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STEELTIMES INTERNATIONAL

Webinar Hydrogen Steelmaking

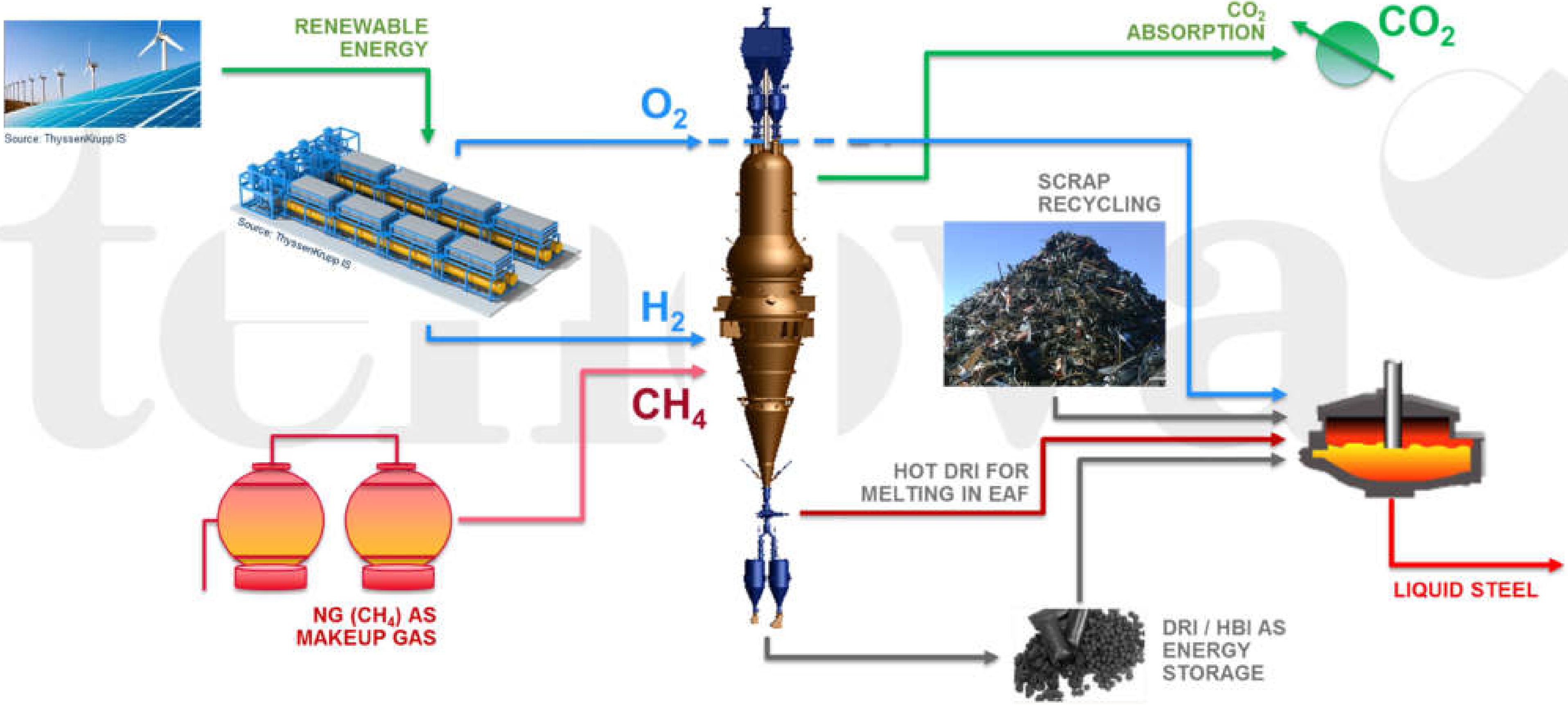
GrInHy2.0 - Another step towards hydrogen based steelmaking

TECHNOLOGIES FOR A SUSTAINABLE STEEL INDUSTRY

Dr.-Ing. Markus Dorndorf
Director Vacuum Degassing Technologies
Business Development Iron & Steelmaking

Steelmaking process of the future

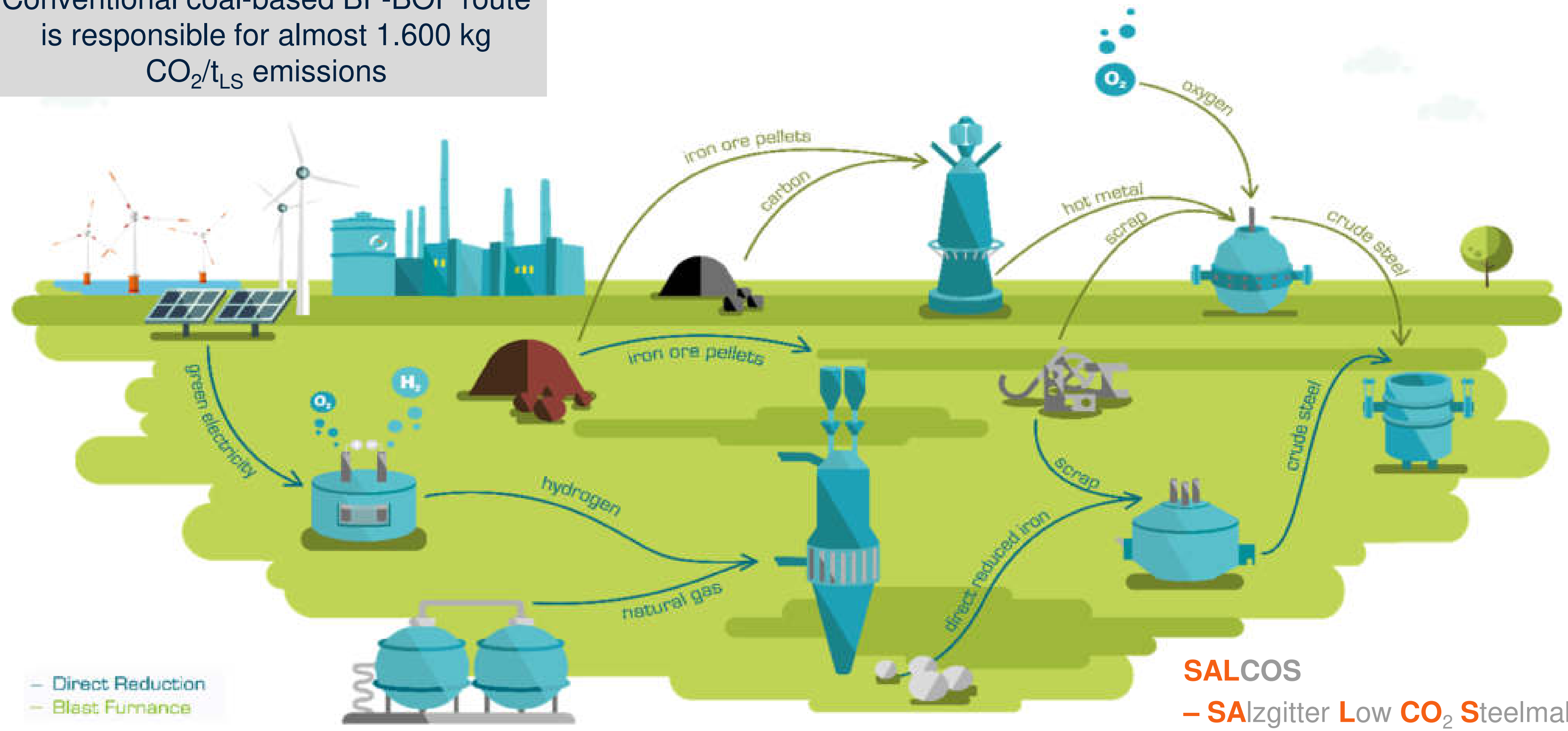
THE TRANSFORMATION PROCESS OF AN INTEGRATED PLANT



The SALCOS approach

THE TRANSFORMATION PROCESS OF AN INTEGRATED PLANT

Conventional coal-based BF-BOF route is responsible for almost 1.600 kg CO_2/t_{LS} emissions



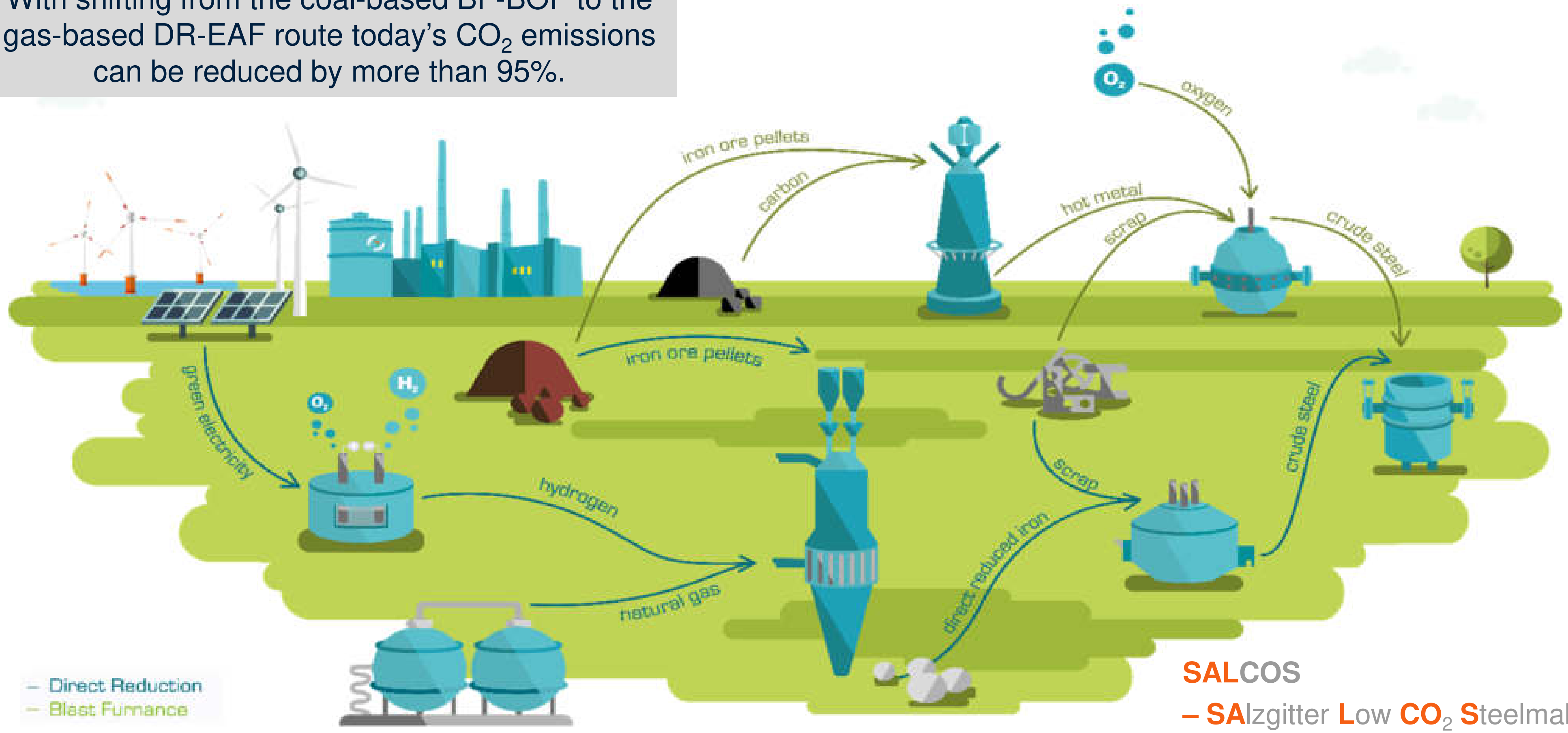
SALCOS

– **SA**lzgitter **L**ow **CO**$_2$ **S**teelmaking

The SALCOS approach

THE TRANSFORMATION PROCESS OF AN INTEGRATED PLANT

With shifting from the coal-based BF-BOF to the gas-based DR-EAF route today's CO_2 emissions can be reduced by more than 95%.



SALCOS
– **SA**lzgitter **L**ow **CO**$_2$ **S**teelmaking

Incremental steps of the transformation process

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THE TRANSFORMATION PROCESS OF AN INTEGRATED PLANT

GrInHy Green Industrial Hydrogen | GrInHy2.0 Green Industrial Hydrogen

First steam electrolysis in megawatt scale at Salzgitter Flachstahl beginning in 2020

SALZGITTER AG Stahl und Technologie

sunfire | PAUL WURTH SMS group | tenova

Wind-H2 – Sector coupling

WINDH2 Salzgitter Hydrogen

Production of electric energy by means of windpower and electrolytic hydrogen on the premises

SALZGITTER FLACHSTAHL | Linde | avacon

Virtual implementation of Direct Reduction Plant in Salzgitter´s digital steelworks.

MACOR – SALCOS-Feasibility Study

BMBF-funded, May 2020 finalized

BeWiSe – SALCOS-Supporting Research

BMBF-funded, July 2020 - June 2023

Fraunhofer | Bundesministerium für Bildung und Forschung

The GrInHy2.0 project - consortium

THE TRANSFORMATION PROCESS OF AN INTEGRATED PLANT

➔ Project start: January 2019

➔ Project duration: 4 years

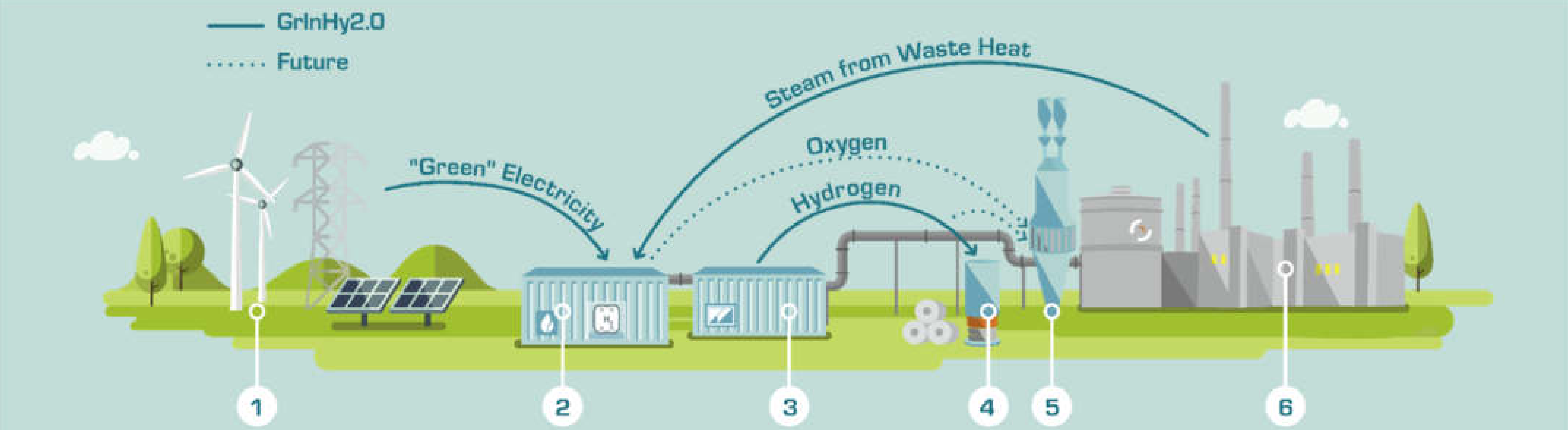
➔ Idea: Realization of a steam electrolysis in an industrial relevant size integrated in an integrated iron & steel works to support the most promising Carbon Direct Avoidance (CDA) approach by substituting the reducing agent carbon by green hydrogen to significantly reduce carbon dioxide emissions in the steel production

➔ Consortium consists of six partners from four different EU countries and is characterized by its interdisciplinary expertise.

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (JU) under Grant Agreement No 826350. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.

The GrInHy2.0 project - concept

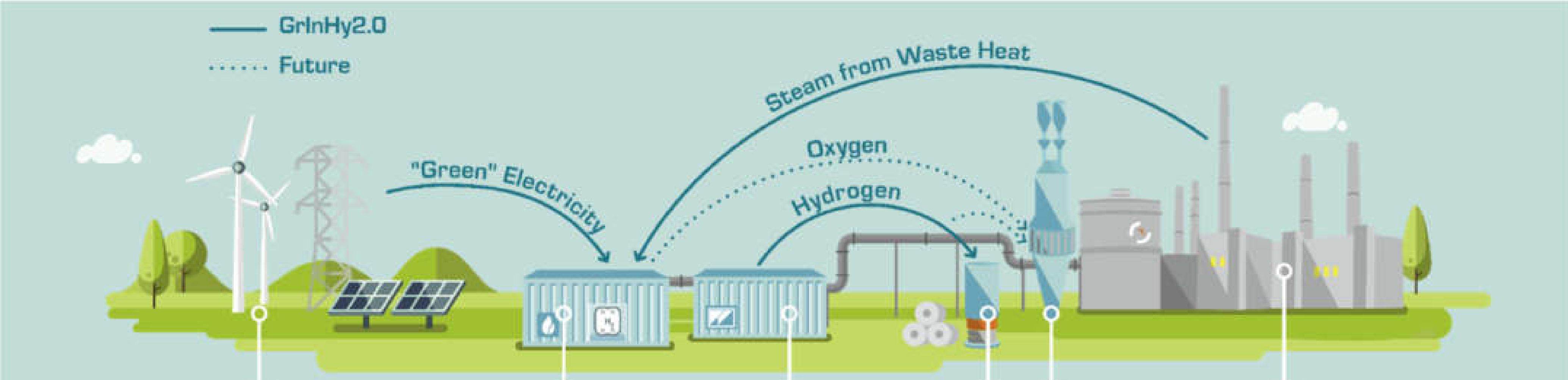
THE TRANSFORMATION PROCESS OF AN INTEGRATED PLANT



1	Renewable Energies	Usage of renewable electricity
2	Steam-Electrolyser	Electrochemical hydrogen production based on steam from waste heat
3	Hydrogen Processing	Compression, drying and injection of hydrogen into existing infrastructure
4	Annealing Processes	Hydrogen for reducing atmosphere during annealing of cold-rolled steel
5	Direct Reduction Plant	Core aggregate of hydrogen-based, low CO_2 steelmaking of the future
6	Integrated Iron-and-Steel Works	Integration into existing infrastructure and provision of steam from waste heat sources

The GrInHy2.0 project - is…

THE TRANSFORMATION PROCESS OF AN INTEGRATED PLANT



- Demonstrating the first Steam Electrolyser (StE) in the Megawatt-class in an industrial environment,
- the most energy-efficient hydrogen production using green electricity and steam from waste heat sources of the steelmaking processes,
- the optimized integration of the system into an existing infrastructure and operation via Salzgitter’s energy management control system,
- producing ‘green’ hydrogen for today’s steelmaking processes while assessing the technology’s potential for a hydrogen-based, low carbon European steel industry in the future,
- setting new standards in long-term stack validation of the Solid Oxide Electrolysis Cell technology.

The GrInHy2.0 project - the way to green steel

THE TRANSFORMATION PROCESS OF AN INTEGRATED PLANT

Technical

- ✓ Electrolyser scale-up to 720 kWel,AC producing 200 Nm³/h (18 kg/h)
- ✓ Electrical electrolyser efficiency up to 84 %el,LHV (< 40 kWhel,AC/kg H_2)
- ✓ > 13,000 operating hours at system level with a proved availability of > 95 %
- ✓ > 20,000 operating hours at stack level
- ✓ Demonstrate hot start from minimum to maximum power in < 5 mins

Economical

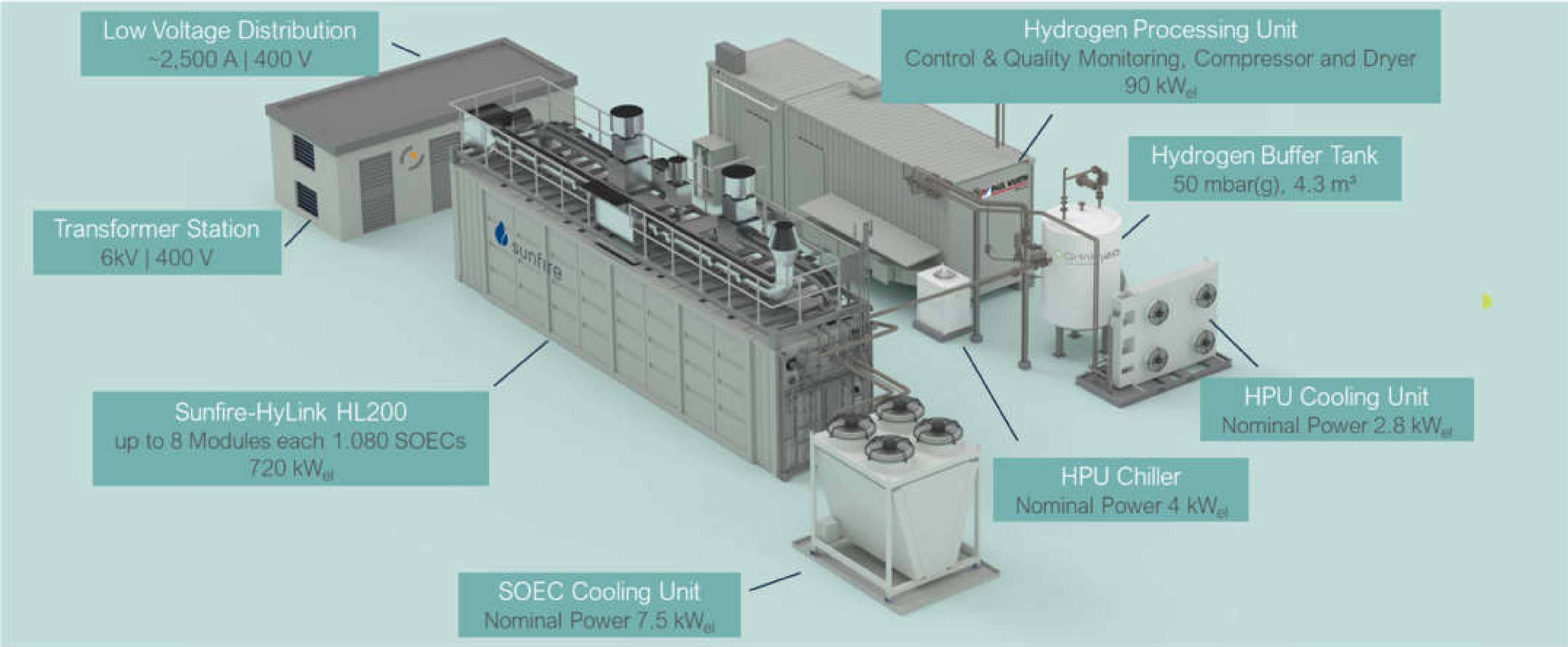
- ✓ Produce >100 tons of green hydrogen
- ✓ Reduce electrolyser CAPEX to < 4.500 €/(kgH_2/d)
- ✓ Provide techno-economic studies for further market deployment

Socio-Political

- ✓ Create viable technology by demonstration in a complex industrial environment
- ✓ Assess CO_2 avoidance potential of a hydrogen-based European steel industry
- ✓ Provide significant share of green hydrogen to the iron-and-steel works
- ✓ Evaluate situation on purchasing renewable electricity and green H_2 certification

The GrInHy2.0 project - layout

THE TRANSFORMATION PROCESS OF AN INTEGRATED PLANT



The GrInHy2.0 project - Tenova's contribution

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THE TRANSFORMATION PROCESS OF AN INTEGRATED PLANT

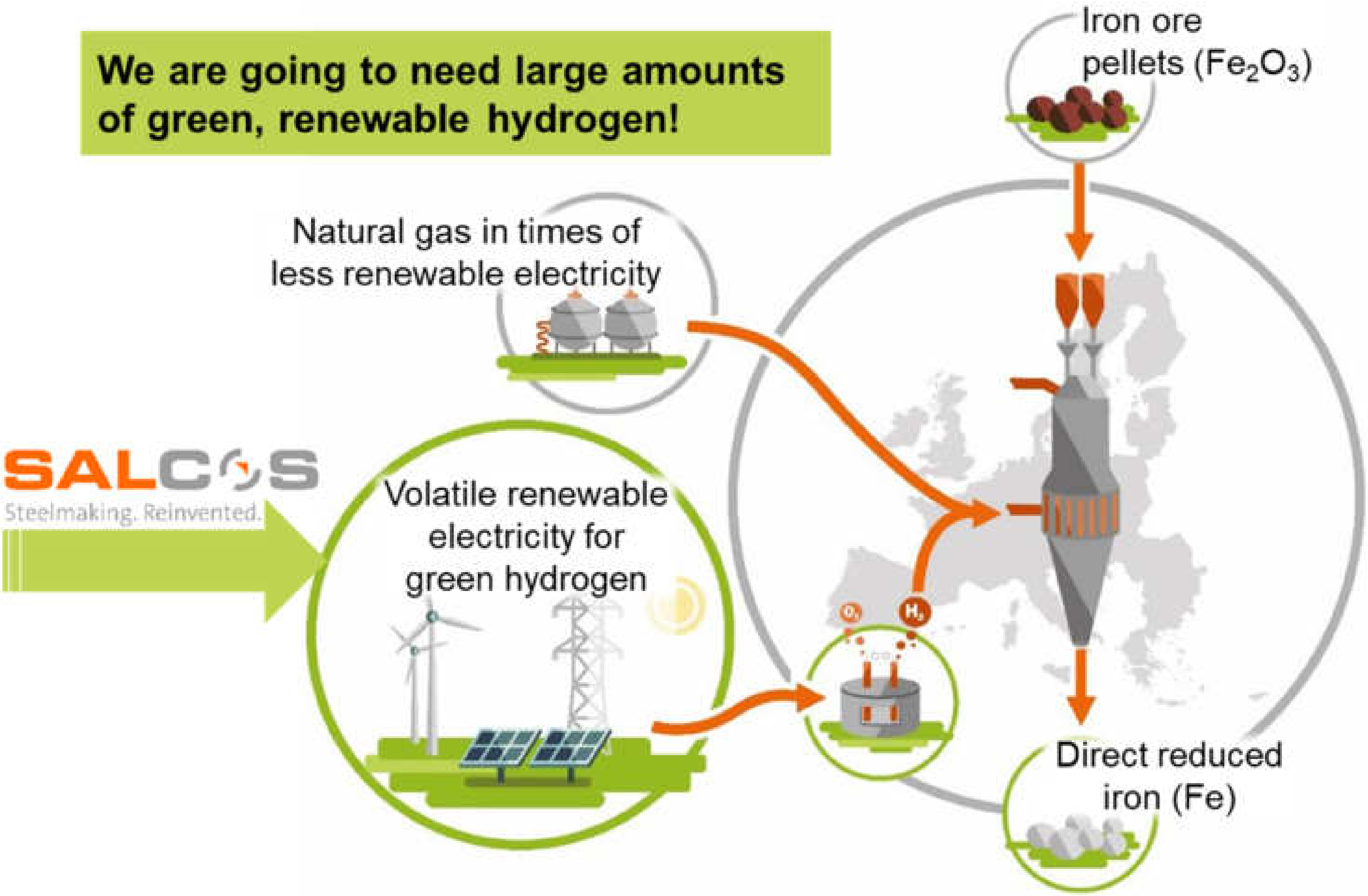
- ✓ Study on hydrogen's CDA potential for integrated iron-and-steel works
- ✓ Identification of optimal system dimensions based on mass and energy balances
- ✓ Evaluation of indispensable process transformation to perform with maximum efficiency

- ✓ In detail (1st phase):
  - ✓ Description of the ENERGIRON-ZR process scheme as potential BAT for hydrogen usage in iron making processes
  - ✓ Investigation of a stepwise transformation process towards direct reduction and electrical energy based processes and calculation of related CO_2 emission reduction potentials based on SZFG
  - ✓ Modelling of different levels of H_2 usage in the DR Plant (based on the ENERGIRON ZR Process)
  - ✓ Investigation and evaluation of the usage of DRI / HBI in Blast Furnaces (BF) and correlated effects on CO_2 emission reduction
  - ✓ Further H_2 use up to 100% modelling and experimentation for DR plants, in combination with BF-BOF mills.

- ✓ Outlook: Upscaling effects and CAPEX/OPEX estimations for European steel works

The SALCOS approach - a summary

THE TRANSFORMATION PROCESS OF AN INTEGRATED PLANT



SALCOS is…

- pairing already established technologies with hydrogen technologies and an innovative operational concept
- a step-wise transformation of the integrated steelmaking route supporting the transition of the energy system
- reducing today's CO_2 emissions by more than 95%
- a sustainable "Carbon Direct Avoidance" approach: Reducing instead of recycling!

The ENERGIRON scheme - the BAT for SALCOS

THE INNOVATIVE HYL DIRECT REDUCTION TECHNOLOGY JOINTLY DEVELOPED BY TENOVA AND DANIELI - UNIQUE FEATURES

REMOVAL OF CO_2

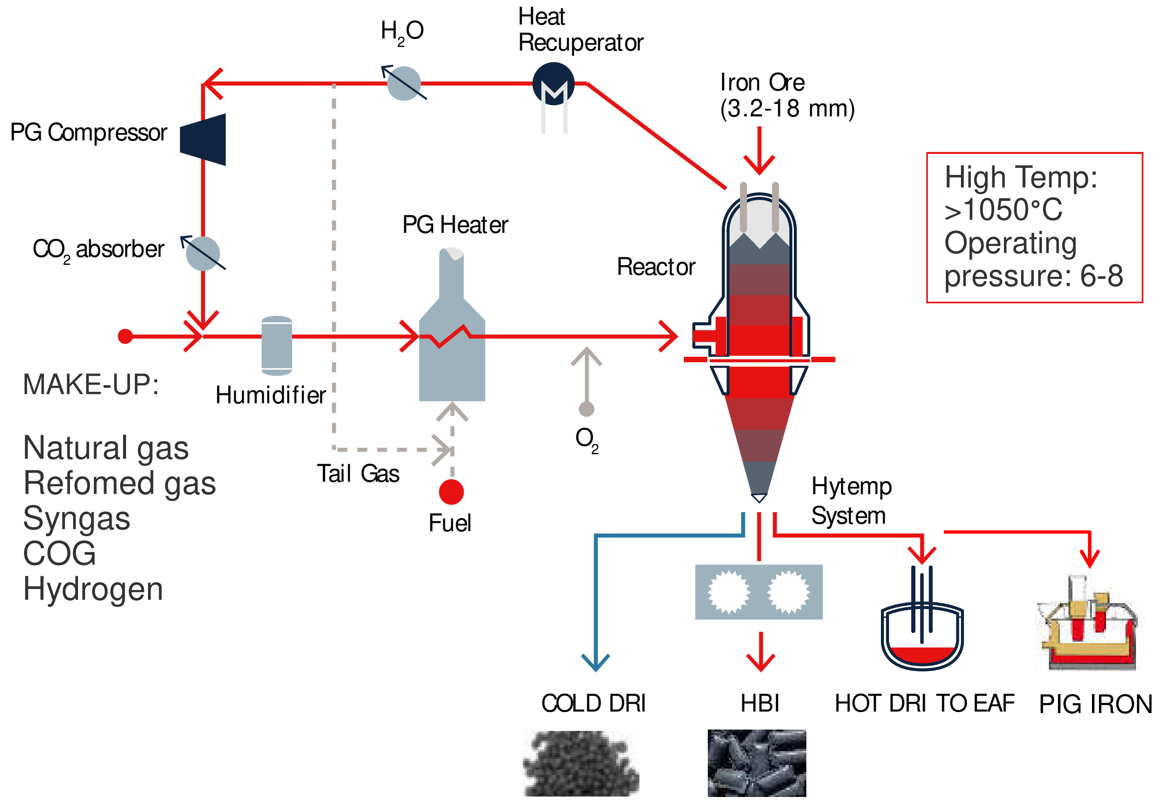
- ✓ Selective removal of CO_2
- ✓ Intrinsic capability for CCU and CCS

DRI QUALITY

- ✓ >94-96% Mtz;
- ✓ 1,5%- 5,0% Carbon (as Fe_3C)
- ✓ High-C CDRI, High-C HDRI, High-C Briquettes

FLEXIBILITY

- ✓ Same scheme for any energy source
- ✓ Energy recovery from the top gas
- ✓ Scheme overall efficiency 83-87%



The ENERGIRON scheme - the BAT for SALCOS

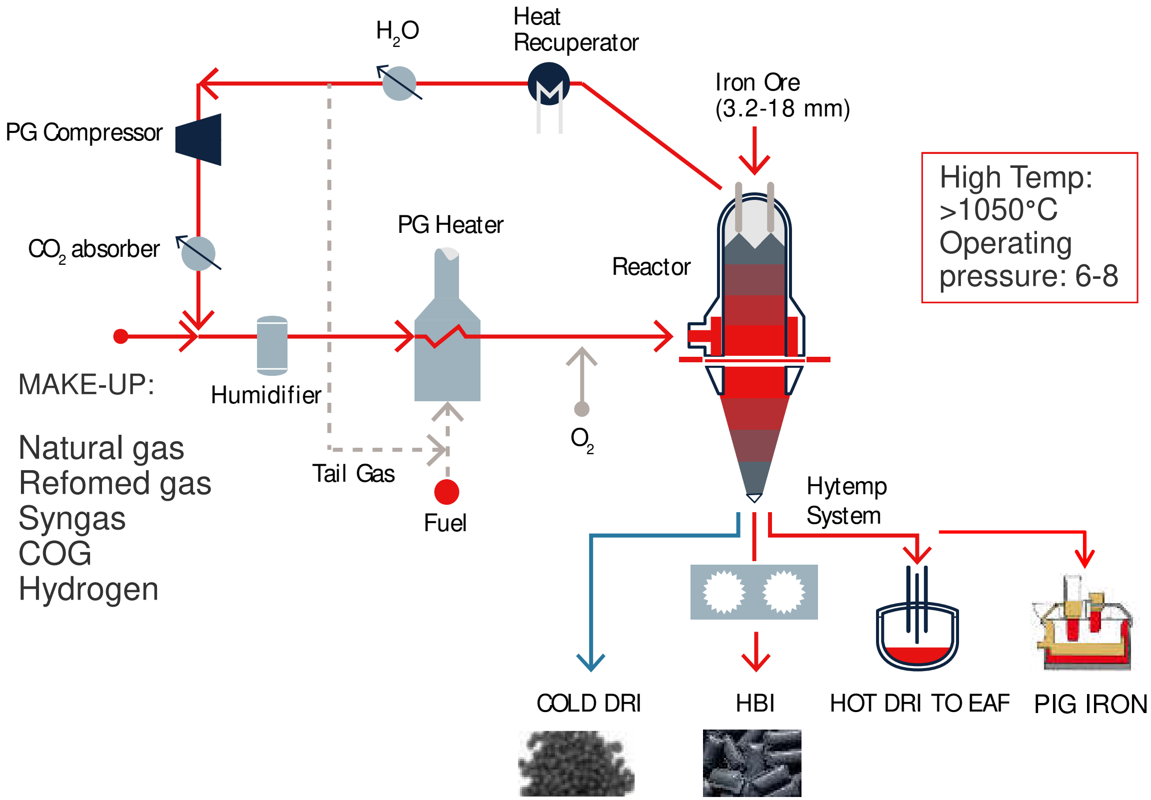
THE INNOVATIVE HYL DIRECT REDUCTION TECHNOLOGY JOINTLY DEVELOPED BY TENOVA AND DANIELI - UNIQUE FEATURES

ENVIRONMENTAL

- ✓ Lowest Nox emissions: 0,030 kg_{NOX} / t_{DRI}
- ✓ Selective removal of iron ore reductions by-products: H_2O & CO_2
- ✓ Use of gas implies that coke/coal is no longer needed as in blast furnace

OPEX

- ✓ Highest overall Energy efficiency
- ✓ < 9,5 GJ/t; < 80 kWh/t
- ✓ High yield: < 1,4 t IO/t_{DRI}



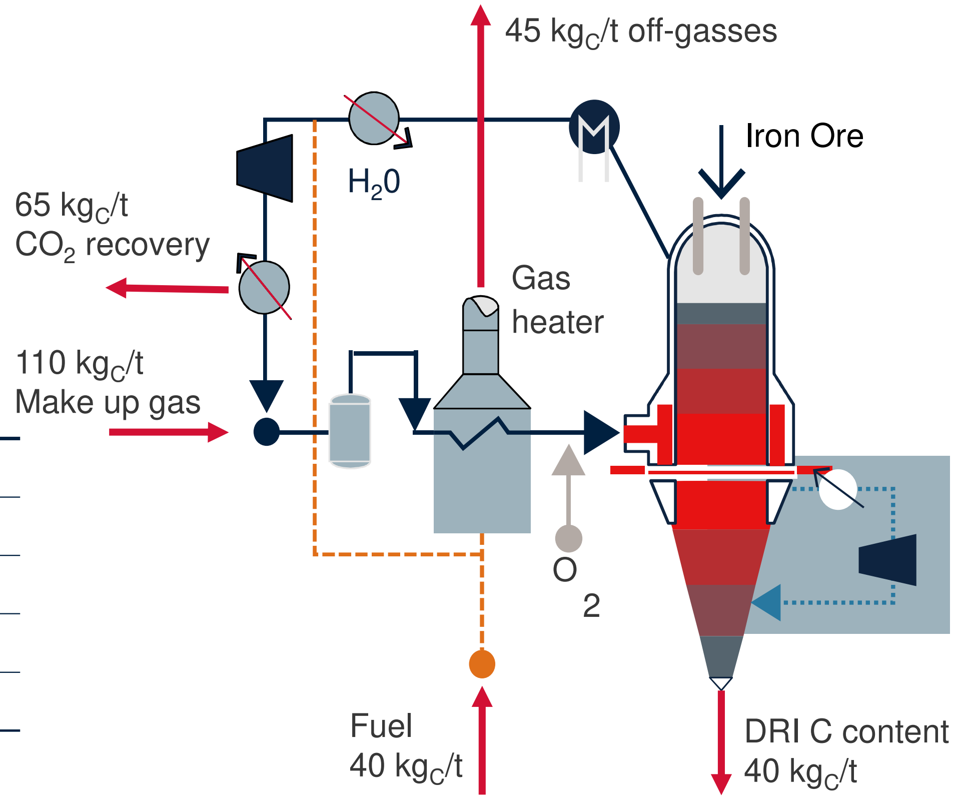
Selective CO_2 removal

CAPTURE AND UTILIZATION OF THE CO_2

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

For the mass conservation law, the total carbon used in the ENERGIRON process ends up as:

- Captured CO_2 Emissions (45% of C input)
- Free CO_2 Emission to Atmosphere (30% of C input)
- Carbon in DRI/HBI product (25% of C input)



Reference Plant	Country	Use	Offtaker
Ternium Monterrey	**Mexico**	Food & Beverage	Linde
Ternium Puebla	**Mexico**	Beverage industry	CryoInfra
PTKS	**Indonesia**	Food industry	Janator
PSSB	**Malaysia**	Food industry	Air Liquide/MOQ
JSW Salav	**India**	Dry Ice	Air Liquide
Emirates Steel	**UAE**	Enhanced Oil Recovery	Masdar/ADNOC

Optimum carbon content in DRI / High-C DRI

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FLEXIBILITY FOR SPECIFIC APPLICATION AND STEEL GRADE

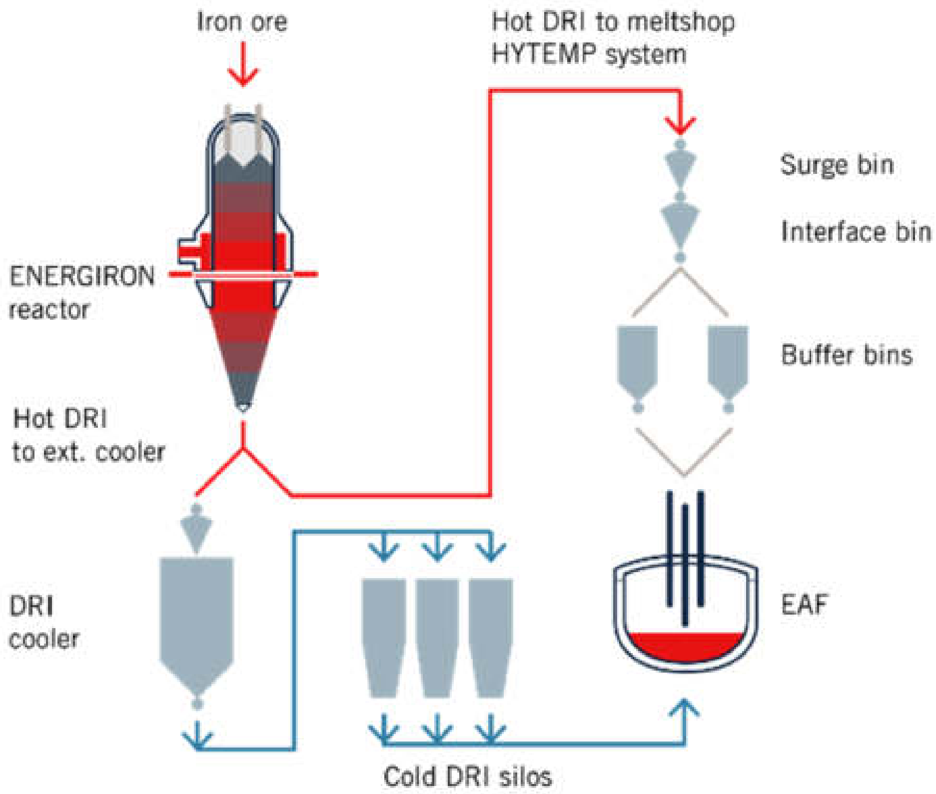
- ✓ Reduction of the residual FeO without graphite injection into EAF, that has lower efficiency
- ✓ Feeding to EAF C in cementite form, provides thermal energy (from Fe3C dissociation) to the **EAF 36 - 40 kWh/t** DRI per each 1% Carbon in the DRI
- ✓ C in DRI reacts with O2 injected into EAF, providing thermal energy, better stirring, foamy slag
- ✓ Higher C content in DRI provides longer electrode's life
- ✓ Higher C content in DRI provides longer EAF refractory's life
- ✓ Feeding DRI with correct C content allows to reduce the tap-to-tap time

DRI CARBON CONTENT	
4.5 %	**DRI to replace Pig Iron**
3.0-4.5 %	**DRI + scrap combination**
2.0-3.0 %	**EAF fed by DRI only**
<2.0%	**Special applications**

High temperature DRI

THE FIRST, WITH THE MOST RELIABLE SYSTEM

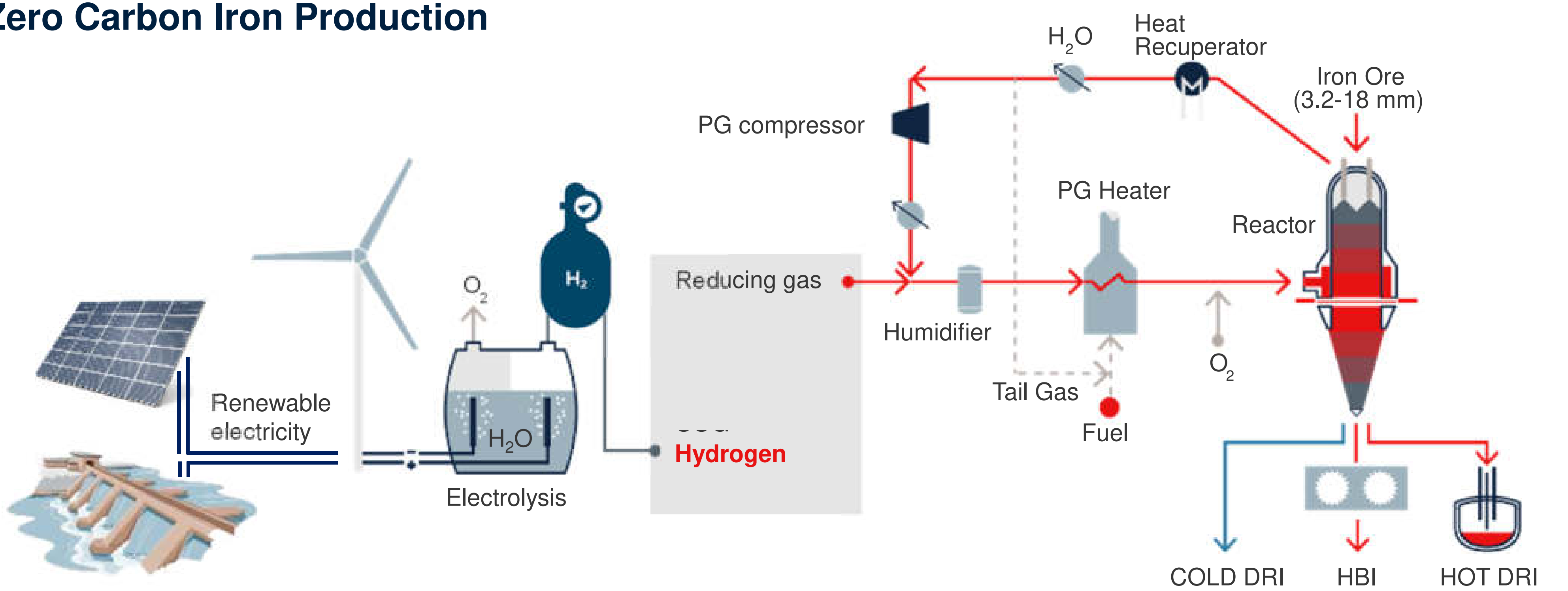
- ✓ Thermal energy of **HOT DRI** can be recovered by transporting it at high temperature directly from the reactor to the EAF
- ✓ DRP & SMP at the same site
- ✓ Savings for every 100°C in DRI T
- ✓ Electric energy -26 kWh/tls
- ✓ Productivity increase +5%



From CCU to Carbon Direct Avoidance (CDA)

HYDROGEN AS ENABLER FOR GREENER STEELMAKING - HYDROGEN BASED DIRECT REDUCTION

Zero Carbon Iron Production



Experience with hydrogen use

ENERGIRON IS READY FOR INDUSTRIAL APPLICATION

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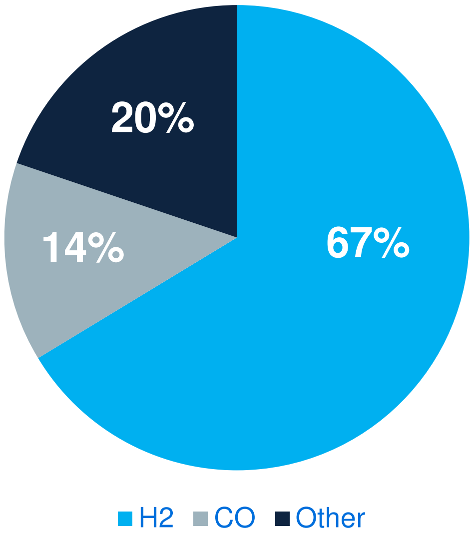
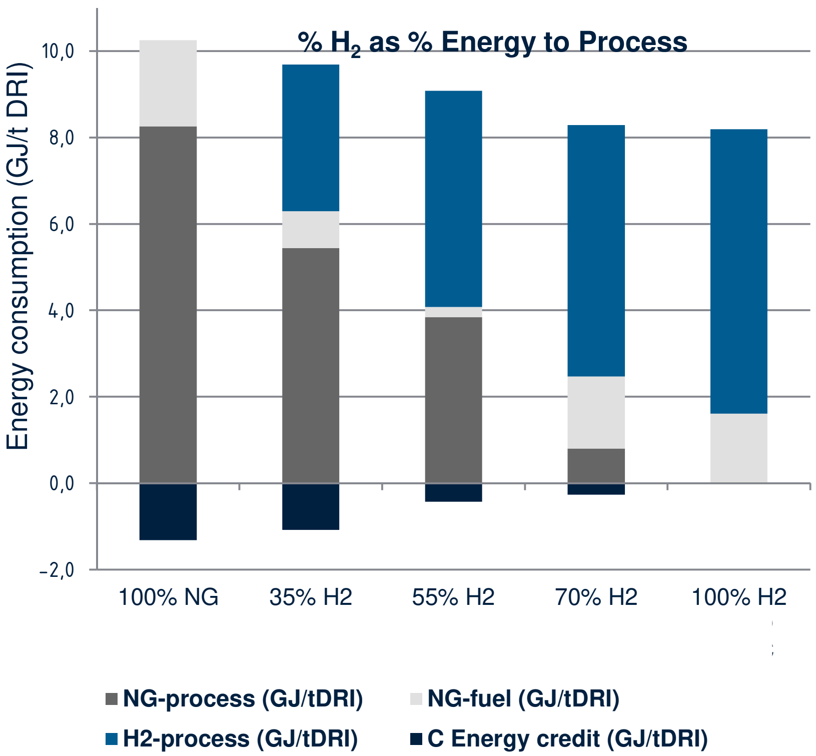
- ✓ Experience in ENERGIRON plants with reformer using in excess of 70% H_2
- ✓ Scheme natively fitted for direct use of H_2
- ✓ Completion of pilot plant tests with ~90% H_2 since 1990's
- ✓ Extensive experience and operation with Process Gas heaters and gas sealing valves design, specifically with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

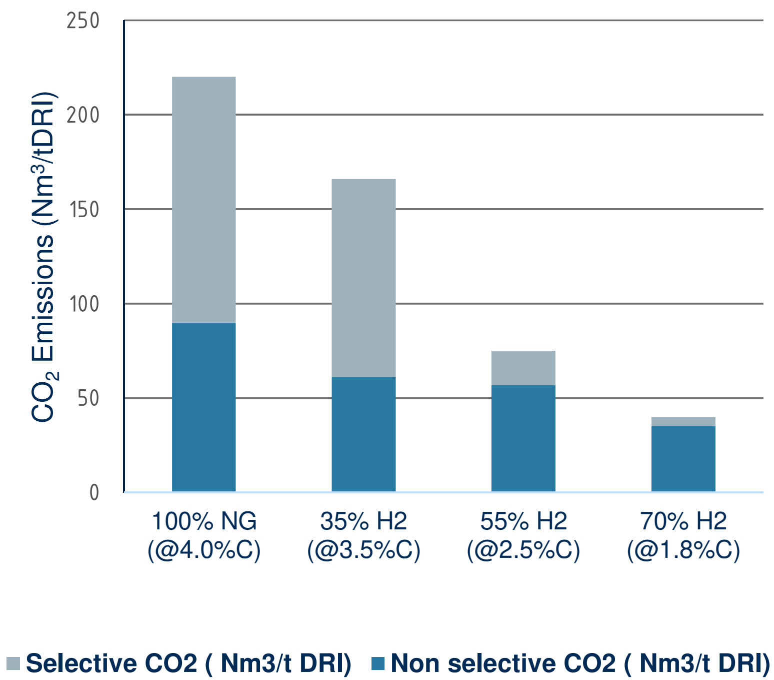
ENERGIRON
DRI TECHNOLOGY BY TENOVA AND DANIELI



Use of hydrogen in an ENERGIRON plant

ENERGIRON AS BENCHMARK FOR CO2 REDUCTION





Hydrogen use: projects under execution

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THE SELECTION OF CHOICE FOR HYDROGEN USE

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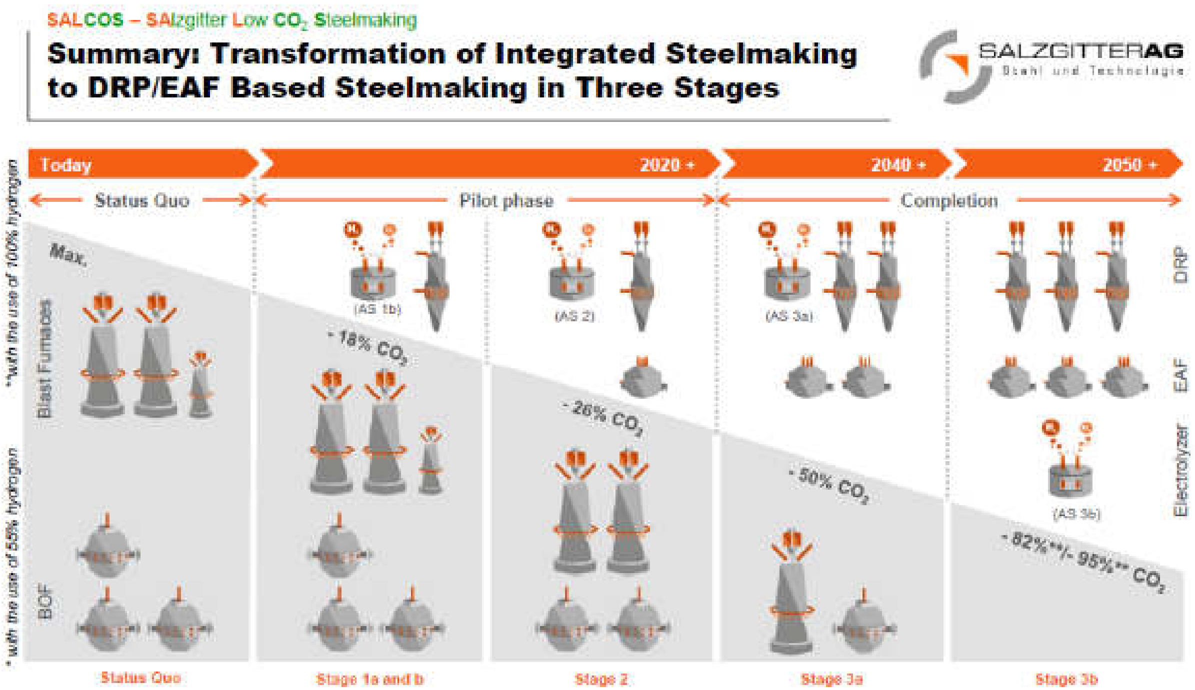
Steelmaking. Reinvented.



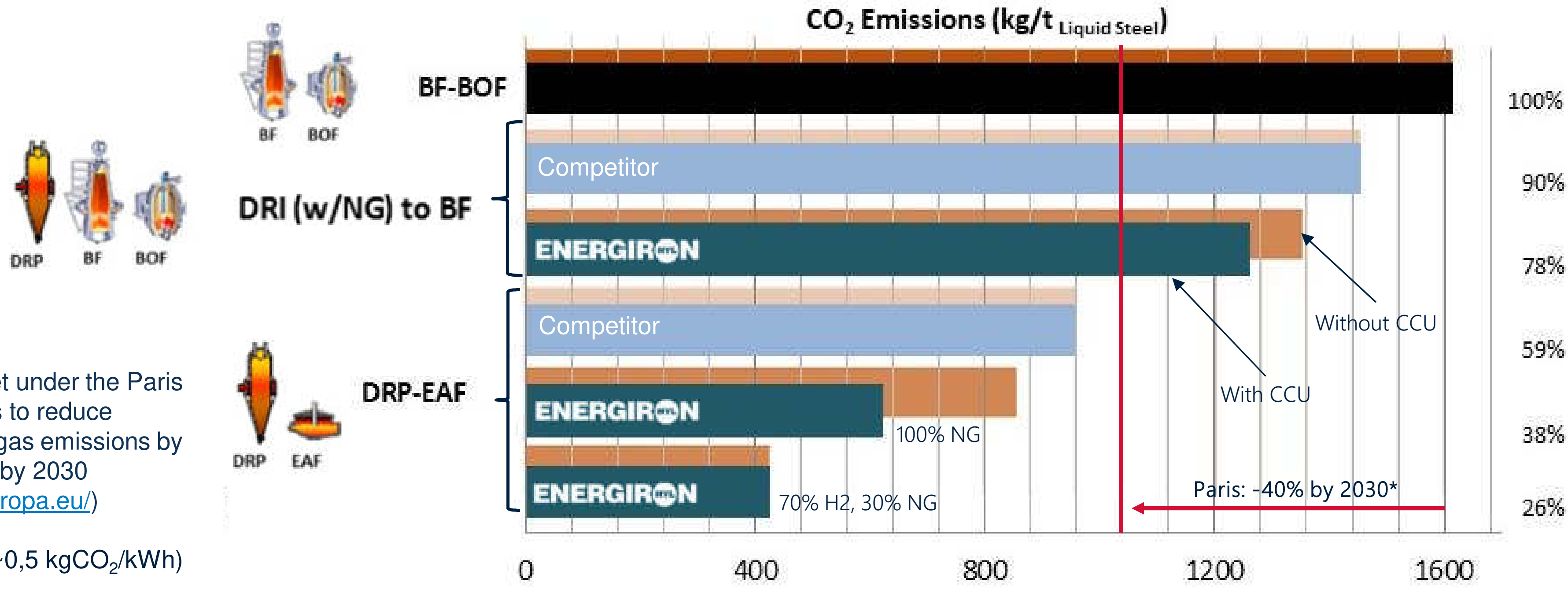
HYBRIT
FOSSIL-FREE STEEL

SSAB LKAB VATTENFALL

Use of H_2 and impact on CO_2 emissions reduction

ENERGIRON AS GAME CHANGER FOR THE SUSTAINABILITY OF STEELMAKING

- A sustainable path for the decarbonization of steelmaking
- ENERGIRON DR-EAF route is ~50% less carbon intensive than the BF integrated process, ~60% less with CCU
- Further reduction to ~75% less carbon intensive with 70% H_2 / 30% NG use



* The goal set under the Paris Agreement is to reduce greenhouse gas emissions by at least 40% by 2030 (https://ec.europa.eu/)

** assumed ~0,5 kgCO_2/kWh)

Steelmaking process of the future

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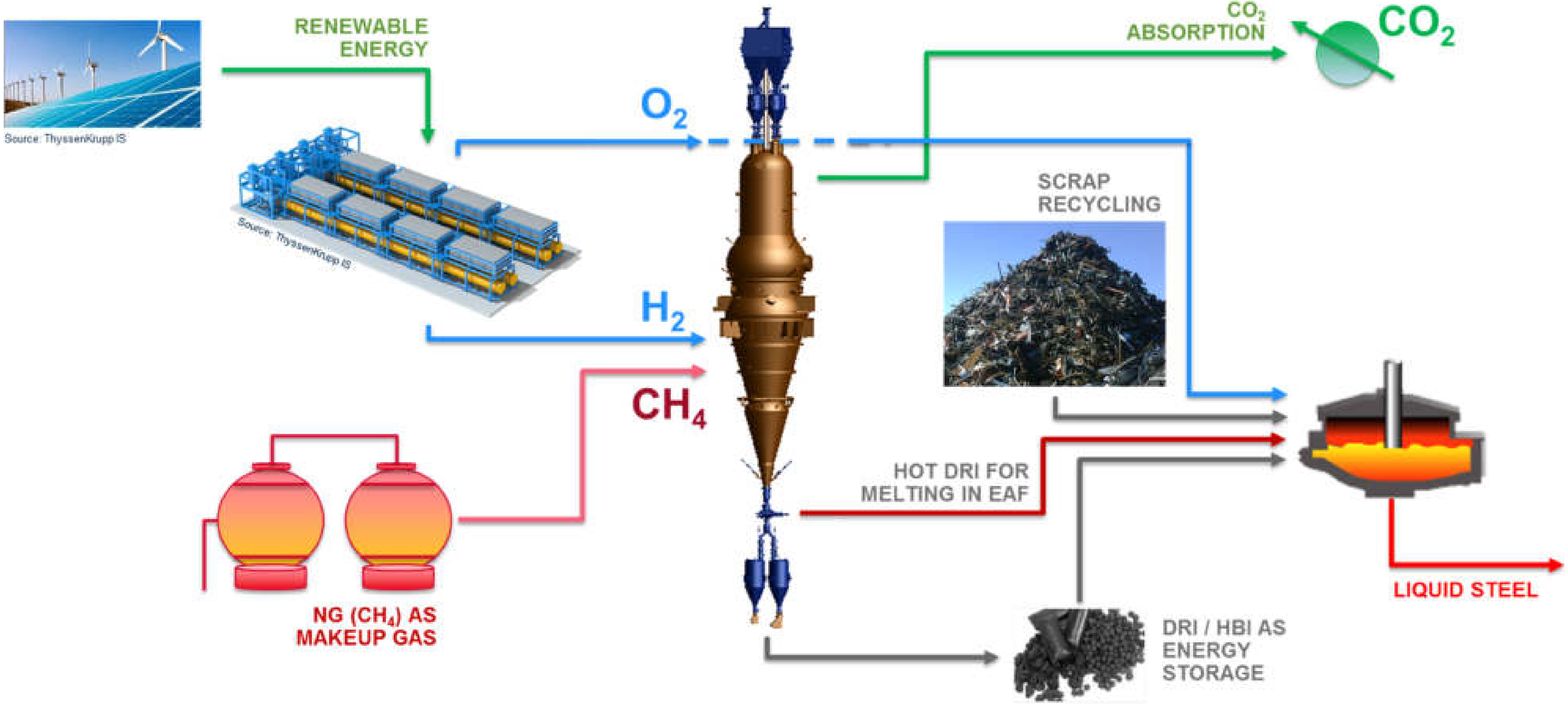

Sustenovability

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SUSTENOVABILITY IS A NEOLOGISM THAT EMBODIES
THE PERFECT BLEND BETWEEN THE TENOVA BRAND, ITS ECO-FRIENDLY VALUES
AND ITS CAPACITY TO DELIVER SUSTAINABLE SOLUTIONS

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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

Thank you!

Tenova / LOI Thermprocess GmbH

markus.dorndorf@tenova.com