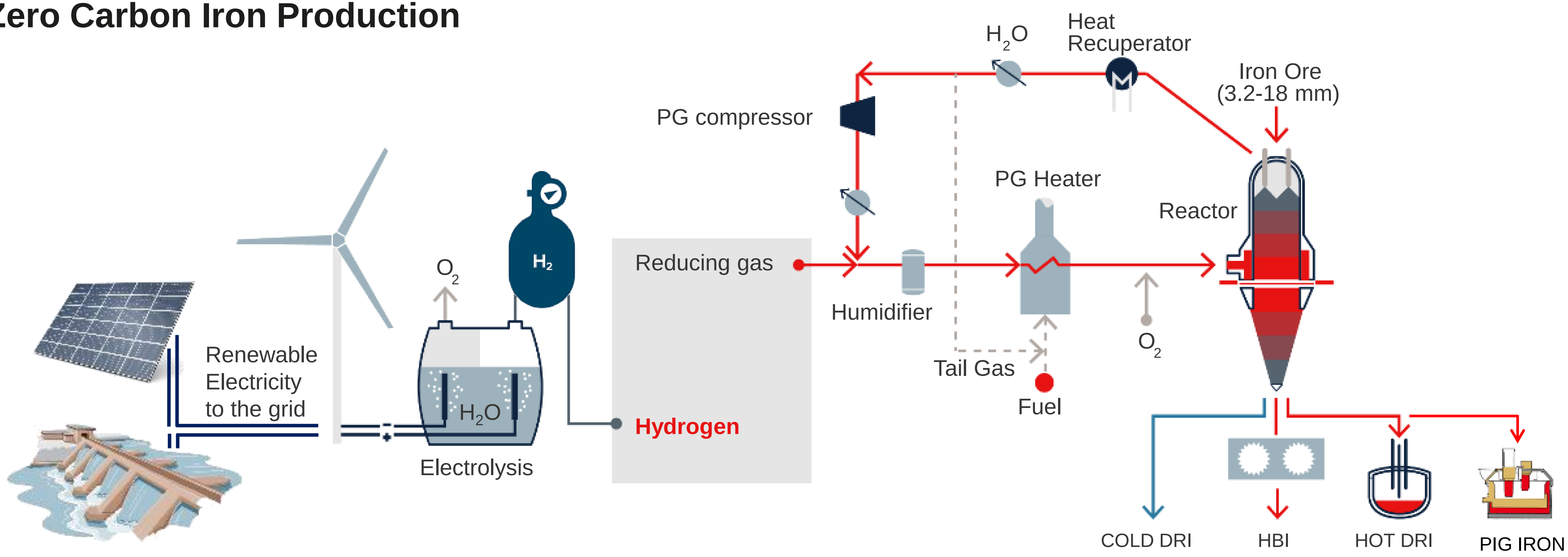
PROVEN EXPERIENCE FROM THE SMALLEST TO THE LARGEST DR MODULES WORLDWIDE

From CCU to Carbon Direct Avoidance (CDA)

tenova

HYDROGEN AS ENABLER FOR GREENER STEELMAKING

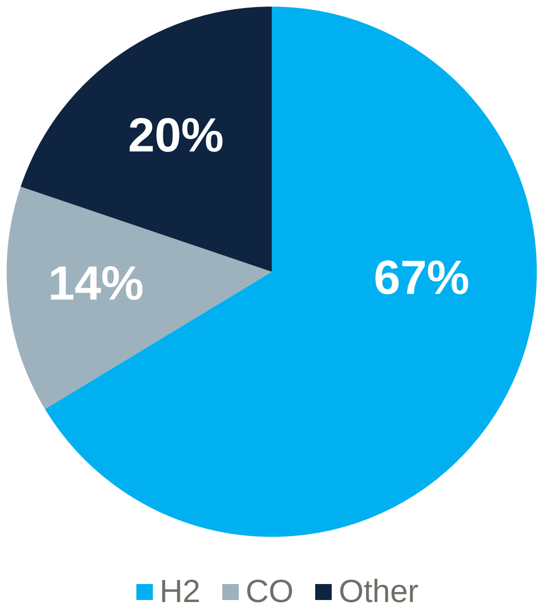
Zero Carbon Iron Production



Experience with Hydrogen use

ENERGIRON IS READY FOR INDUSTRIAL APPLICATION

- ✓ Experience in ENERGIRON plants with reformer using in excess of 70% H_2
- ✓ Scheme natively fitted for direct use of H_2
- ✓ Completion of pilot plant tests with ~90% H_2 since 1990's
- ✓ Extensive experience and operation with Process Gas heaters and gas sealing valves design, specifically with high percentages of H_2



Use of Hydrogen in Direct Reduction processes

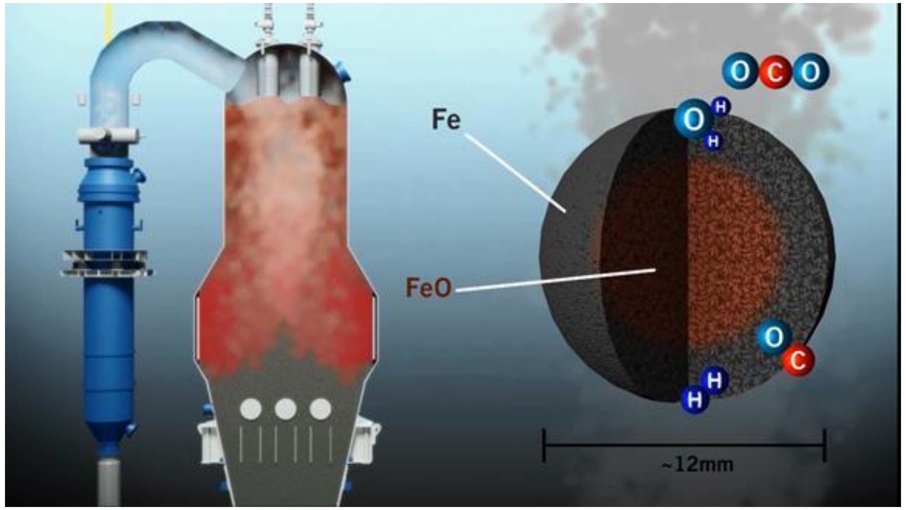
DIRECT REDUCTION FUNDAMENTALS

$Fe_2O_3 + 3H_2 \Rightarrow 2Fe° + 3H_2O$ ΔG° @ 1118°K: - 9.201 kJ/kg mol H_2

$3Fe_2O_3 + 2CO \Rightarrow 2Fe° + 3CO_2$ ΔG° @ 1118°K: - 8.222 kJ/kg mol CO

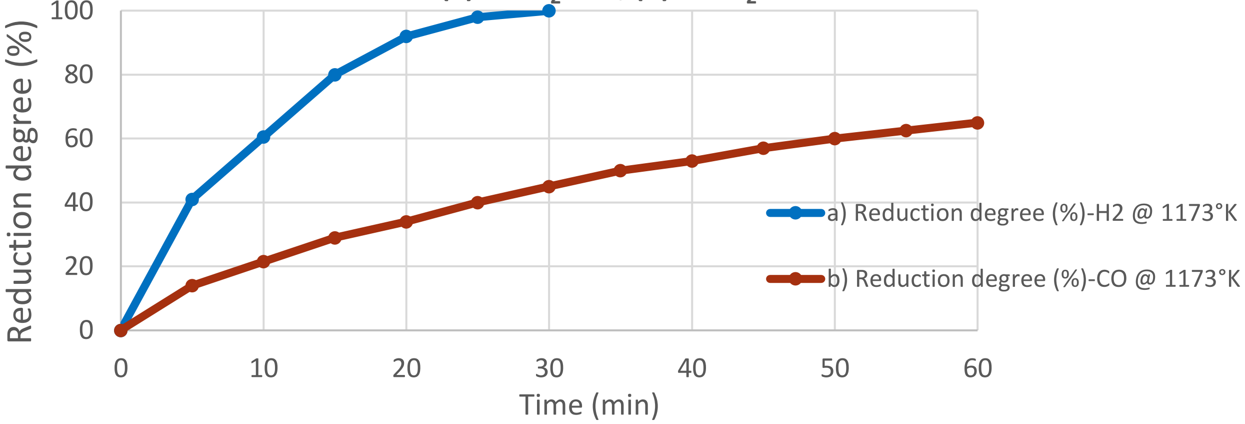
$Fe_2O_3 + 3H_2 \Rightarrow 2Fe° + 3H_2O$ ΔH_{rxn} @ 1118°K: +21.763 kJ/kg mol H_2

$3Fe_2O_3 + 2CO \Rightarrow 2Fe° + 3CO_2$ ΔH_{rxn} @ 1118°K: -12.081 kJ/kg mol CO



Reduction with H_2	Reduction with CO
• Highly Endothermic: favored by high Temp and higher % of H_2 • Easier / Faster than CO	• Highly Exothermic: favored by low Temp and lower % of CO • Harder / Longer than H_2

Change of reduction degree with time:
(a) $CO:H_2$=0:1; (b) $CO:H_2$=1:0

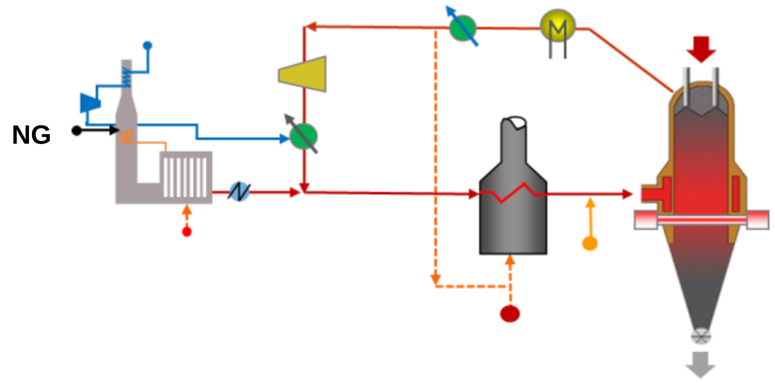


Kinetically, **iron ore reduction with H_2 is >4 times faster as compared to CO** which requires higher reducing gas temperature.

INDUSTRIAL EXPERIENCE: USE OF H_2

ENERGIRON HYL

LONG LASTING EXPERIENCE WITH H_2 USE



ENERGIRON/HYL Plants with high %H_2 PG Heaters

DR Plant w/Reformer	%H_2	H_2/CO
Ternium 3M5 (to ZR in 2003) (*)	72	5
Arcelor Mittal LC	60	3
Perwaja Steel (*)	76	6
PT Krakatau Steel (*)	75	6
JSW (*)	70	4
Hadeed (*)	70	4
Lebedinsky (*)	70	4
Emirates Steel 1 & 2 (*)	60	4
EZZ (*)	66	5

- For any reformer, H_2 is produced in different concentration, depending on the oxidants ratio being used; i.e.

$CH_4 + H_2O = 3H_2 + CO$ (3 vol. H_2 / 1 vol. CO)
$CH_4 + CO_2 = 2H_2 + 2CO$ (2 vol. H_2 / 2 vol. CO)

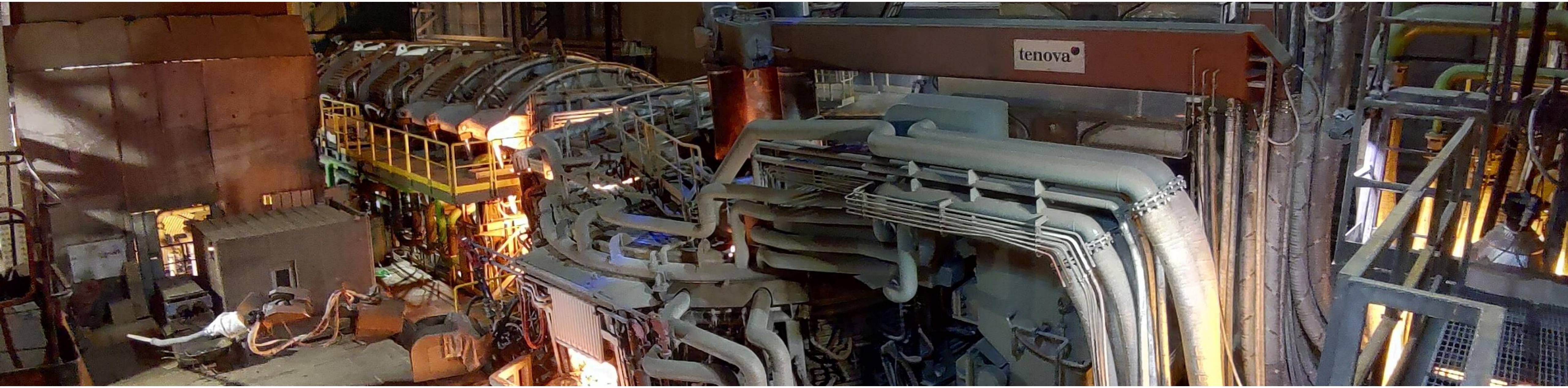
- Since the 1950's, the HYL/ENERGIRON technology using Reformed gas as source of reducing gas, includes a conventional steam/NG reformer. Typical operation characteristics are:

Parameter related to H_2	ENERGIRON	Other DR technology
H_2O/C ratio in Reformer	2.0 – 2.5	1.5
H_2/CO ratio in reducing gas	4 - 5	1.7
%H_2 to reactor (% vol.)	~70%	~55%

- The above reflects the long-lasting industrial experience with intensive use of H_2 for DRI production.

➢ Long and lasting proven industrial experience since 1980 with design of PG Heaters (alloys selection, temperature profiles, ΔP, etc.).

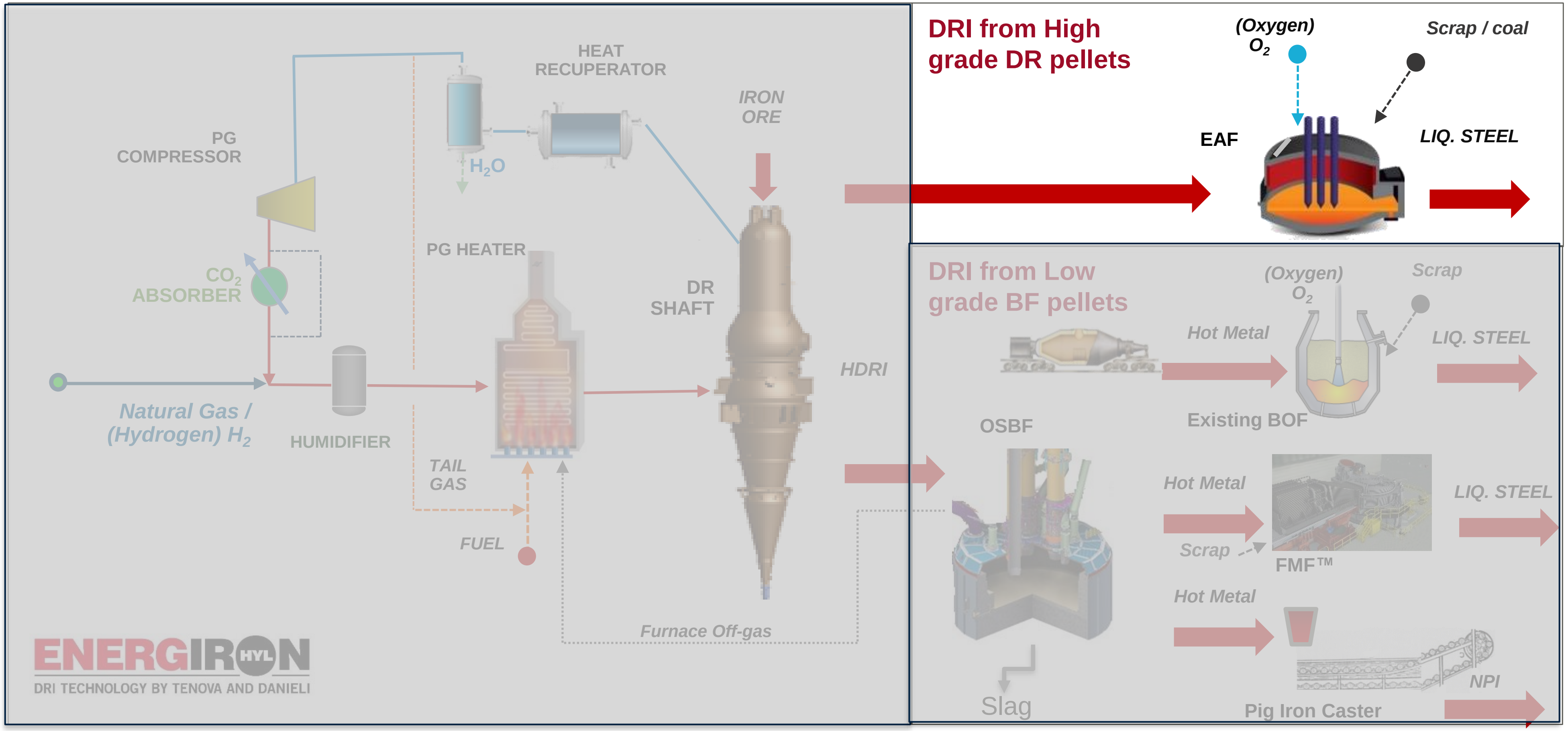
FROM DRI TO GREEN STEEL



MELTING HIGH GRADE DRI PELLETS

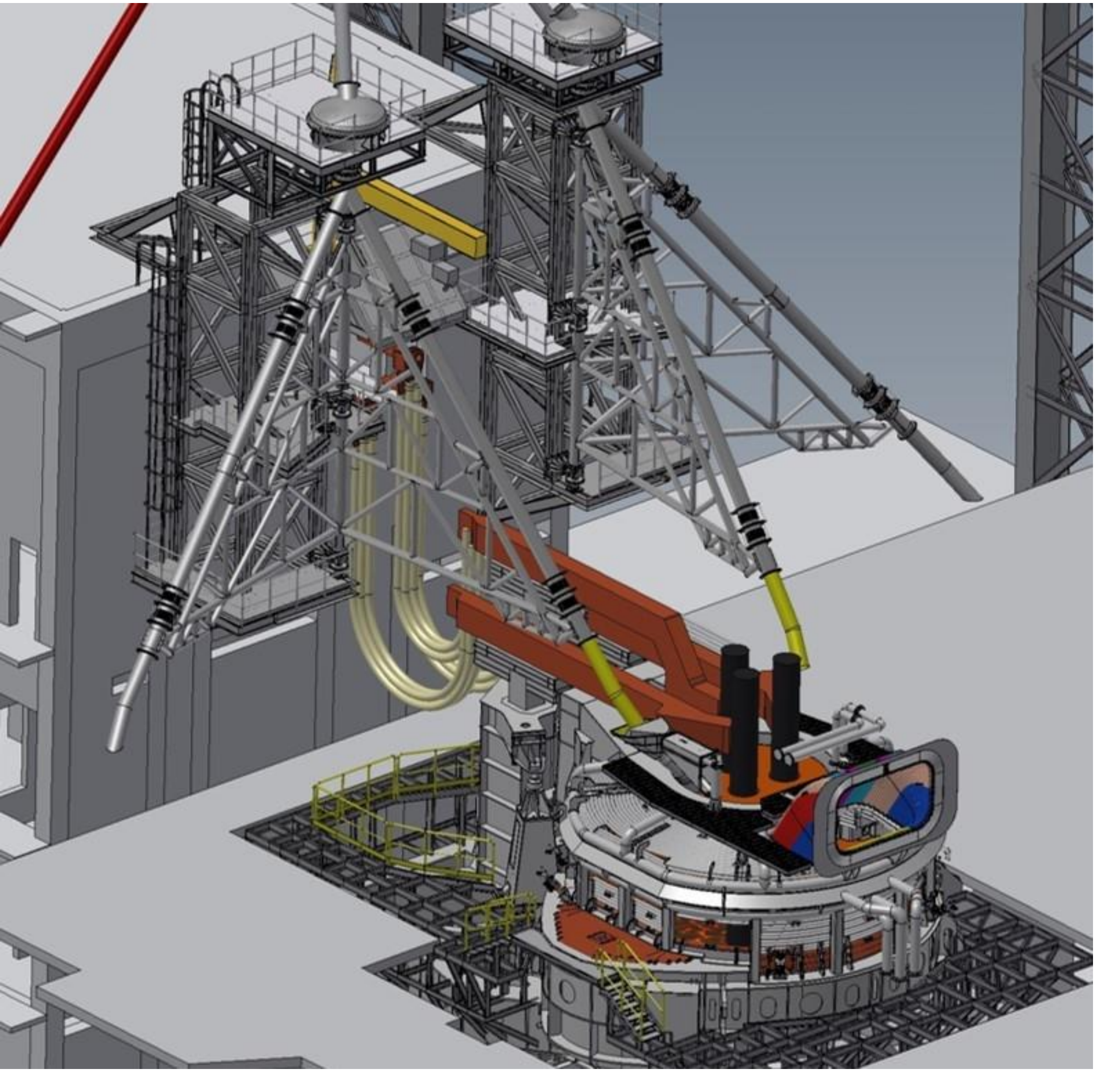
Routes for low-C footprint steelmaking

GENERAL APPROACH



Key features

EAF



Operating Environment

- <u>Oxidizing</u> environment, so possible to remove trace elements, and tap liquid steel
- Batch process

Feed material requirements

- Due to <u>oxidizing</u> environment, DR grade DRI needed, to maximise yield (minimize slag FeO content)
- Can accept large quantities of scrap, without major constraints on scrap size

Electrodes

- Graphite electrodes

Final Products

- *Liquid steel*
- Slag is a waste product (not possible to sell to cement industry)

Gas cleaning

- Burnt gas (ie high CO_2 content, due to oxidizing environment, and combustion of CO in free board)

Maintenance life-cycle

- Fortnightly maintenance on shell refractory

Electrical system

- High flicker (inherent part of process), STATCOM is needed

A reference case: Tosyali Algerie (startup: 2018)

tenova

100% DRI, 2’300’000TLS PER YEAR

The furnace of Tosyali, that began operating in 2018, is the largest AND **most productive** furnace in the world operating with DRI .

Due to the very high DRI charging rate (>8t/min), the pellets are charged in two separate points between phases 1-2 and between phases 2-3 to minimize the entrainment of fines in the off-gases.

The furnace is based on the latest TENOVA design, allowing to swing independently the superstructure and the roof to allow quick and safe handling of the roof delta in less than 30 min.

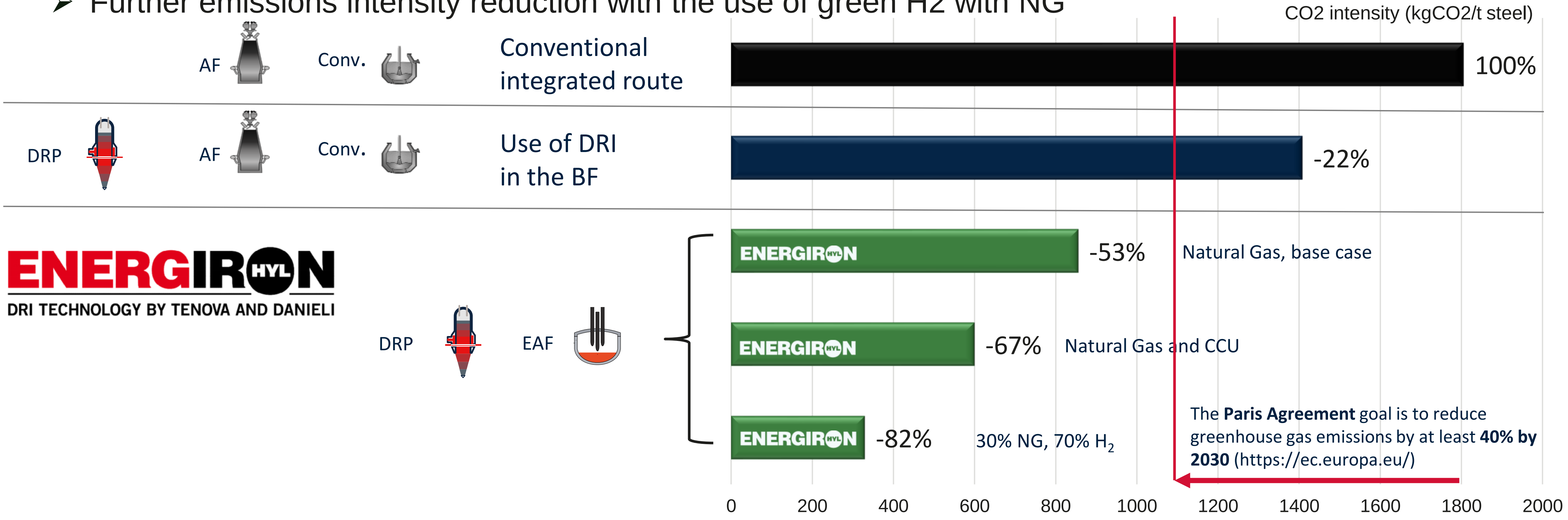
- **Plant Location:** Bethioua, Oran region, Algeria
- **Type:** full-platfomr AC furnace with EBT, shell diameter 8900mm
- **Tap size:** design 240t, 100t hot heel
- **Power ON:** 32,5’ with 70%HDRI, 30%CDRI (as of Feb.2020)
- **Yearly productivity:** about 2,2Mt (2020 projection)
- **DRI feeding rate:** up to 10t per minute, in two charging points
- **Transformer rating:** 240MVA
- **Injection system:** TENOVA, up to 17’000Nm3/h of oxygen

Between 2001 and 2020 TENOVA installed 28 EAFs operating with hot and cold DRI worldwide, and TECHINT group produces DRI since the ’50s.

ENERGIRON: the greenest ironmaking route

THE PATH TO CLIMATE NEUTRAL STEEL PRODUCTION - STEEL SUCCESS STRATEGIES 2020

- ENERGIRON DR-EAF route is ~50% less carbon intensive than the BF integrated process, ~60% less with CCU
- Further emissions intensity reduction with the use of green H2 with NG



BF-grade pellets in DRI-EAF route

EFFECTS OF GANGUE ON YIELD AND ENERGY CONSUMPTION

Considering production of low Carbon steel (0,03%C) from BF-grade pellets:

- Amount of fluxes required 100kg/tls, total slag generated 344 kg/tls with > 40% FeO
- Loss of iron in slag: about **122kg** per ton of liquid steel produced (FeO+iron droplets suspended in slag), yield 77%
- Energy for slag production: 689kWh/t

GREEN PELLET

Fe2O3	93.09%	min
Fe3O4	0.00%	min
FeO	0.10%	max
MnO	0.22%	max
SiO2	1.93%	max
Al2O3	1.76%	max
S	0.012%	max
P	0.010%	max
Cu	0.00%	max
TiO2	0.55%	max
CaO	1.72%	
MgO	0.39%	
C	0.00%	
Na2O	0.08%	
V2O5	0.07%	
K2O	0.08%	
Moisture	0.00%	

DRI

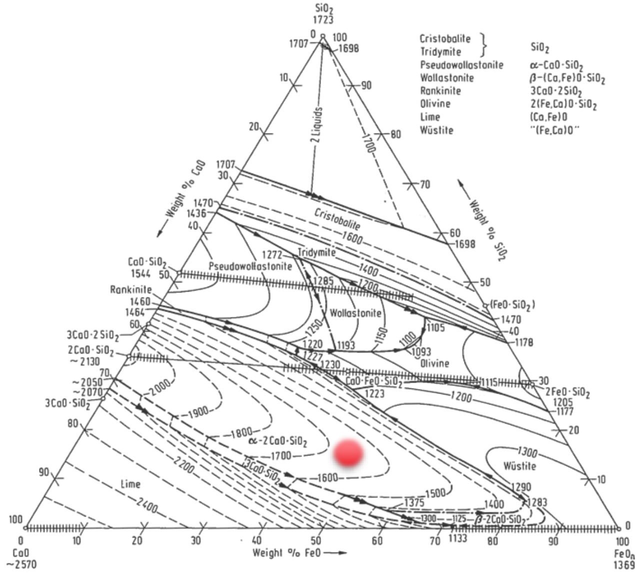
Fe total	87,43%
Fe metallic	82.18%
FeO	6.75%
Mn	0.23%
SiO2	**2.59%**
Al2O3	**2.36%**
S	0.016%
P	0.013%
Cu	0.00%
TiO2	0.74%
CaO	**2.31%**
MgO	**0.52%**
Na2O	0.10%
V2O5	0.09%
K2O	0.10%
C	2.00%
Metallization	**94.00%**

SLAG

FeO	42.01%
MnO	1.03%
CaO	22.31%
MgO	11.28%
Cr2O3	0.01%
Al2O3	8.82%
SiO2	9.73%
TiO2	2.68%
P2O5	0.13%
Other	2.00%
Total slag amount	344,6 kg/lts

LIQUID STEEL

Yield	77.03%
C	0.035%
Mn	0.009%
P	0.004%
S	0.008%
Cr	0.001%
O	1242 ppm
Temperature	1640 °C



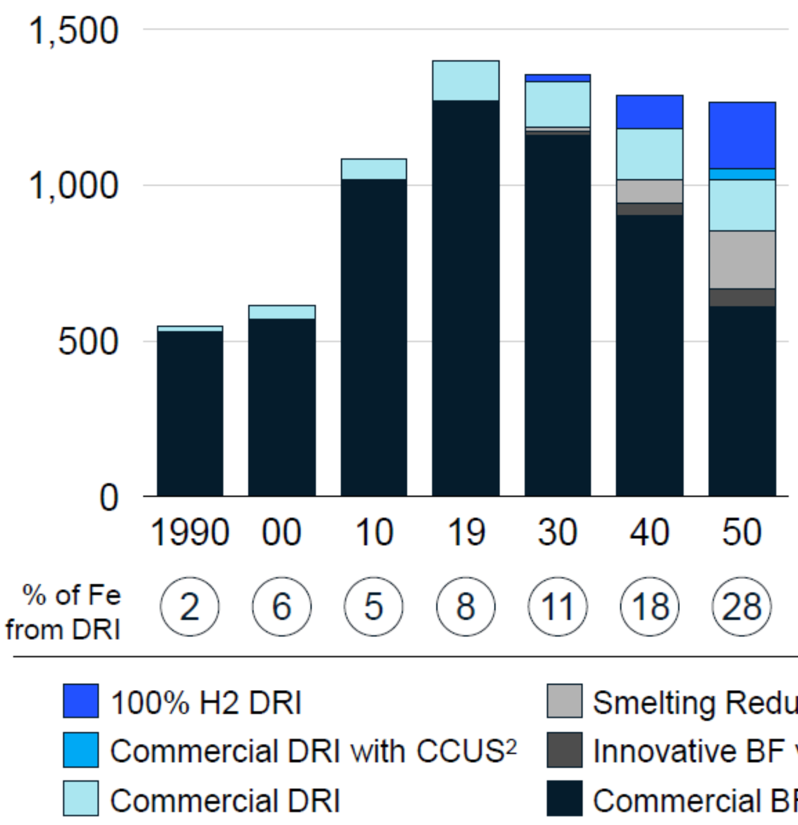
- Effective removal of Phosphor in EAF requires IB_2 (CaO/SiO2)>2
- 0,03%C in liquid steel at end of refining implies FeO in slag >40%
- Slag formers require twice as much energy as Iron to melt

The IEA states that a CO_2-neutral industry needs 170 Mt of DRI in 2030, rising to 410 Mt by 2050

DRI production under IEA Sustainable Development Scenario

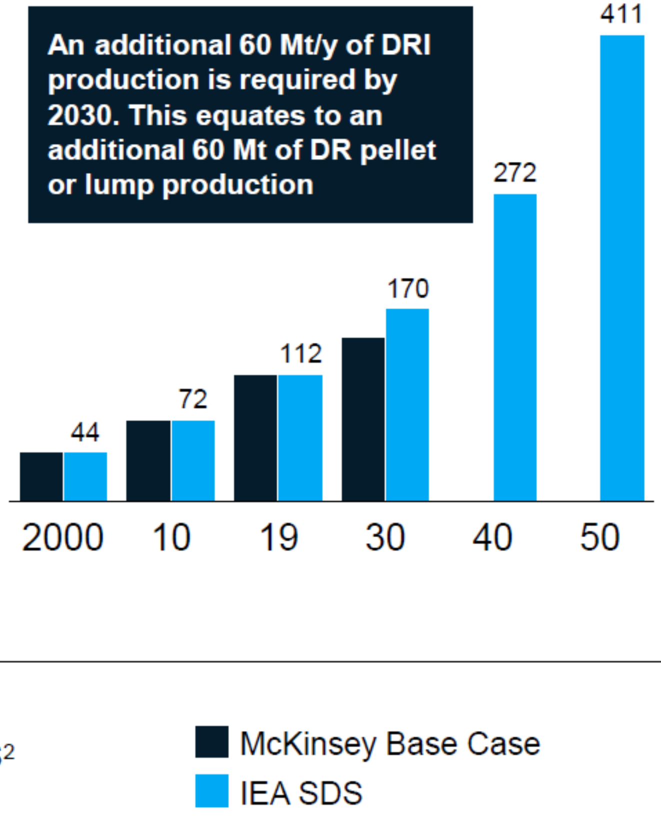
Iron production under IEA SDS[1]

Million Tonnes Fe by production method



DRI Production

Million Tonnes



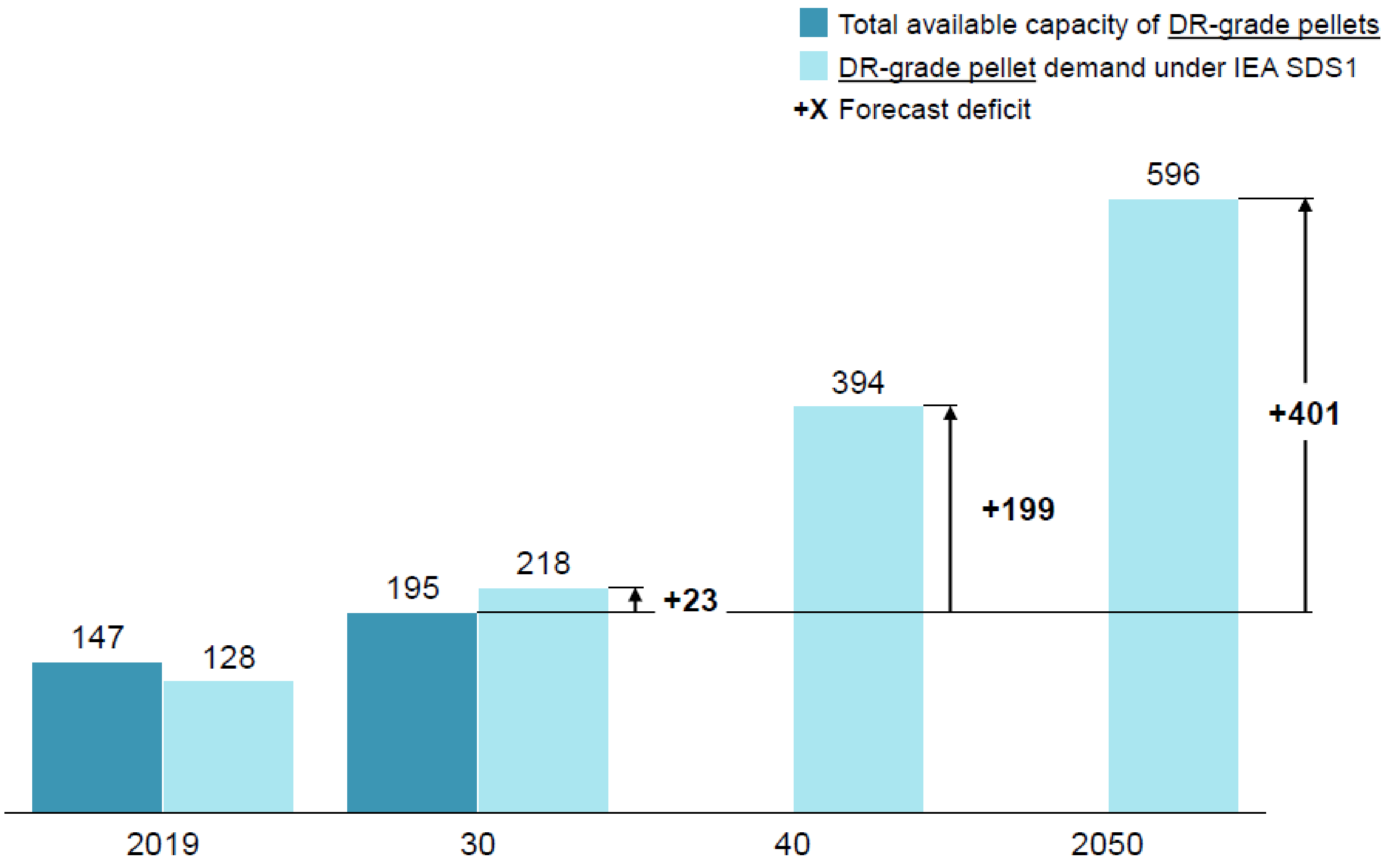
- The IEA Sustainable Development Scenario envisages a reduction in emissions in line with the Paris agreement, reaching a global "net-zero" CO_2 emission position by 2070
- This provides an explicit forecast of DRI production that we can compare to the relatively more conservative base case
- The IEA SDS is more aggressive in 2030, requiring 170 Mt of DRI production, as opposed to 145 Mt in the base case, an increase of 18%

1. International Energy Agency Sustainable Development Scenario - carbon neutral by 2070
2. Carbon capture usage and storage

Source: IEA iron and steel technology roadmap 2020

The IEA scenario shows that the DR pellet market will fall into deficit in the next decade

Supply & demand balance of direct reduction grade pellets



Looming deficit

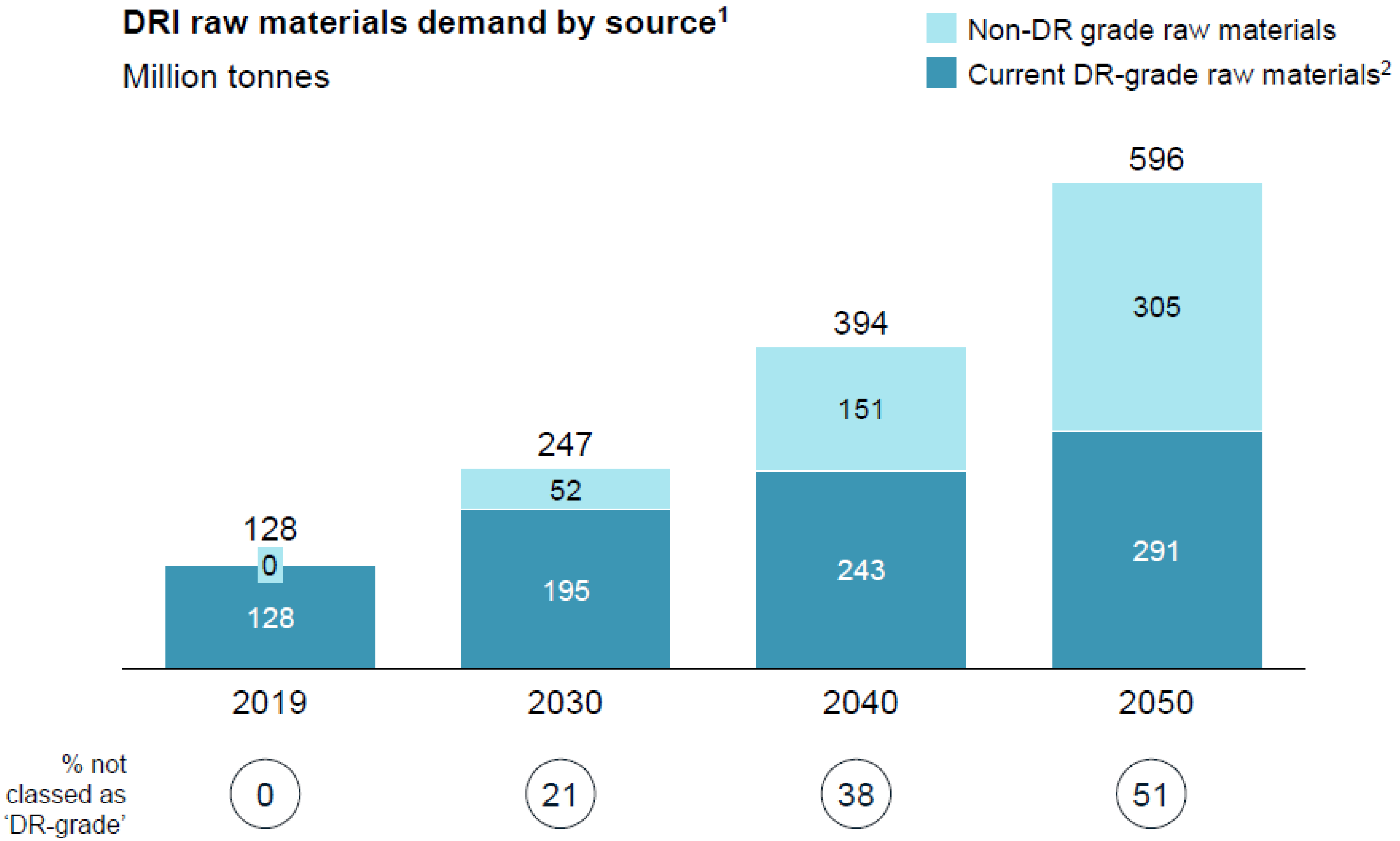
- The DRI market currently has access to sufficient raw materials
- However, before 2030 a deficit will emerge between the DRI production needed to keep the steel industry on a pathway to decarbonization
- Then, from 2030 to 2050, an additional 378 Mt of DR pellets (or other raw material) need to be brought online, trebling the size of this industry in 20 years

1. Based upon IEA SDS – International Energy Agency Sustainable Development Scenario

Source: MineSpans, McKinsey Iron ore demand model, IEA

Increasing amounts of low-quality (BF-grade) iron ore could be used to make DRI

IEA Sustainable Development Scenario - raw material implications



DRI consumption trends

- Under the IEA's Sustainable Development Scenario, an increasing share of raw materials for DRI production must come from iron ore that is too low-quality to be currently classified as DR-grade
- Current processes to upgrade lower-quality DRI for use in EAFs are more costly than using pig iron and emit further CO_2, lessening the environmental impact of higher usage of DRI
- One area of active development is technologies that convert DRI into hot metal for use in BOFs. This would allow the use of low-quality iron ore while still keeping carbon intensity low

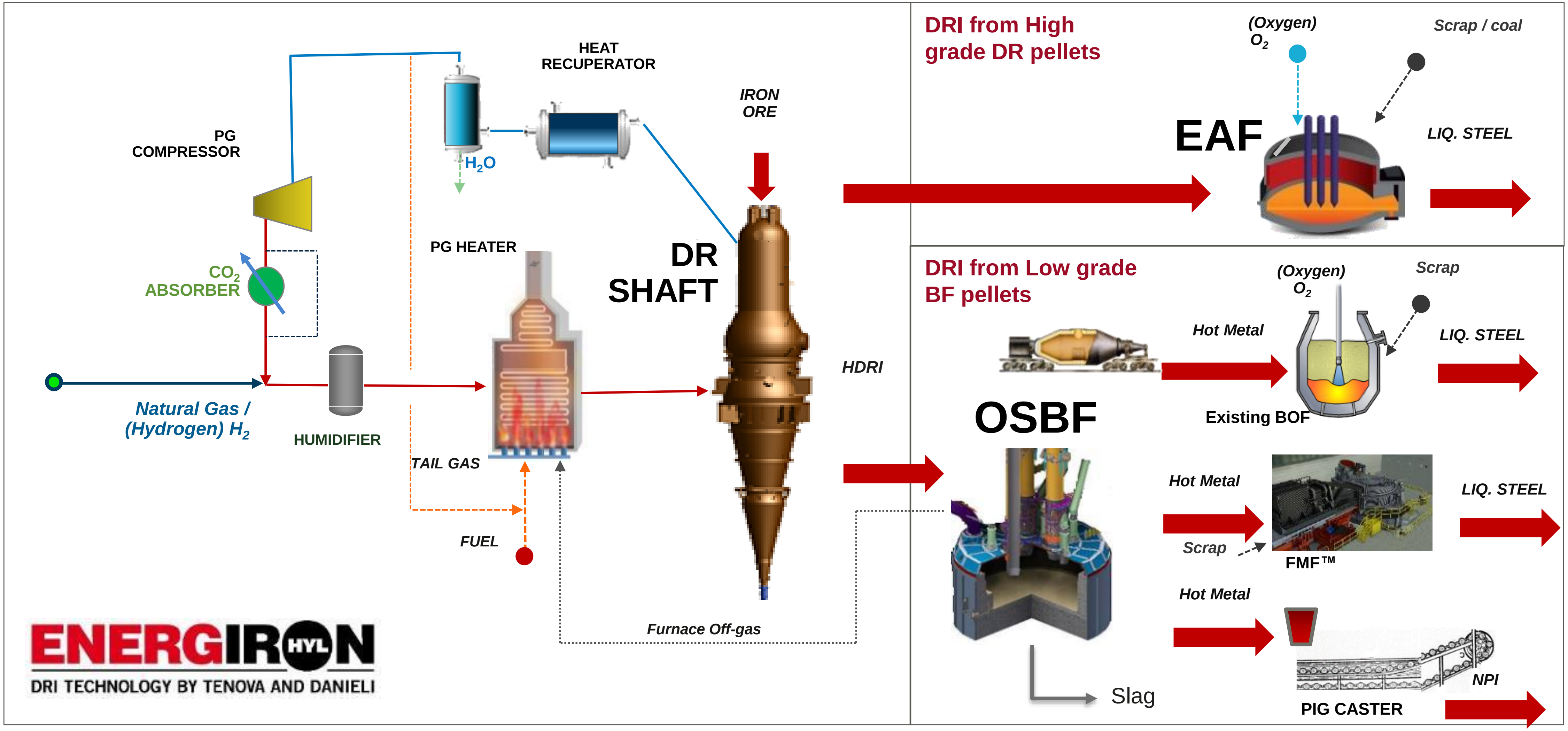
1. Assuming raw materials yield of 1.45:1
2. Using MineSpans base case to 2030 and linear extrapolation forwards

Source: McKinsey analysis, IEA SDS, MineSpans by McKinsey

iBlue: HM via Open Slag Bath Furnace

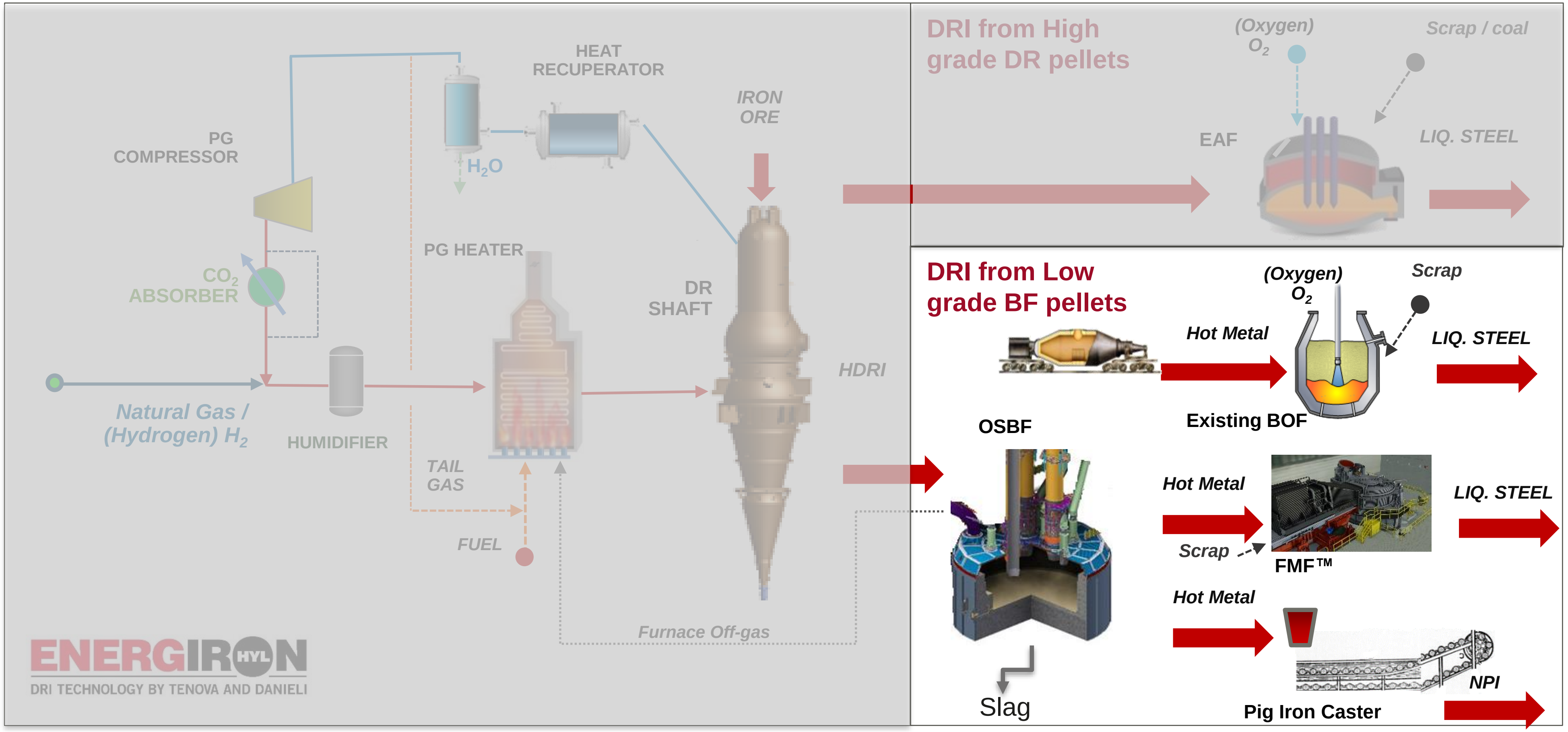
Routes for low carbon steelmaking

TODAY AND TOMORROW



Routes for low-C footprint steelmaking

GENERAL APPROACH



Evolution of steelmaking flow sheet

REPLACE BLAST FURNACE, REDUCE CARBON EMISSIONS

Pellet requirement	Direct Reduction	Hot Metal	Steelmaking

Existing

BF grade pellet

Sinter

Lump

Coke

Hot metal
± 4% C
± 0.3% Si

Liquid Steel

DRI-OSBF

BF grade pellet

Natural gas / H_2

Hot DRI

Hot metal
± 4% C
± 0.3% Si

Liquid Steel

>50% less CO_2 emissions

Tenova vision for the decarburization transition

The TENOVA Approach to support the industry to reach the carbon footprint reduction:

ENERGIRON DRI Technology, jointly developed by Tenova and Danieli, to produce high quality reduced iron

+

a) An **Electric Arc Furnace (EAF)** for liquid steel production, and/or,

b) An **Open Bath Slag Furnace (OSBF)** for hot metal production

Is this transition enough for the long term objective?

Yes, but complementing, **Hydrogen** needs to be used

SOME FACTS

Many technologies are being studied for the decarburization of the industry.

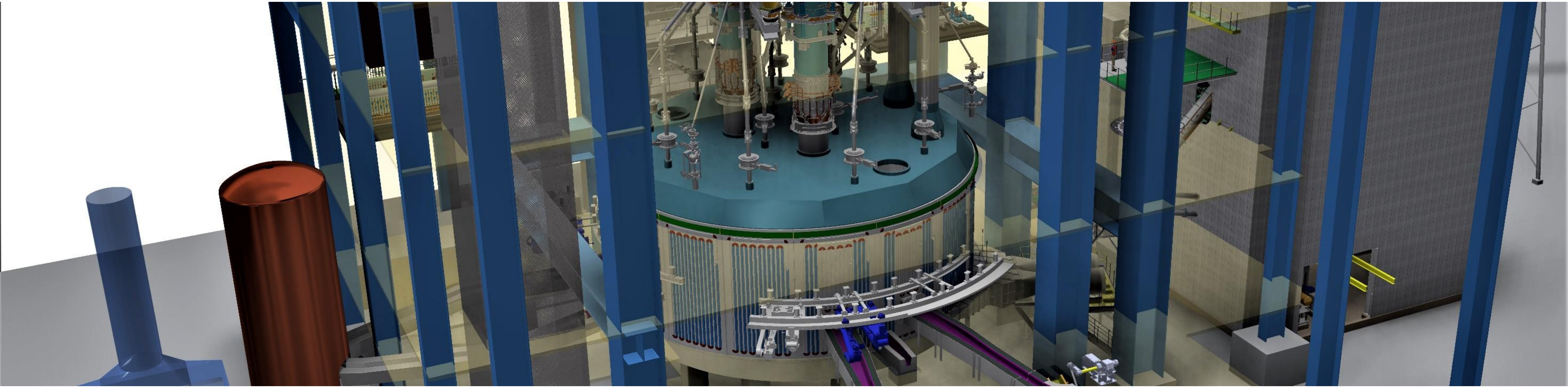
So far only gas based direct reduction has been proven and readily available at industrial scale as a reliable vehicle to industry decarburization.

The use of high percentages of hydrogen (up to 100%) as reduction gas allow a terrific abatement of CO emissions

Direct reduction iron needs to be molten in an electric arc furnace.

iBLUE® TECHNOLOGY

DECARBONIZATION STRATEGIES



Reinventing Integrated Steelmaking

> Pig Iron production via Direct Reduction

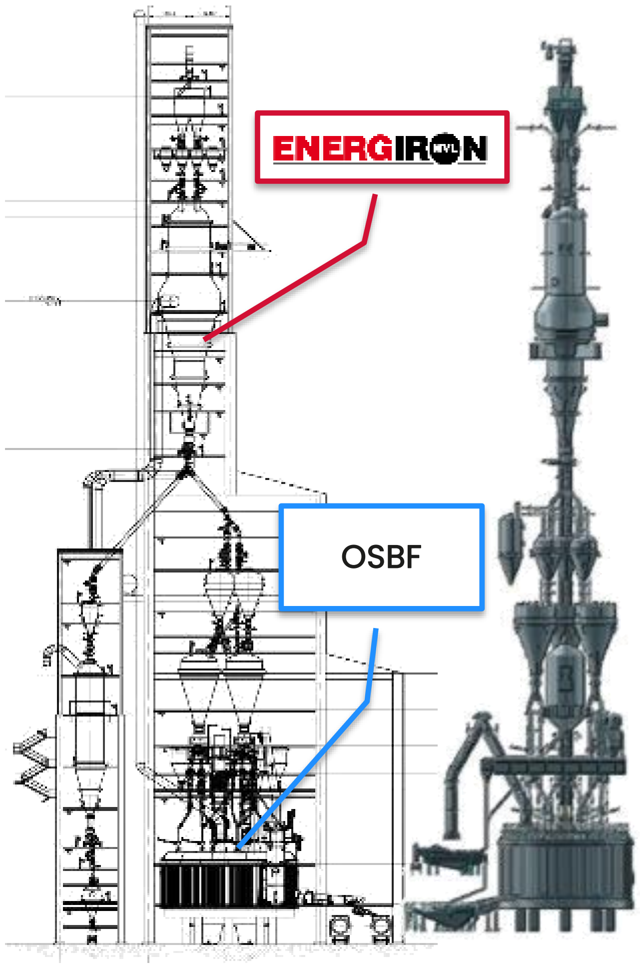
Natural gas–based Pig Iron production

MERGING TWO PROVEN TECHNOLOGIES OF TENOVA

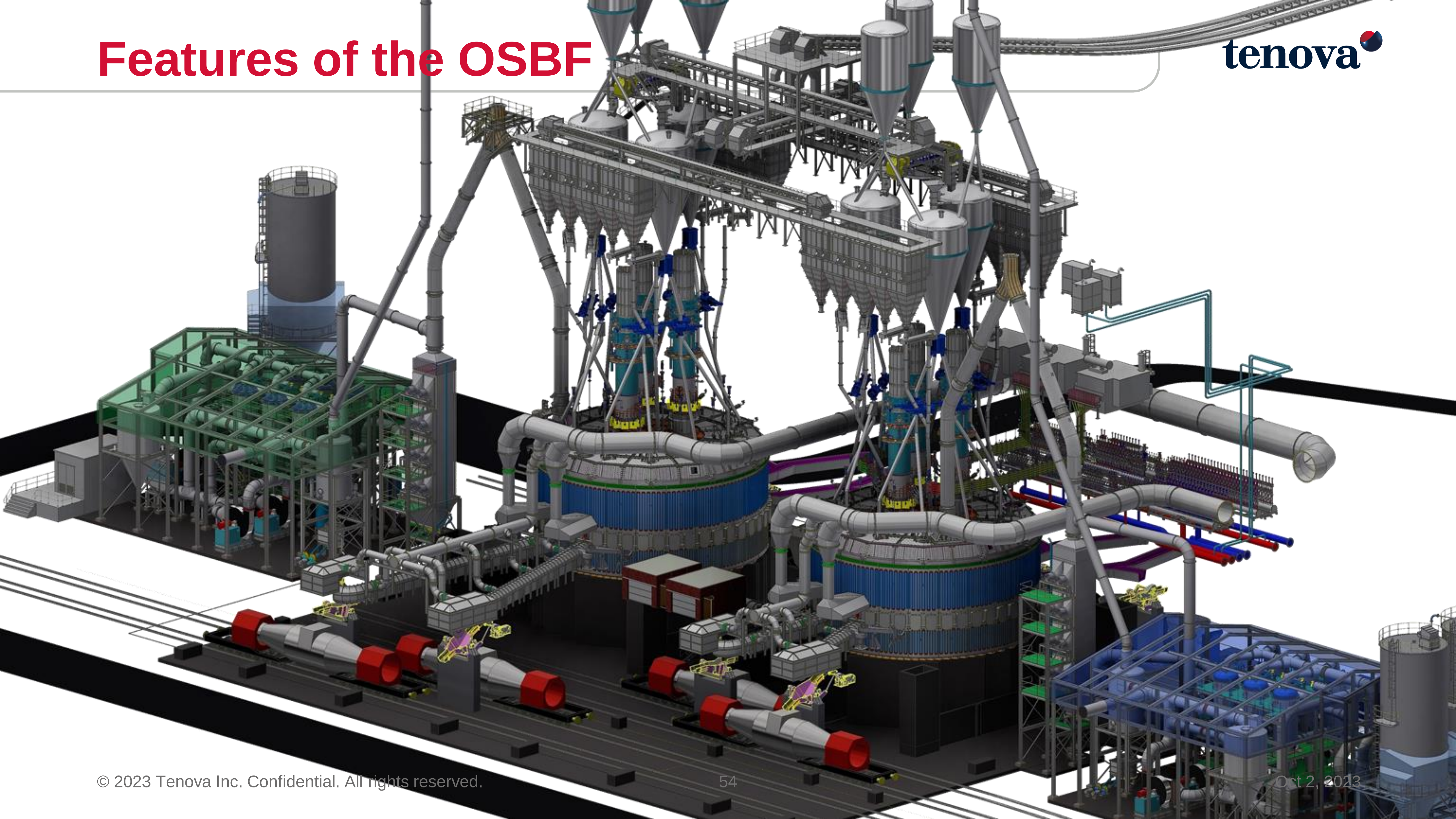
IRONMAKING REINVENTED

Valuable production of **Hot Metal / Pig Iron** thanks to:

- ✓ ENERGIRON High-C DRI + Reducing Arc Furnace
- ✓ DRI C content > 4.0%
- ✓ More than 90% of Carbon bonded as Fe_3C
- ✓ Maintaining downstream BOF facilities, just replacing the BF
- ✓ **Use of conventional BF-grade pellets**
- ✓ BF-like slag by product for the concrete industry
- ✓ Optimized Capex for the lowest possible CO_2 footprint



Features of the OSBF



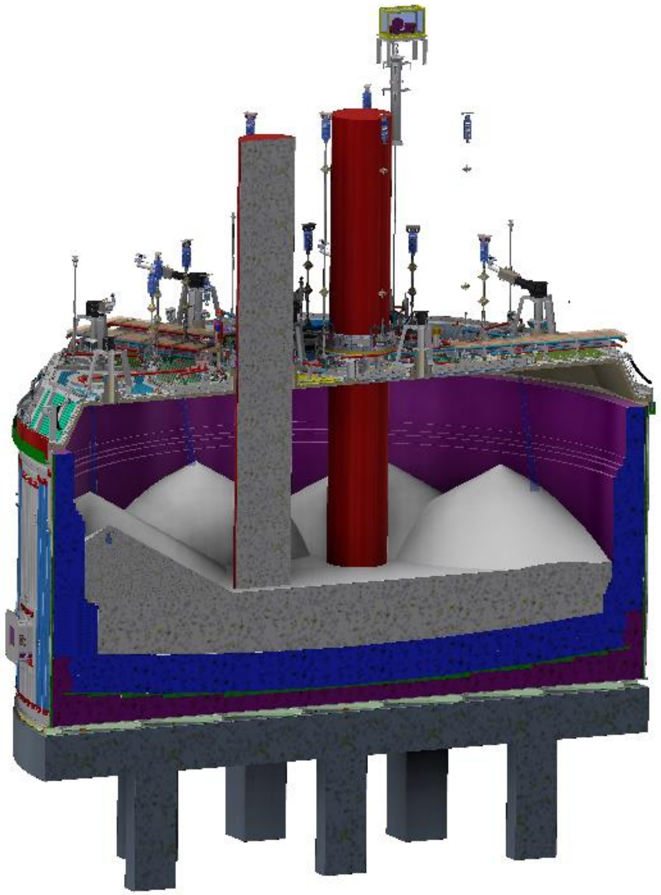
What is an OSBF?

Submerged arc furnace design, operating in brush arc mode

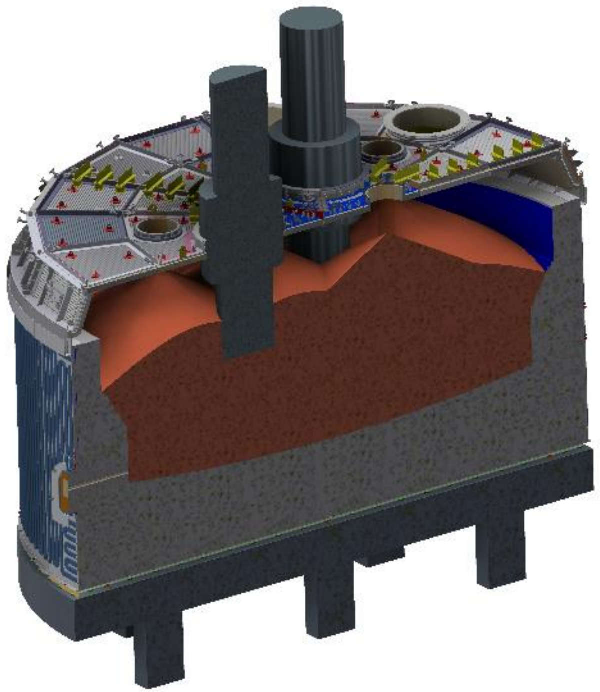
OSBF = ‘Open Slag Bath Furnace’

- Conventional SAF design, but operating in Brush Arc Mode
- Portion of pellet feed is small (6mm), so bed is not that porous
- Very little reductant/flux addition
- Arc length 20 – 50mm, not immersed
    - Depending on specific slag properties, can operate in immersed arc mode
- Feed pile design is critical

OSBF operation



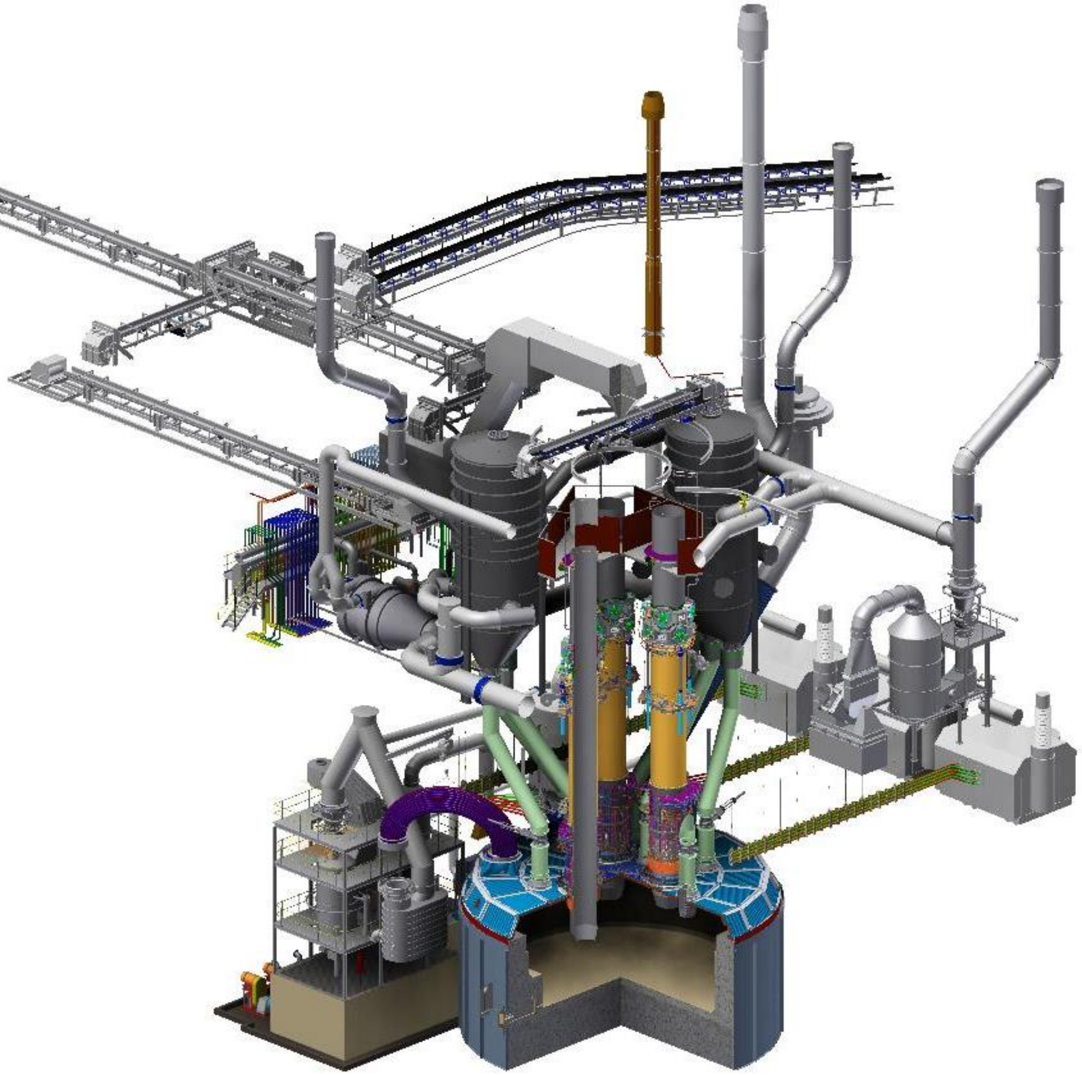
SAF operation (Ferroalloy design)



Tenova Pyromet

Large capacity SAF furnace

Kazchrome Aksu shop 6 renovation project – 1 x 81MVA (2015)

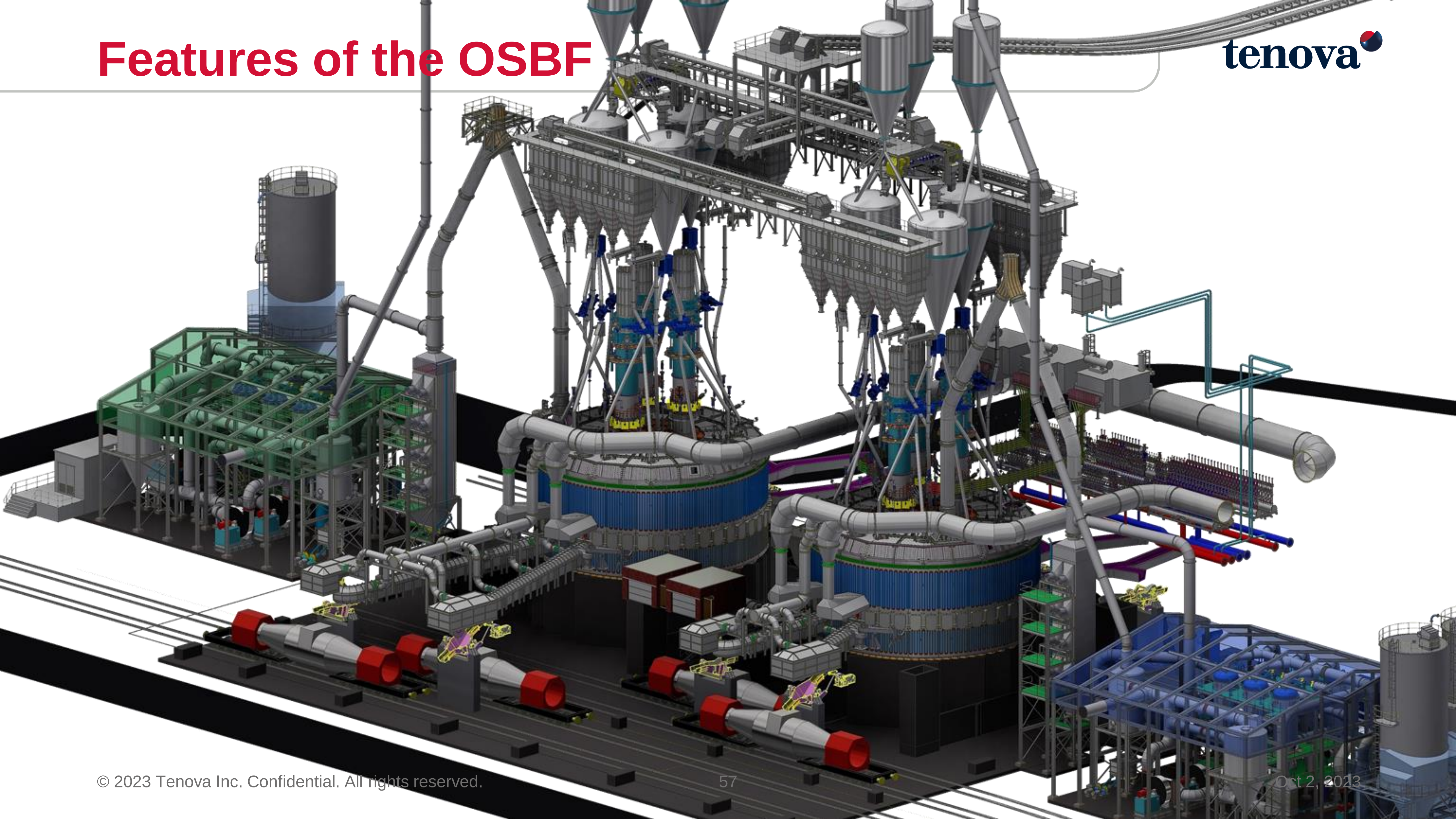


Aksu Shop 6 Renovation Project – 65MW power input

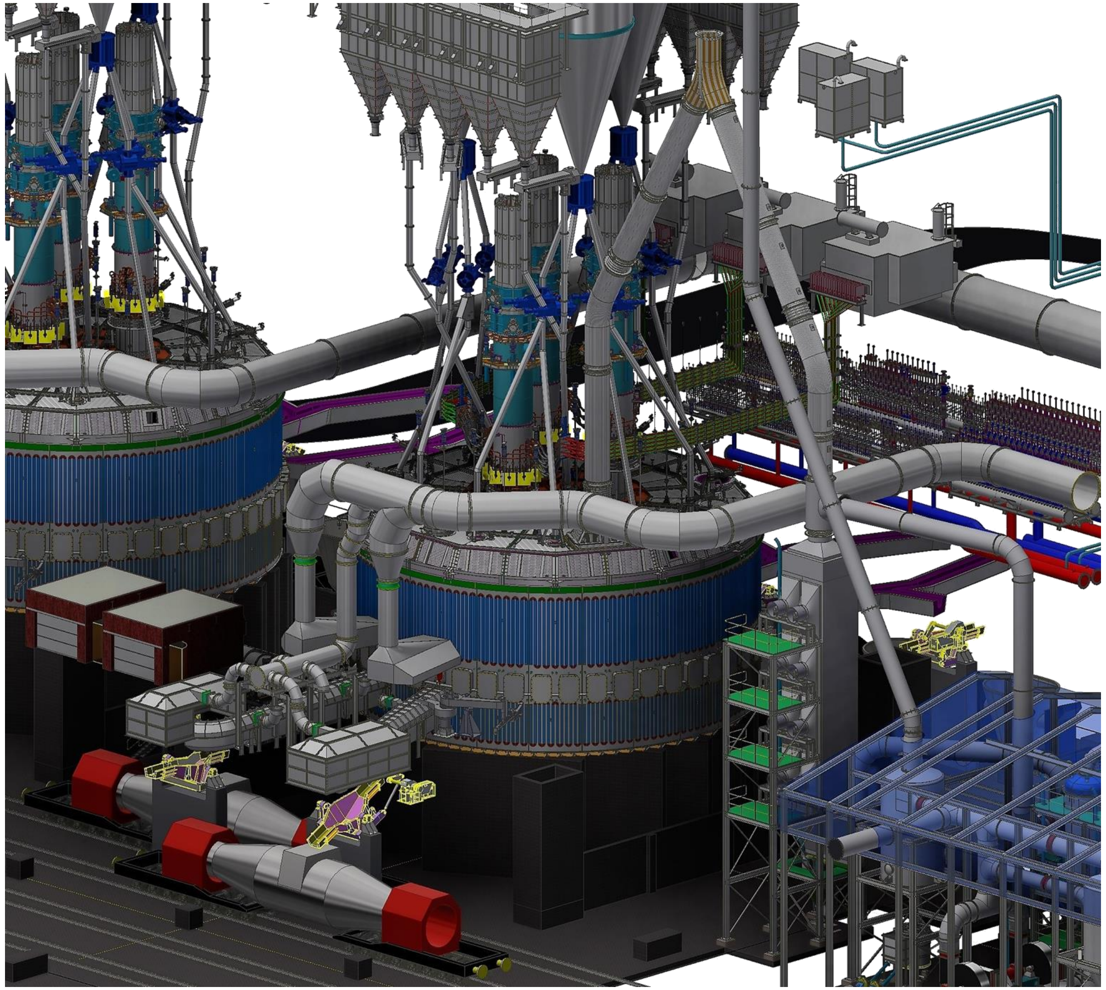
- Basic engineering for complete aksu shop 6 (4x81MVA FeCr furnaces)
- Detail engineering and equipment supply for shop 64
  - Patented Multiple pre-heater
  - 1,700mm Soderberg electrodes
  - Wet gas scrubbing plant
  - Shell ID – 16,500mm
  - Furnace transformers, designed to receive power at 220kV with secondary compensation built into furnace transformer

Power on! 19 July 2019

Features of the OSBF



Features of the OSBF



Furnace Atmosphere

- **Reducing environment**, allowing slag modification and re-carburization
- **Steady state** process

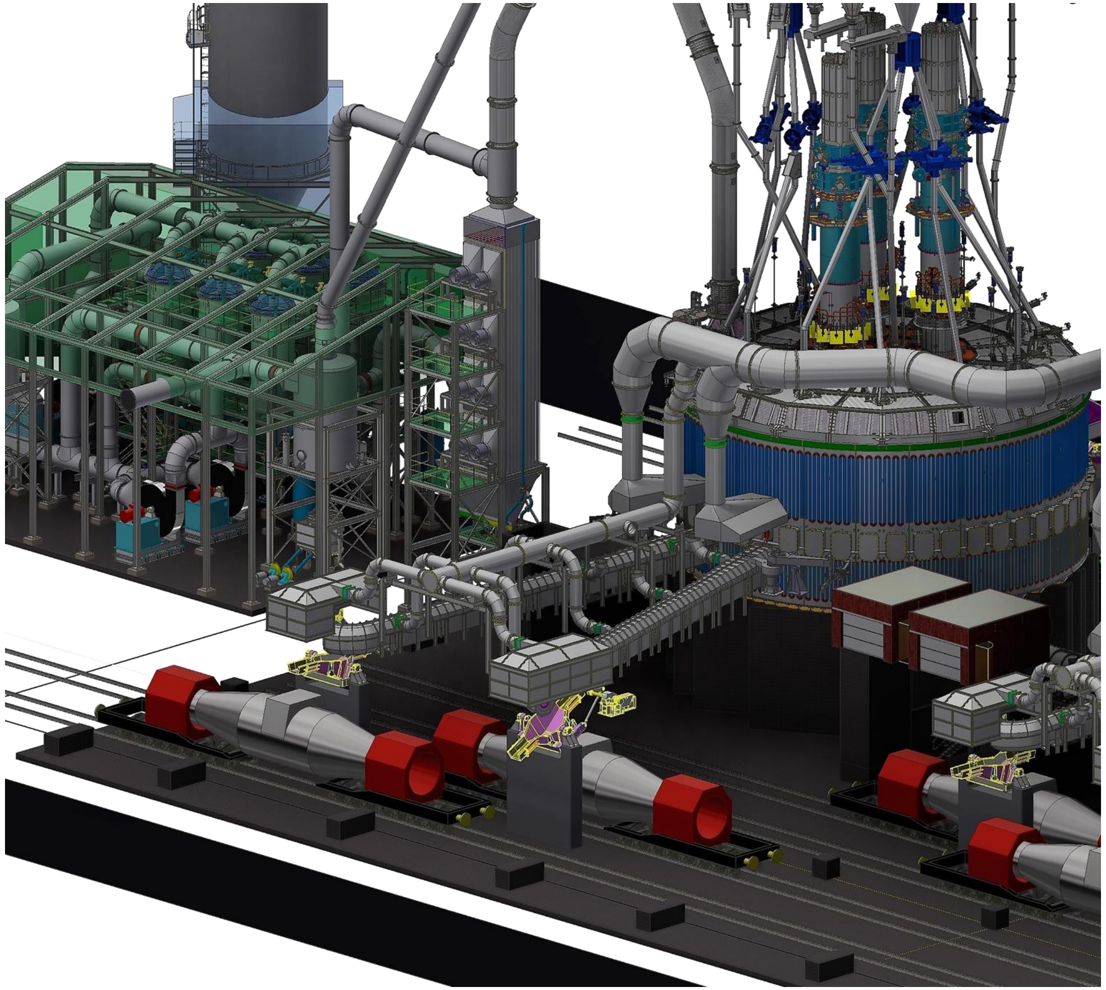
Feed material requirements

- **BF grade pellets** can be used, as slag can be modified to reduce FeO content to 1%
- Due to **sealed design** and process, slag additions are limited (± 50mm top-size)

Final Products

- ***Hot metal***, similar to blast furnace pig iron
- **Slag**, as sellable product similar to BF slag

Features of the OSBF



Electrodes

- **Soderberg** electrodes

Electrical system

- Due to very **low operating resistance**, minimal impact on electrical grid

Gas cleaning and recycling

- **CO-rich furnace gas** produced, with high chemical energy content, reusable in the process gas heater of Direct Reduction

Maintenance life-cycle

- **10+ years** for shell refractory

Design a flexible feed system

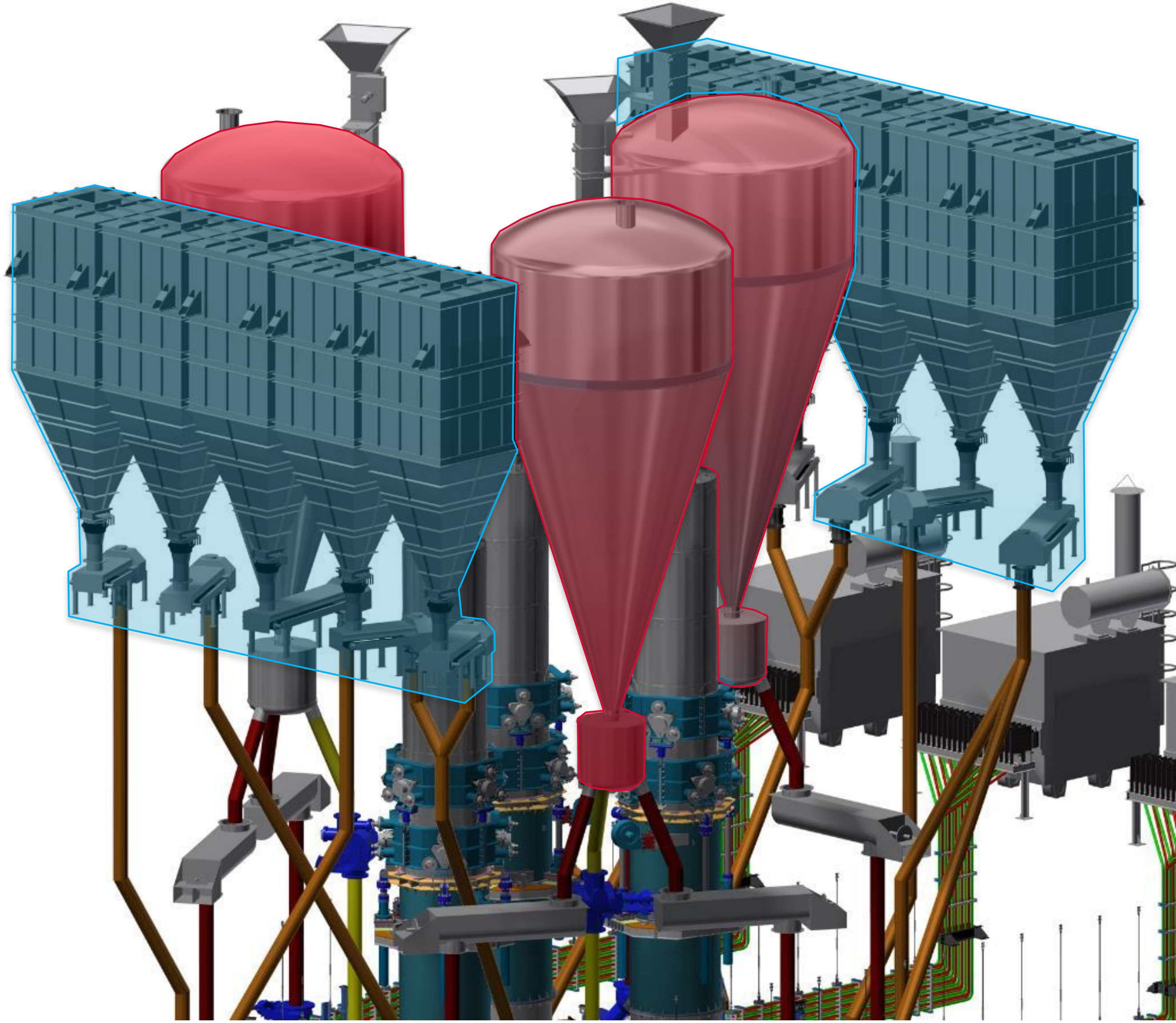
Understand the process requirements

Primary feed system

- HDRI
  - HDRI feed a function of DRP availability
- Can be used for CDRI (but never a blend of HDRI and CDRI)

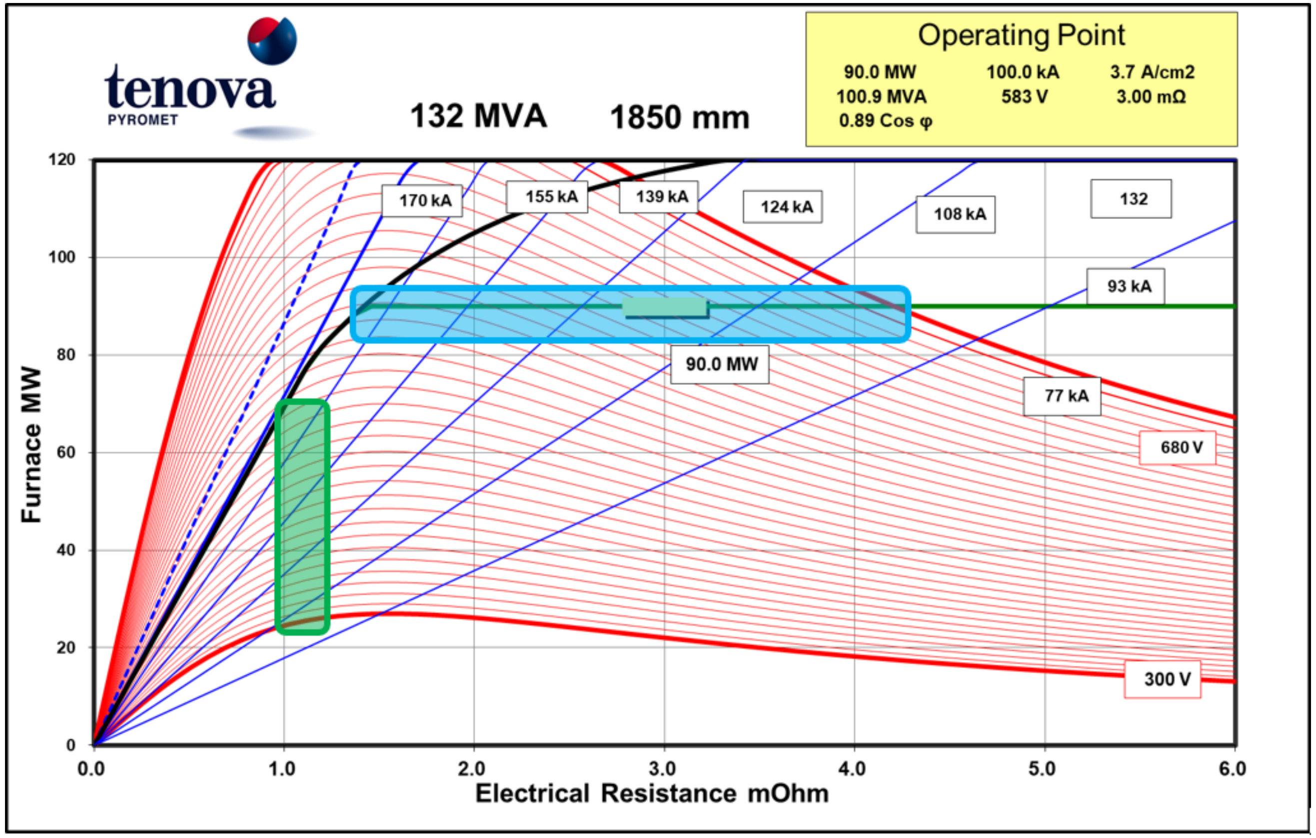
Secondary feed system

- Separate feed, so not dependent on DRP annual availability
- All reductant and fluxes
- Other Fe containing materials



OSBF Electrical Design Parameters

WIDE OPERATING RANGE – GIVING OPERATORS MAXIMUM FLEXIBILITY



Fundamental design concept

- Wide operating mode for submerged and brush arc
- Additional MVA needed for submerged arc mode provides additional MW at higher operating resistances

Submerged Arc Mode: SAF

- Lower furnace operating resistances (< 1mΩ)
- 'Slower reaction' operating conditions
- Typically used for start-up conditions

Brush Arc Mode: OSBF

- Higher furnace operating resistances (2 – 4.5mΩ)
- Requires faster power-feed control

OSBF-EAF Differences in Slag Chemistry

HOW PELLET QUALITY IMPACTS OSBF AND EAF PERFORMANCE

OSBF

- Can use both **BF and DR grade pellets**
- Due to reducing environment FeO is reduced, improving yield, **minimizing FeO content in slag**, regardless of pellet composition, **producing a slag saleable to the cement industry**
- A lower quality pellet will require more electrical energy to produce the Hot Metal

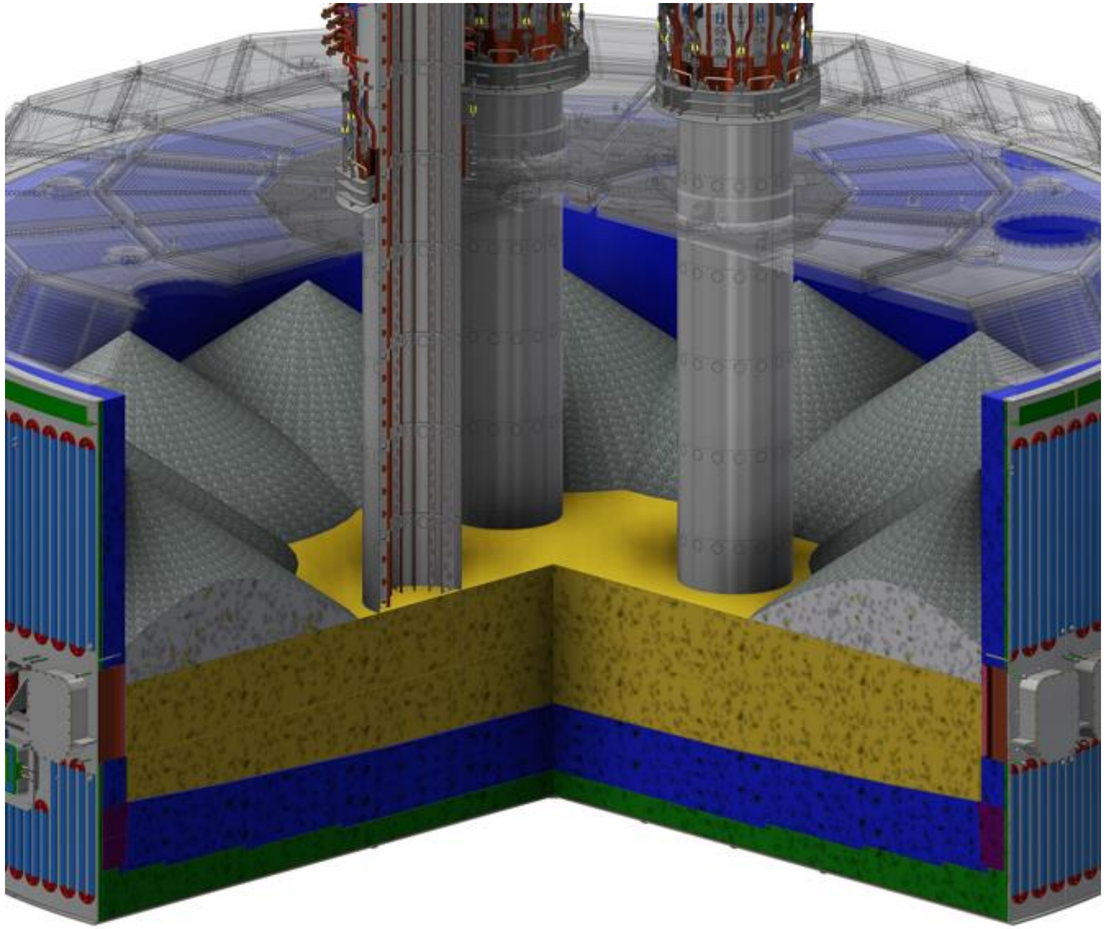
EAF

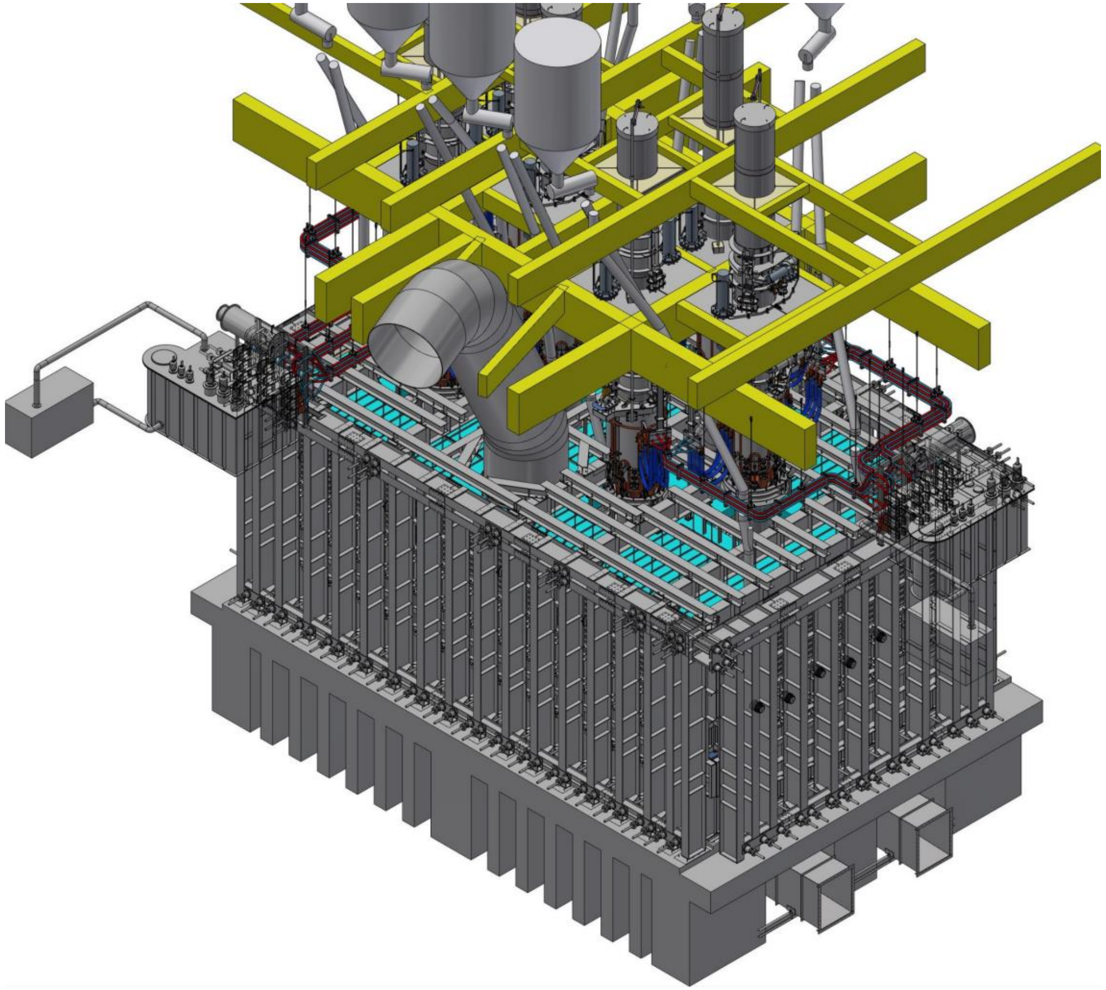
- The higher the gangue percentage in the DRI, the more slag is produced
- Slag basicity is a key part of the EAF process, and the **EAF cannot process high quantities of gangue** (therefore no BF grade pellets)
- Higher slag volumes = lower yield, and impacts furnace operation (as the EAF is not designed for high slag volumes)

OSBF-EAF Differences in Process

Production parameters	Unit	OSBF	EAF
Maximum annual production	Mt/a	**1.0 – 1.2 Hot Metal (110MVA)** *(depending on DRI grade)* *Downstream refining still needed*	**2.5 – 3.0 Liquid Steel (240MVA)** *(no further refining needed)*
Slag	kg/t	**80 – 120** *Slag meets cement industry requirement (revenue generator)*	**120 – 150** *High FeO content (up to 20%-30%)*
Energy consumption	kWh/t	DR grade: **450 - 500** BF grade: **500 - 600**	DR grade: **380 – 450** *(dependent on charge mix)*
Electrode consumption (based on $3/kg for graphite electrode)	$/t product	**2 – 2.5** *Soderberg paste, 80% saving on graphite electrodes*	**± 3** for Liquid Steel *Higher productivity will lead to lower electrode consumption*

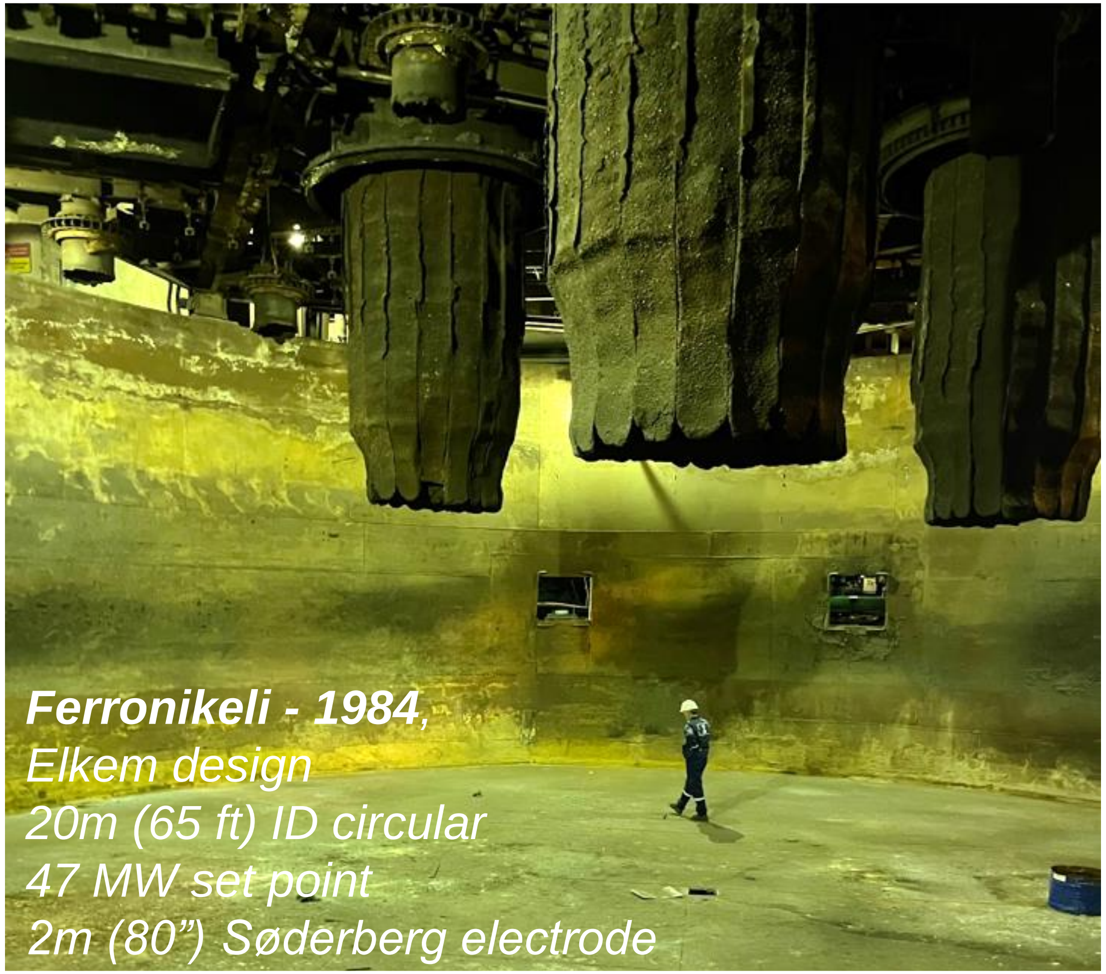
Circular OSBF vs. Rectangular OSBF





OSBF References

LIMITED REFERENCES FOR PIG IRON PRODUCTION FROM PRE-REDUCED IRON FEED



OSBF References for ironmaking

Circular

Used at Highveld Steel and IDI for DRI melting

- 38 – 42 MW

Rectangular (six-in-line)

Used at New Zealand Steel for DRI melting

- 39 – 43 MW

OSBF for other commodities

Circular

- 94 MW (FeNi)

Rectangular

- 90 MW (FeNi)

Key consideration for reference installations is whether the process is a slag rich process

Circular vs. Rectangular Summary

Circular design

Advantages

- Lower energy consumption requirement (~15% less)
- Lower maintenance (3 electrodes vs. 6)
- Simpler feed system design
- Simpler shell design, simpler construction
- Can stand higher hearth power densities
- Better bath stirring
- Simpler / smaller auxiliary systems

Challenges

- Limited power input

Rectangular design

Advantages

- Higher absolute MW rating potential

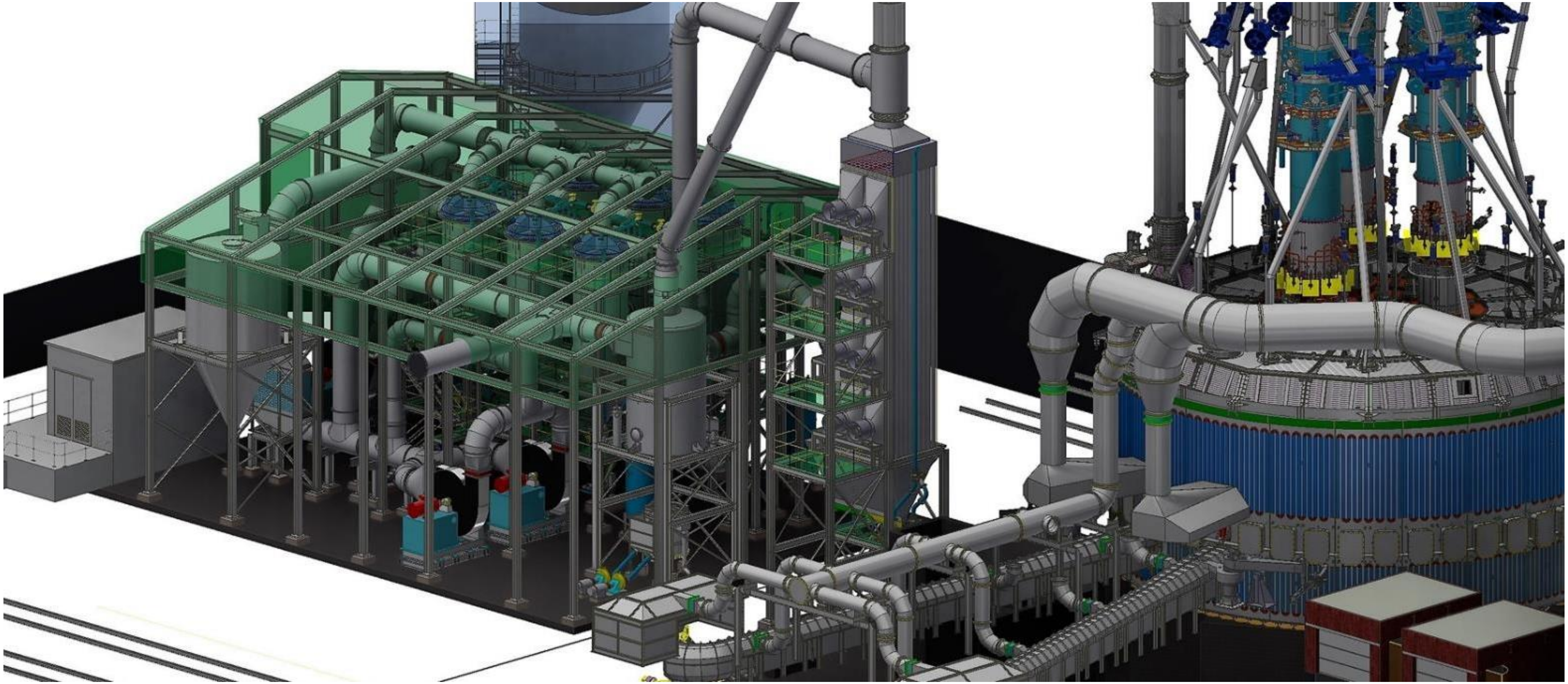
Challenges

- Footprint: 110MW furnace is 40m x 15m
- Long term sealing arrangements of the furnace
- Feed system design – ensuring homogenous feed profile over large area
- Higher capex / opex

SAF users prefer circular furnaces whenever their application (process and power) is possible.

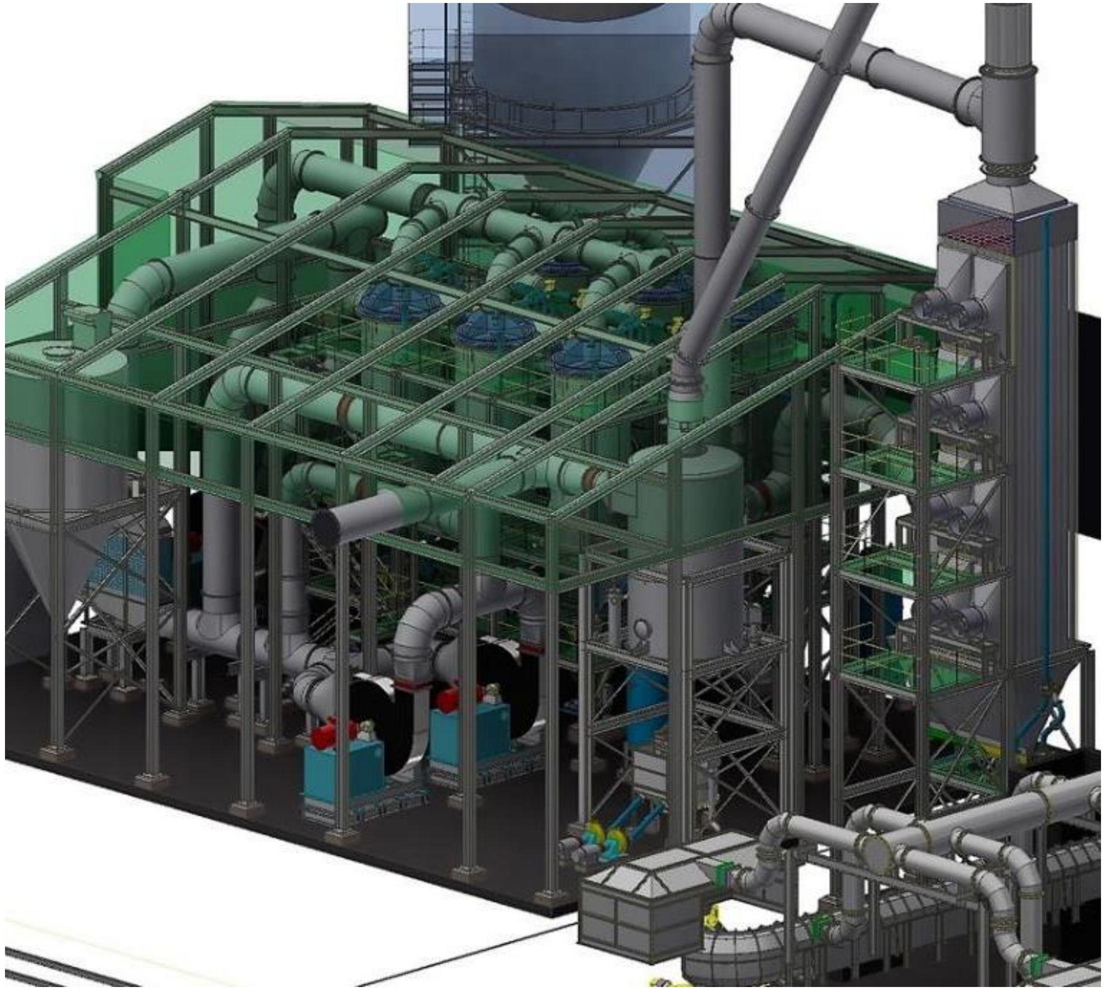
Gas cleaning technology

PATENTED DRY GAS CLEANING SYSTEM – 90% REDUCTION IN WATER CONSUMPTION



Minimize CO_2 emissions

MAXIMISE THE POTENTIAL OF iBLUE FLOW SHEET



Sending clean CO-rich gas to the ENERGIRON® Process Gas Heater:

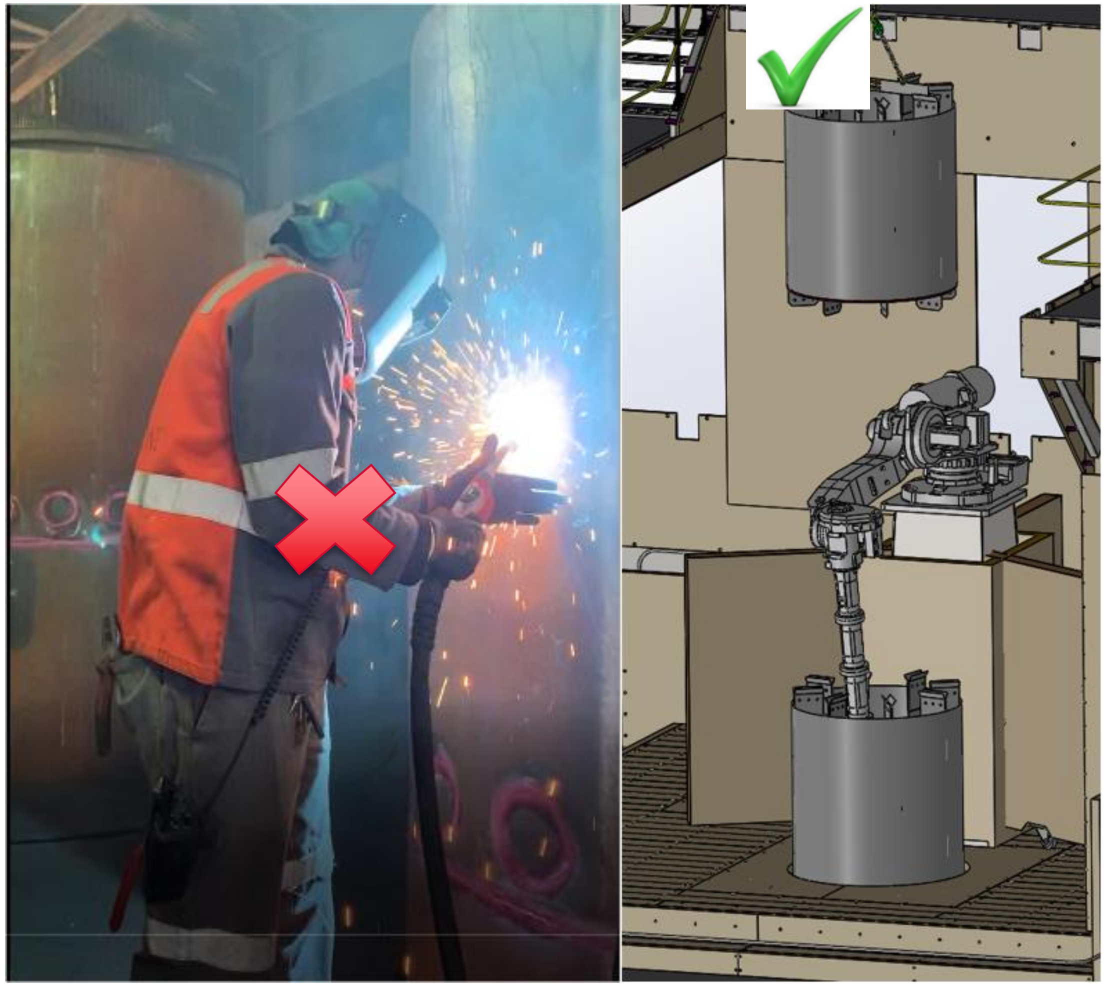
- **Reducing Natural Gas consumption**: OSBF gas is a 'free' substitute to fuel
- The Combusted OSBF gas is absorbed in existing DRP gas handling system, meaning no dedicated equipment is needed for the gas sequestration

Can such gas can be used otherwise?

- Yes, it can be combusted, heat can be recovered in a Waste Heat Recovery System, and CO_2 shall be captured: its more expensive and less efficient

Robotization and Digitalization Examples

USE TECHNOLOGY TO MAKE THE PLANT SAFER

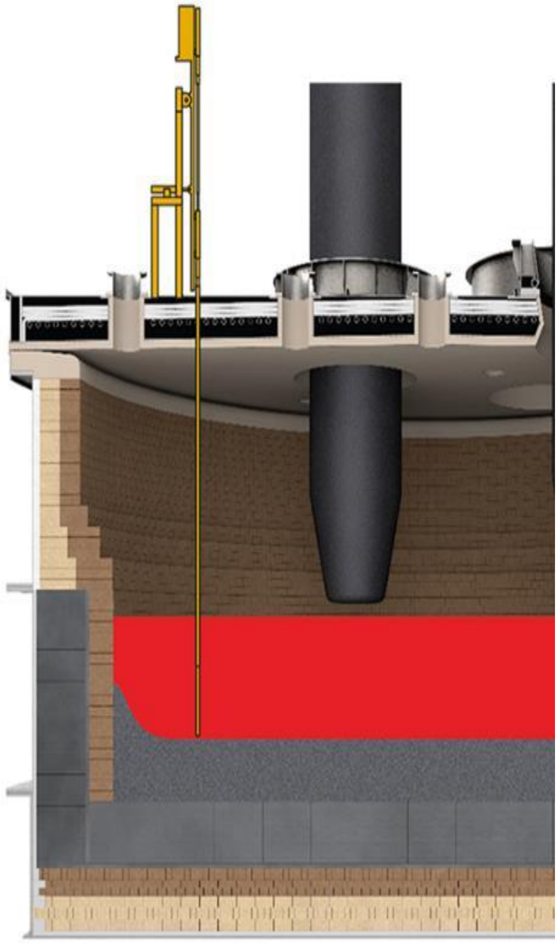


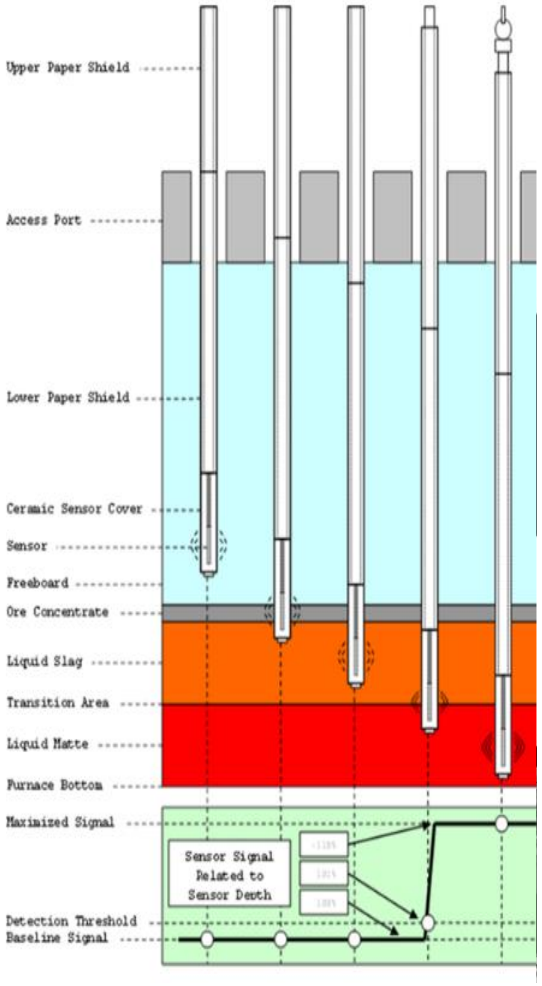
Automated casing welding solution

- **Robotized welding of steel casings** during casing extension avoids prolonged presence of operators on the casing floor
- **Removes potential hazards** related to welding and potential flames from the furnace.
- **Ensures reliability and consistency** of the welding process

Digitalization and new sensors

DIGITALIZATION ALLOWS SAFER AND HIGHER QUALITY PERFORMANCES





Automated bath sounding solution

- Automated hoist with encoder
- Thermal camera combined with image processing to differentiate between matte and slag levels on dip bar

The Greenest Pig Iron plant in the World

tenova

mine and plant already fully permitted
producing High Purity Pig Iron, V, TiO_2
As low as ~0.6 tCO2/t using NG
already set up to use H_2

Port Saguenay, Quebec

BLACKROCKMETALS

A mix of proven Tenova proprietary technologies

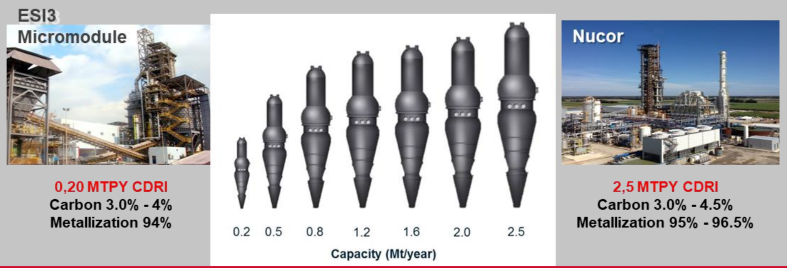
TENOVA masters all technologies involved with a 50 years experience

DRP

HyL started first pilot in 1984. HyL is THE world recognized brand for Direct reduction.

2006: strategic alliance “ENERGIRON” with Danieli.

21 DR Plants worldwide

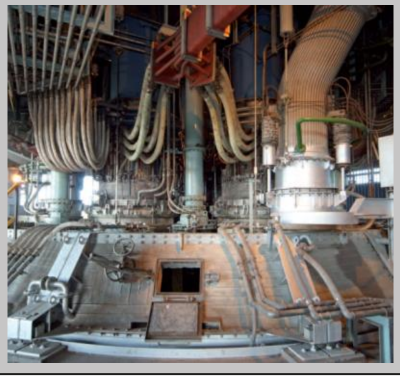


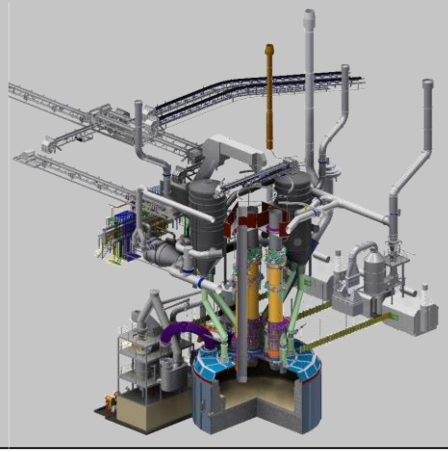
40+ years of experience in DRP

OSBF

Tenova Pyromet is the result of the successful merger between the submerged arc furnace division of Techint Technologies (Tagliaferri) and Pyromet Technologies.

First furnace in 1968 and today counts 300+ references in the world





iBlue as future proof technology

ADDING A FMF® DOWNSTREAM ALLOWS INCREASE OF SCRAP UTILIZATION AND substitutes BOF

Tenova FMF® furnace melting hot metal and scrap to produce steel

Increasing the hydrogen utilization requires a flexible handling of the metal in a way to follow the process as hydrogen becomes more available.

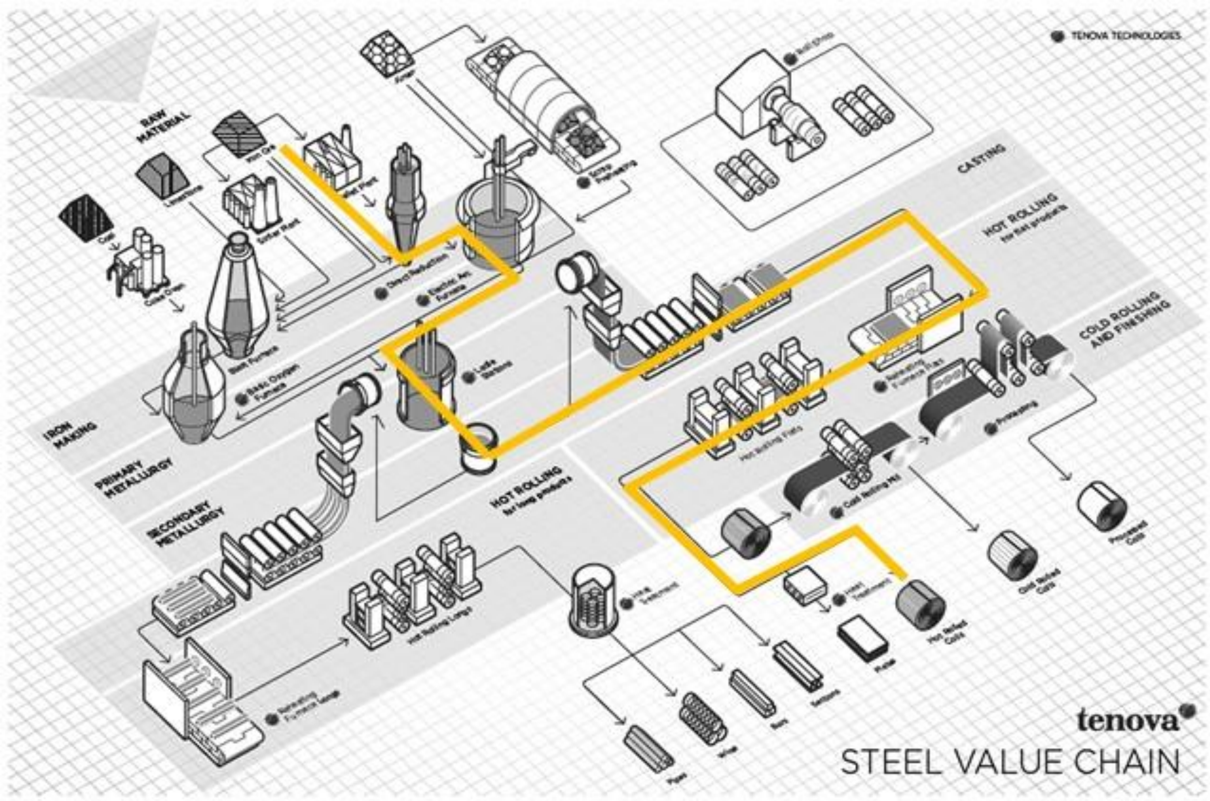
FMF® (Flexible modular furnace) concept allows to charge high percentage of HOT METAL (80-90%) into a furnace with continuous feed of scrap via CONSTEEL®.

The possibility to add electrical power can increase the % of scrap added to the mix

Tenova has 40+ references of these solutions around the world.

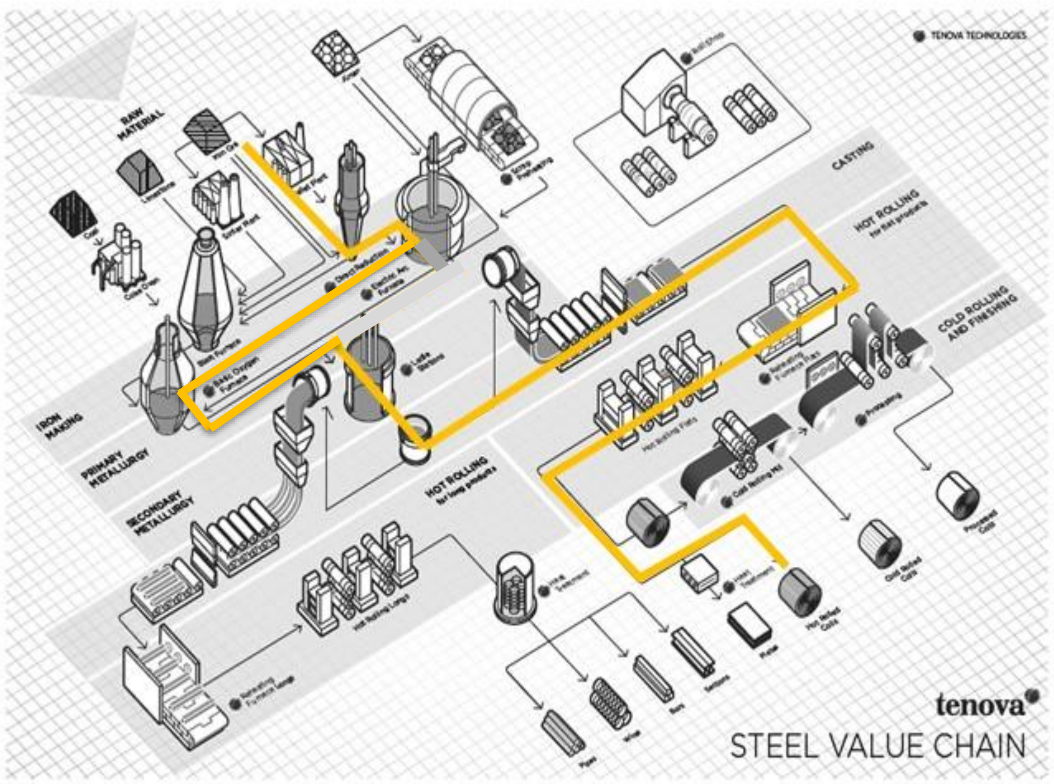
The Tenova Pathway for Green Steel

1. DRI + EAF → Liquid Steel



NG-DRI/EAF route ~ **0.7-0.9** tCO_2/ton to **0.5** tCO_2/ton or less with 35% H_2 mixed to NG

2. DRI + OSBF (iBLUE) → Hot Metal

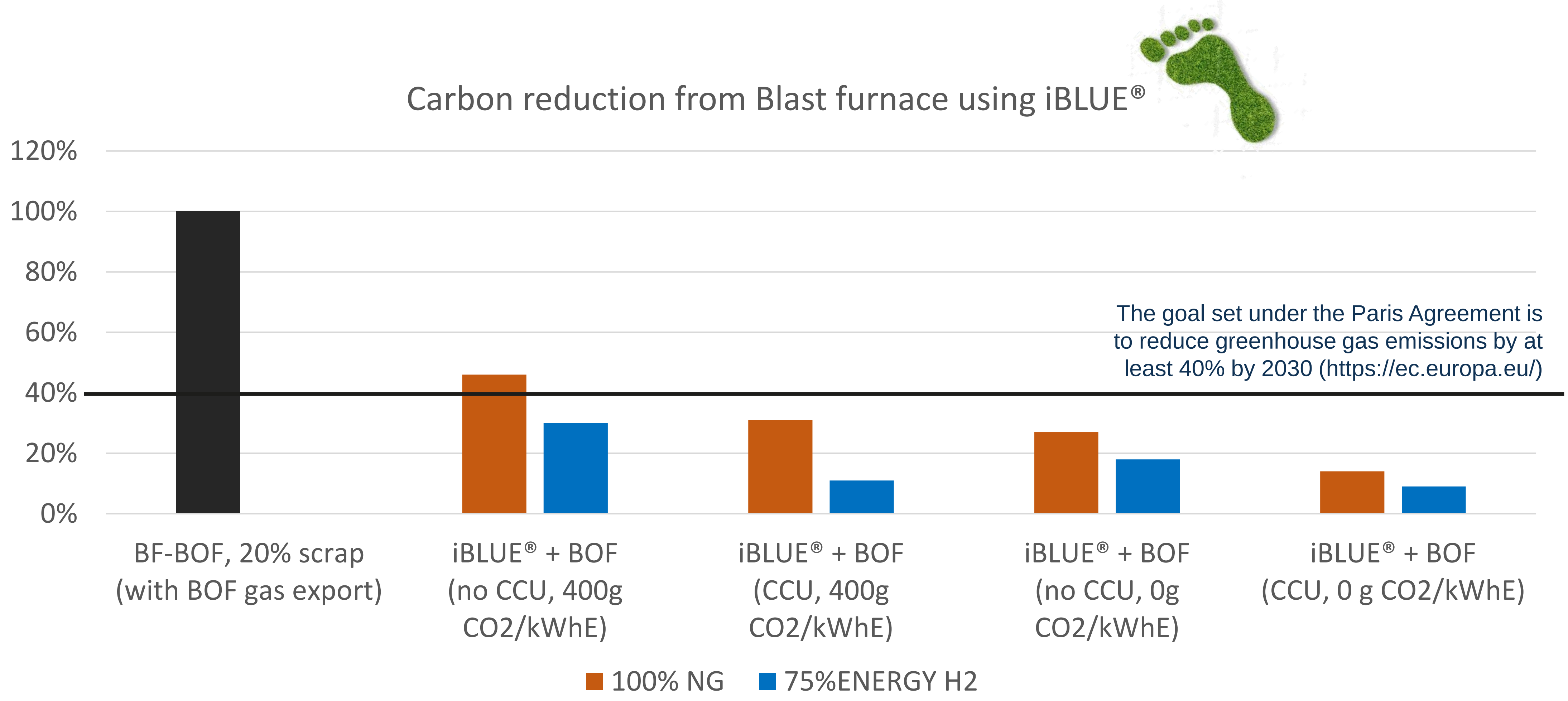


NG-DRI/OSBF route ~ **0.9** tCO_2/ton to **0.7** tCO_2/ton with 35% H_2 mixed to NG

METEC & 6TH ESTAD 2023

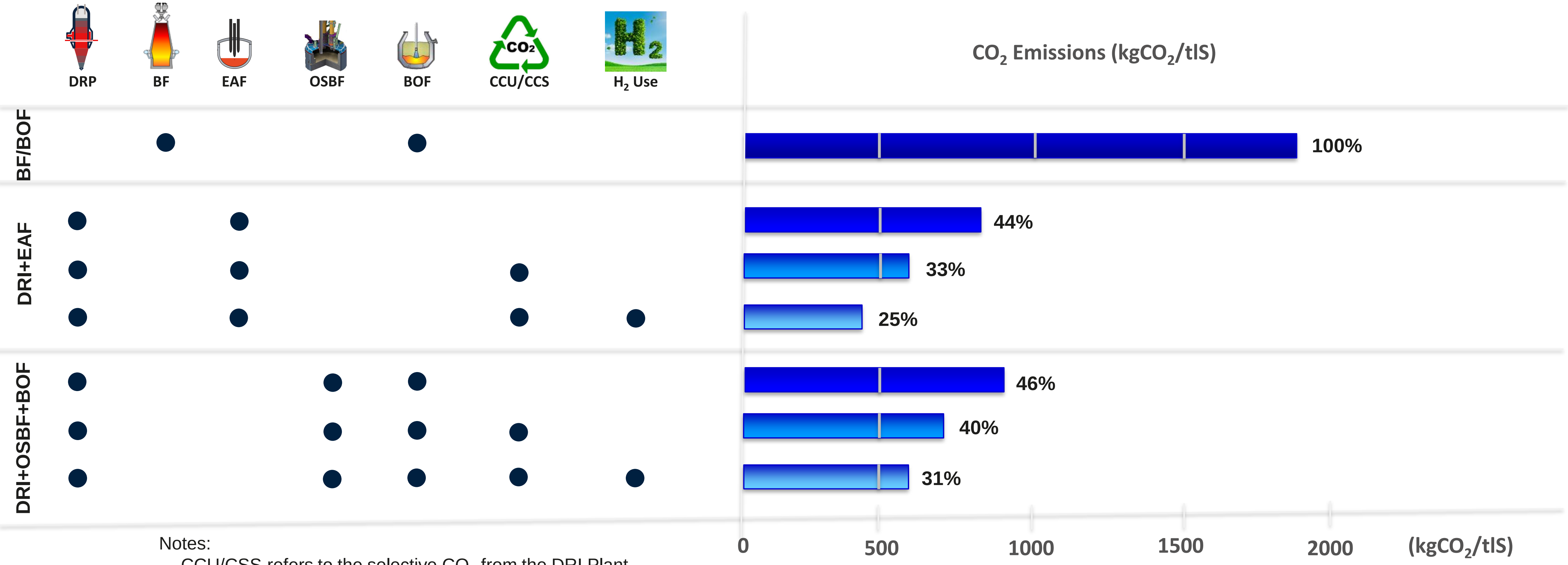
CO_2 Emissions reduction with iBLUE®

IT IS ALREADY POSSIBLE TO MEET THE PARIS AGREEMENT WITHOUT HYDROGEN



CO_2 emissions through each production route

tenova



Notes:

- CCU/CSS refers to the selective CO_2 from the DRI Plant.
- H_2 use at 35% as energy (or ~70% vol) in the makeup gases to the DRP.
- Location: 0.4 $kgCO_2$/kWh

Conclusions

- The way to decarbonization goes through Direct Reduction
- DRP + EAF route has a number of advantages, it is a very well proven technology, but **works only with high grades pellets**
- The increase of DRI production will lead to a **shortage of DR grade pellets** and it is a question if the supply will be able to match the demand
- Tenova iBLUE® offers a proven way to produce steel from **low grade Blast Furnace pellets**
- iBLUE ® can count on high Carbon DRI produced via the ENERGIRON™ process and can supply green hot metal to the traditional steelmaking route (i.e. BOF) or to other advanced technologies (i.e. Tenova FMF™) able to take advantage of an increased scrap addition to the metal.
- iBLUE ® can also be coupled to EAF /FMF® technology to enhance production flexibility.

sustenovability.

tenova

IBLUE Video

Praveen Chaturvedi
VP & Head – Sales Upstream India

Tenova Technologies Pvt Ltd
iThink Techno Campus,
A Wing, 5th Floor,
Off Pokhran Road No. 2,
Thane (West) 400 601
India
T +91 22 6248 9874 M +91 9167725604
F +91 22 6148 9701
www.tenova.com

Email : Praveen.Chaturvedi@tenova.com

Tenova S.p.A.

Via Gerenzano 58
21053 Castellanza, VA - Italy
tenova@tenova.com

Follow us on:

Twitter
YouTube
LinkedIn