KallanishPower MATERIALS

HYDROGEN FOR STEELMAKING

WEBINAR | 7 DEC 2022

Hydrogen for Steelmaking Webinar

7th December 2022

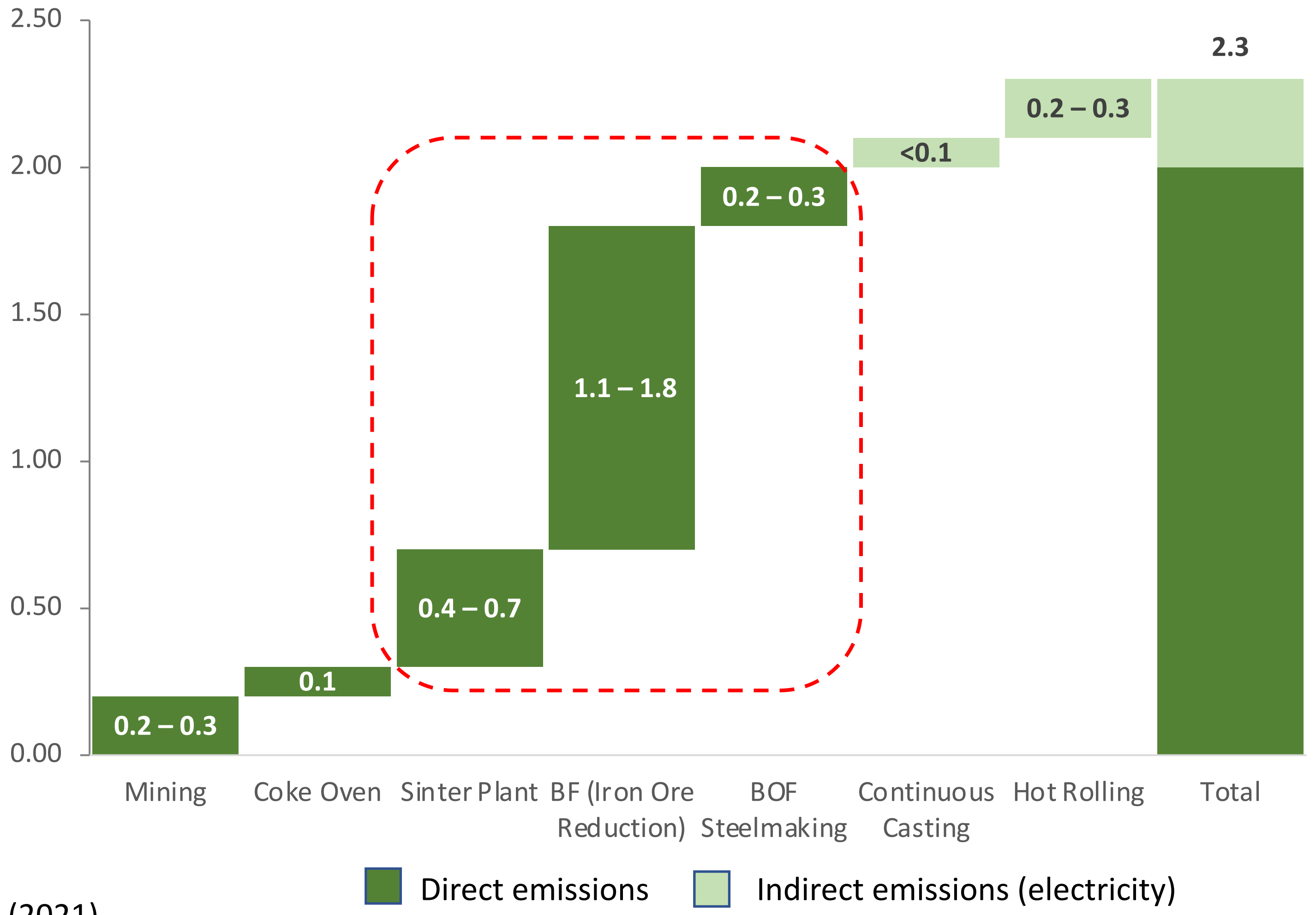
KIS Kallanish Index Services

Steve Randall
Managing Director
Kallanish Index Services

The steel industry is currently responsible for around 6-7% of global carbon emissions

- The sintering and iron ore reduction (using coal/coke as the reduction agent) process steps account for the majority of the carbon emissions in steel production
- Basic Oxygen Furnaces (BOFs) emit up to 4x the carbon of Electric Arc Furnaces (EAFs)
- Approx 70% of global steel production is currently via the BF/BOF route and 30% via EAFs

CO_2 Emissions (tonnes of CO_2 / tonne of Hot Rolled Coil from the BF)



Source: Carbon Trust: International Carbon Flows (2021)

Just over half of the major steel companies around the world have published carbon emission reduction targets to achieve net-zero

Steel Company	Region / Country	Steel Production (MT)	Interim Reduction Target	Net-Zero Target
ArcelorMittal	Global	79	25% Globally by 2030 35% in Europe by 2030	2050
thyssenkrupp Steel	Europe	12	>30% by 2030	2050
Tata Steel Europe	Europe	12	>30% by 2030	2050
SSAB	Europe	8	35% by 2032	2045
voestalpine	Europe	8	30% by 2027	2050
Salzgitter	Europe	7	30% by 2025, 50% by 2030	2050
Saarstahl	Europe	3	‘significant savings by 2035’	2045
China Baowu Group	China	120	30% by 2025	2050
HBIS Group	China	42	30% by 2030	2050
Nippon Steel	Japan	49	30% by 2030	2050
JFE Steel	Japan	27	30% by 2030	2050
POSCO	South Korea	43	20% by 2030, 50% by 2040	2050
Hyundai Steel	South Korea	20	50% by 2032	2050
Cleveland Cliffs	USA	16	25% by 2030	-
US Steel	USA	16	20% by 2030	2050

Sources: KIS and company reports

Achieving significant carbon emission reduction targets requires major changes in technology and raw material use

Steel Industry Decarbonisation Technologies

Technology	BF/BOS		BF/BOS + DRI	BF/BOS + CCS	EAF with Scrap & DRI	DRI-EAF with Green H_2
Basis	Maximise use of high-grade iron ore	Coke use reduction	Replace some iron ore with DRI	Capture all off gases	Production of all steel qualities	Replace natural gas with green H_2
Approx. CO_2 Reduction Potential with Renewable Power	3%	5%	15%	50%	60%	95%

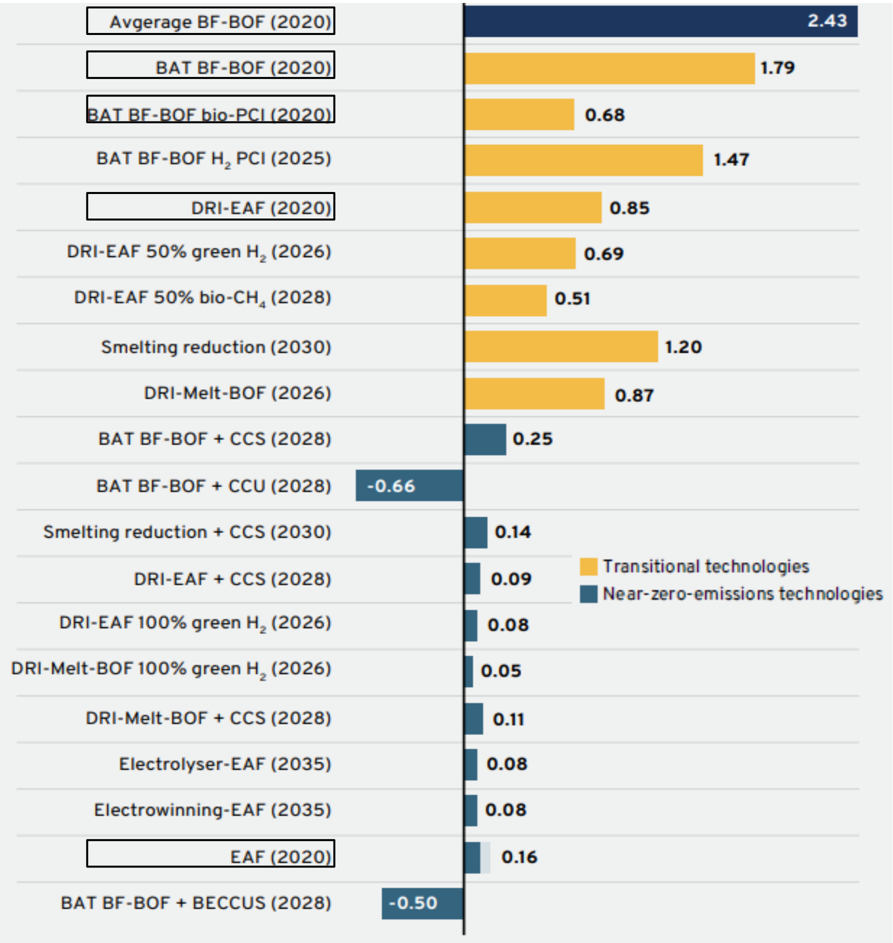
- Most steel companies are taking a multi-strand, phased approach to decarbonisation, involving:
  - optimising existing process routes (e.g. maximising use of high grade ore and scrap)
  - implementing carbon capture and offset measures
  - maximising use of renewable electricity
  - ultimately adopting new technologies

Source: McKinsey & Co.

A multitude of low carbon steelmaking technologies are under varying stages of development, with green H_2 often a key component

- Any transition to net-zero steel production will not look the same for every company or country
- Specific technology choices will be driven by the regional context in which each steel plant operates
- Historically, decisions over where to locate steel plants were driven by their proximity to coal and iron ore supplies
- In a net-zero world, the most relevant regional context parameters will be the availability and cost of zero-carbon power, hydrogen and carbon storage
- Proximity to industrial clusters, and therefore to potential users of waste gas streams, is also relevant when considering carbon capture and utilisation (CCU) pathways

Selected Steelmaking Technologies with Emissions Intensities (Scopes 1 and 2) in 2050 and dates of expected commercial availability (t CO_2/t crude steel)*



* Based on zero-carbon electricity, zero-carbon hydrogen, or carbon capture

Sources: MPP, WEF

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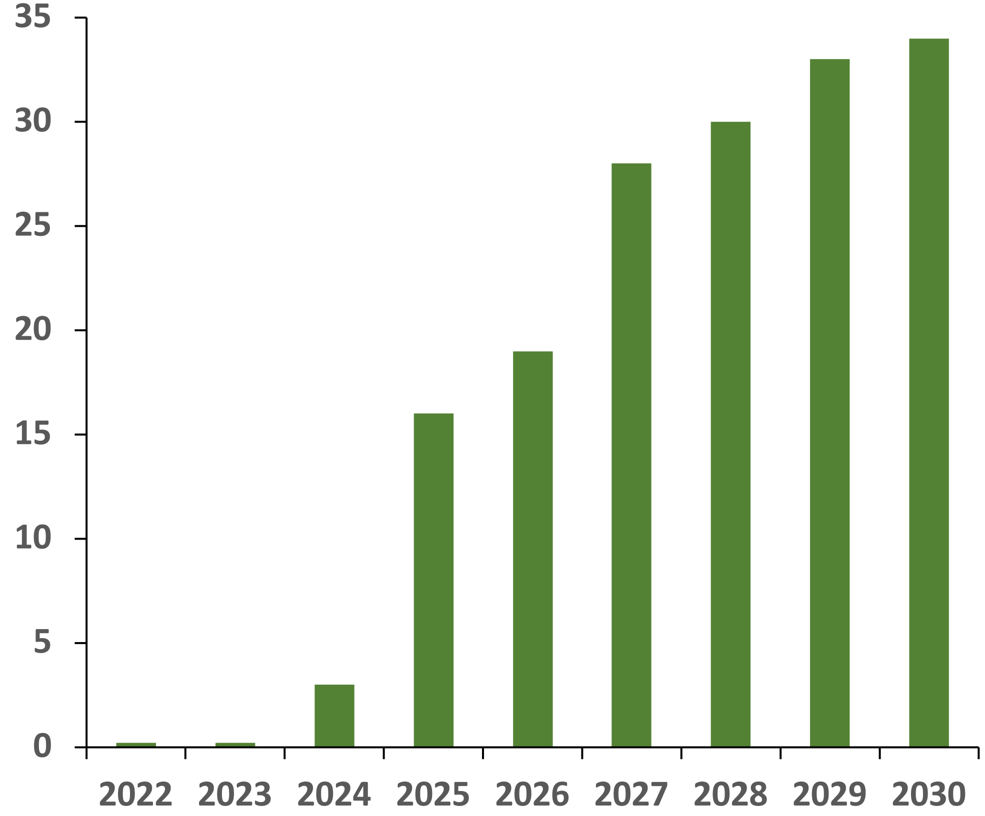
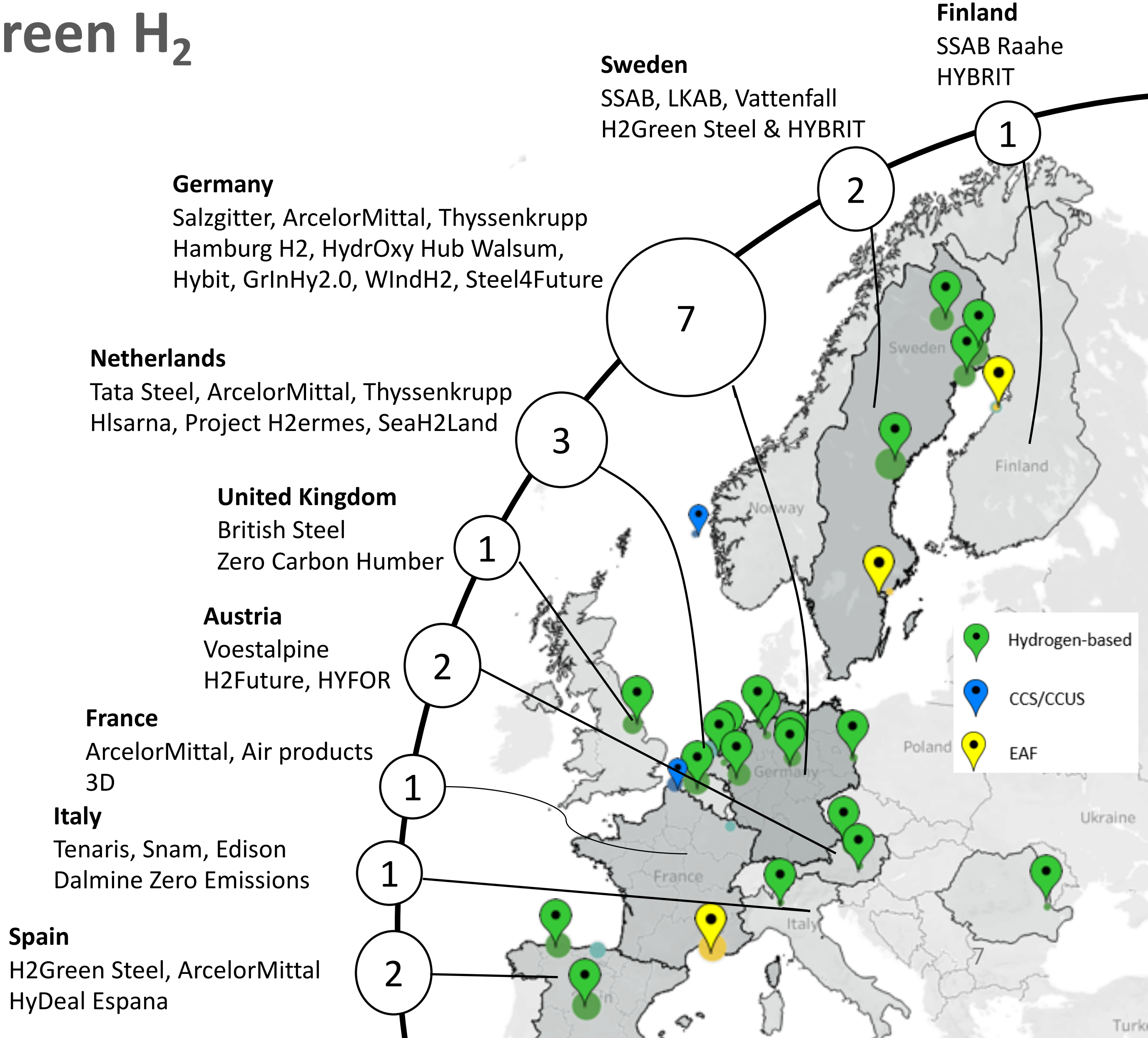
Most decarbonisation plans announced by EU steelmakers include producing DRI and using green H_2

Announced DRI Capacity Additions in EU (28)



Source: VisualCapitalist 2022 and KIS

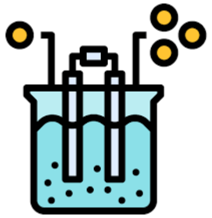


H_2-based steelmaking requires large quantities of H_2 which in turn requires large amounts of renewable electricity and water

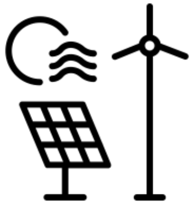
- **1 million tonnes of steel production** requires approximately…

50,000 tonnes of H_2

→ **50,000 tonnes of green H_2 requires…**

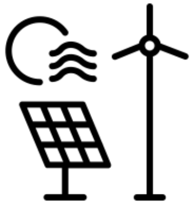


- 300 – 560 MW of electrolyser capacity
- 2,500 – 4,900 GWh of renewable electricity

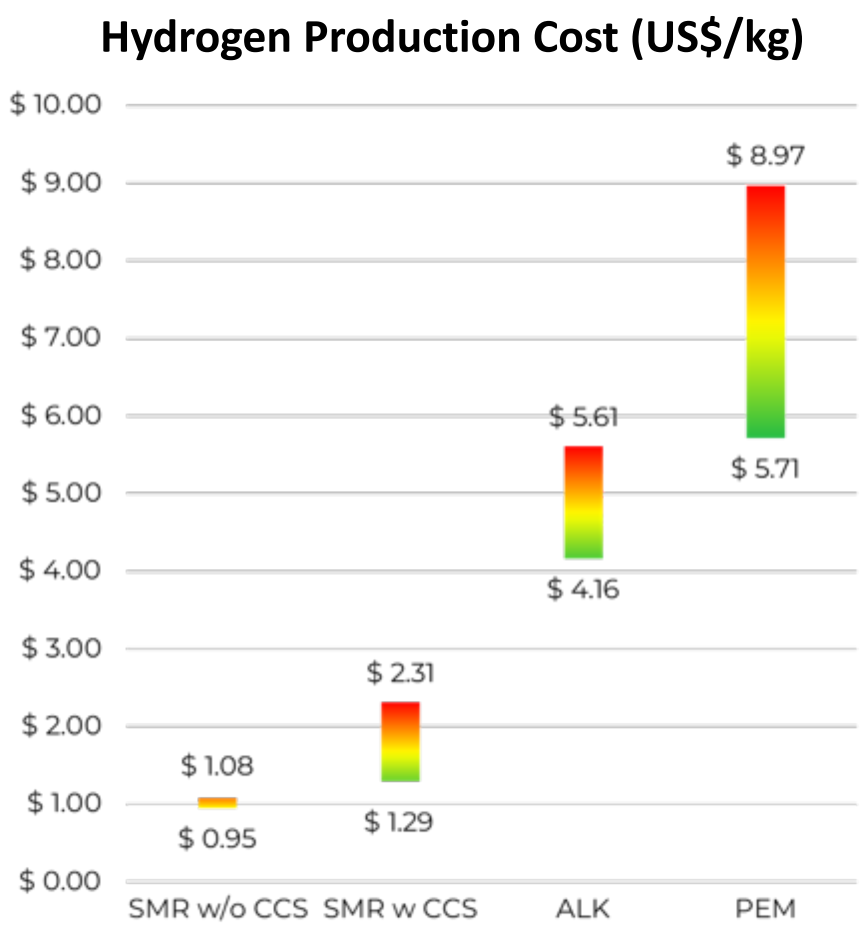


- 450 million litres of water

- plus a further 1,000 – 1,500 GWh of renewable electricity for other power requirements in the production process



Green H_2 production costs (electrolysis) depend on location, scale and technology, with the renewable electricity cost the main factor

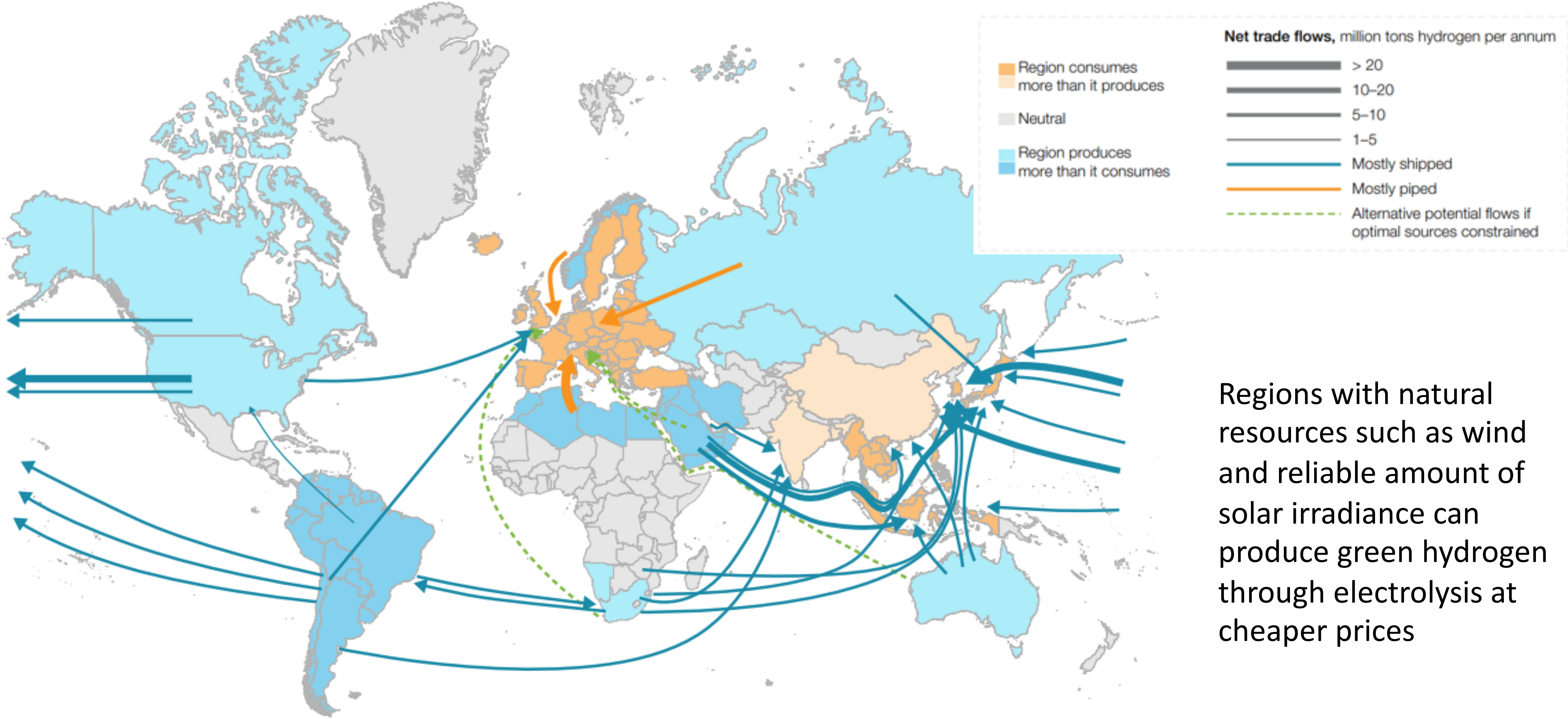


Source: Kallanish Index Services, October 2022

Category	Technology	Region/Country	H_2 Cost Range ($/kg)	KIS H_2 Index ($/kg)*
Green Hydrogen	Alkaline Electrolysis (ALK)	West Europe	4.53 – 5.42	4.63
		USA	4.15 – 5.60	4.34
		Canada	4.41 – 5.06	4.43
		Australia	4.45 – 5.25	4.51
		Japan	5.17 – 5.54	5.19
	Polymer Electrolyte Membrane (PEM)	West Europe	6.07 – 8.86	6.21
		USA	5.71 – 8.97	5.95
		Canada	6.00 – 8.05	6.06
		Australia	6.01 – 8.89	6.46
		Japan	6.84 – 8.03	6.88
Blue Hydrogen	Steam Methane Reformer with Carbon Capture & Storage	West Europe	1.29 – 2.31	1.29
Grey Hydrogen	Steam Methane Reformer without Carbon Capture & Storage	West Europe	0.96 – 1.08	1.08
		USA	0.95 – 1.08	1.06
		Canada	0.95 – 1.04	1.04
		Australia	0.95 – 1.06	1.06
		Japan	0.95 – 1.01	1.01

* For 20,000 kg of H_2 output/day

Significant green H_2 trade flows from low cost locations to centres of demand can be expected by 2050



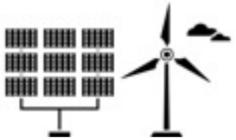
Regions with natural resources such as wind and reliable amount of solar irradiance can produce green hydrogen through electrolysis at cheaper prices

Source: Hydrogen Council, 2022

Using green H_2 to decarbonise the steel industry involves massive challenges

- Scale of H_2 generation capacity required (to meet steelmakers' announced plans to achieve net-zero)
- Scale of renewable energy capacity required (to produce green H_2 via electrolysis and power steelmaking operations)
- Scale of investment required in hydrogen infrastructure – storage and transportation facilities (liquification, tankers, pipelines, etc)
- Cost of green H_2 production (hydrogen-based steelmaking is currently $$$ more expensive than existing process routes)
- Availability of high grade iron ore: DRI currently requires iron ore pellet feedstock with >67% Fe content and low impurities (around 3% of current iron ore supply)
- Increased demand for ferrous scrap – impact on prices and supply chains

52 MT of green H_2



2000 GW of renewable capacity (67% of current capacity)

Capture & store 400-500 MT

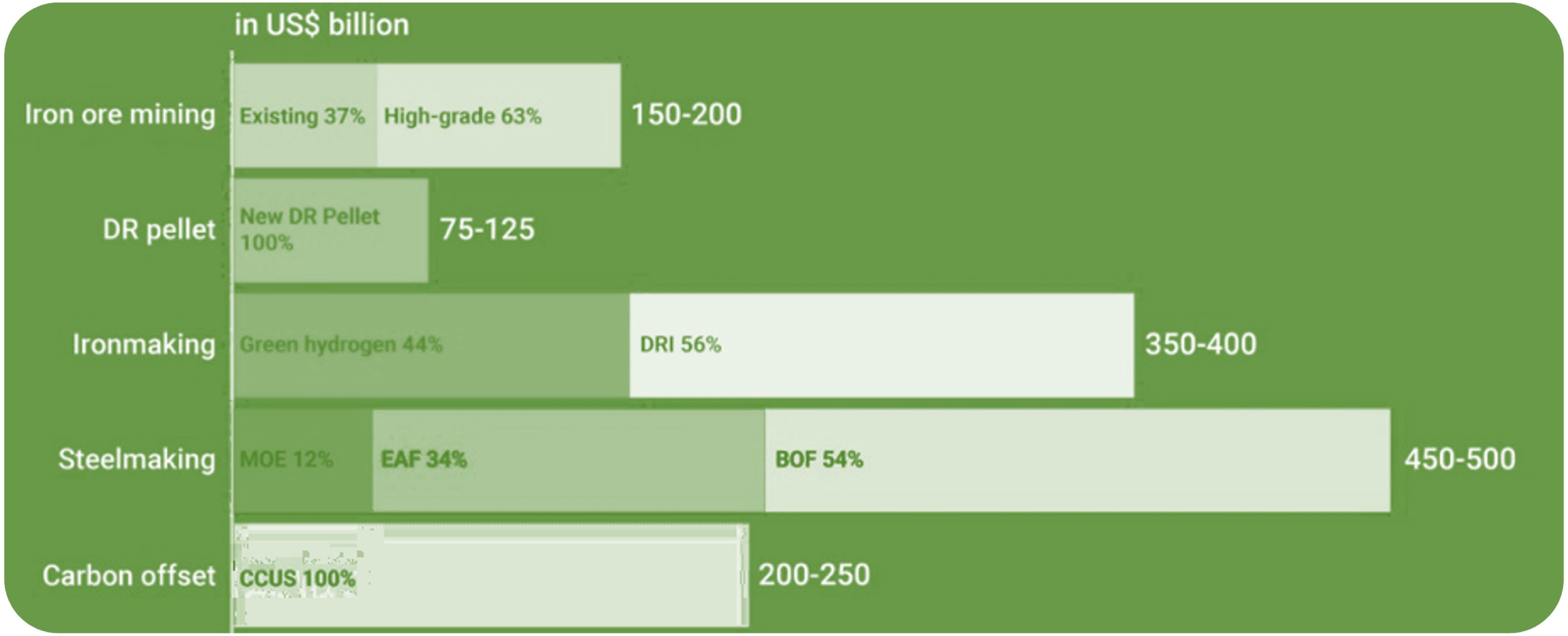
750 MT of High-grade iron ore (DR pellet feed) (5.5x current supply)

1300 MT Scrap pool (2x current supply)

Source: Wood Mackenzie, 2022

The investments required for the steel industry to achieve net zero by 2050 are estimated to be in the order of US$1.4 trillion

Estimated Investments Required to reach Net Zero (2050)



Source: Wood Mackenzie 2022

Thank you!

Feel free to contact us
if you have any questions.

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www.kallindex.com

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Hydrogen for steelmaking

Håkon Volldal
CEO, Nel
7 December 2022

This is Nel

Nel is a global, dedicated hydrogen technology company that delivers optimal solutions to produce, store and distribute hydrogen from renewable energy

We unlock the potential of renewables and enable global decarbonization

nel•

Leading pure play hydrogen technology company with a global footprint

Pure play hydrogen technology company listed on the Oslo Stock Exchange (NEL.OSE) since 2014

World’s largest electrolyser manufacturer, with >3,500 units delivered in 80+ countries since 1927

Alkaline prod. capacity: ~500 MW → ~1 GW /year
PEM prod. capacity: ~50 → ~200 MW/year

Leading manufacturer of hydrogen fueling stations, with ~120 H2StationTM solutions delivered/in progress to 14 countries.

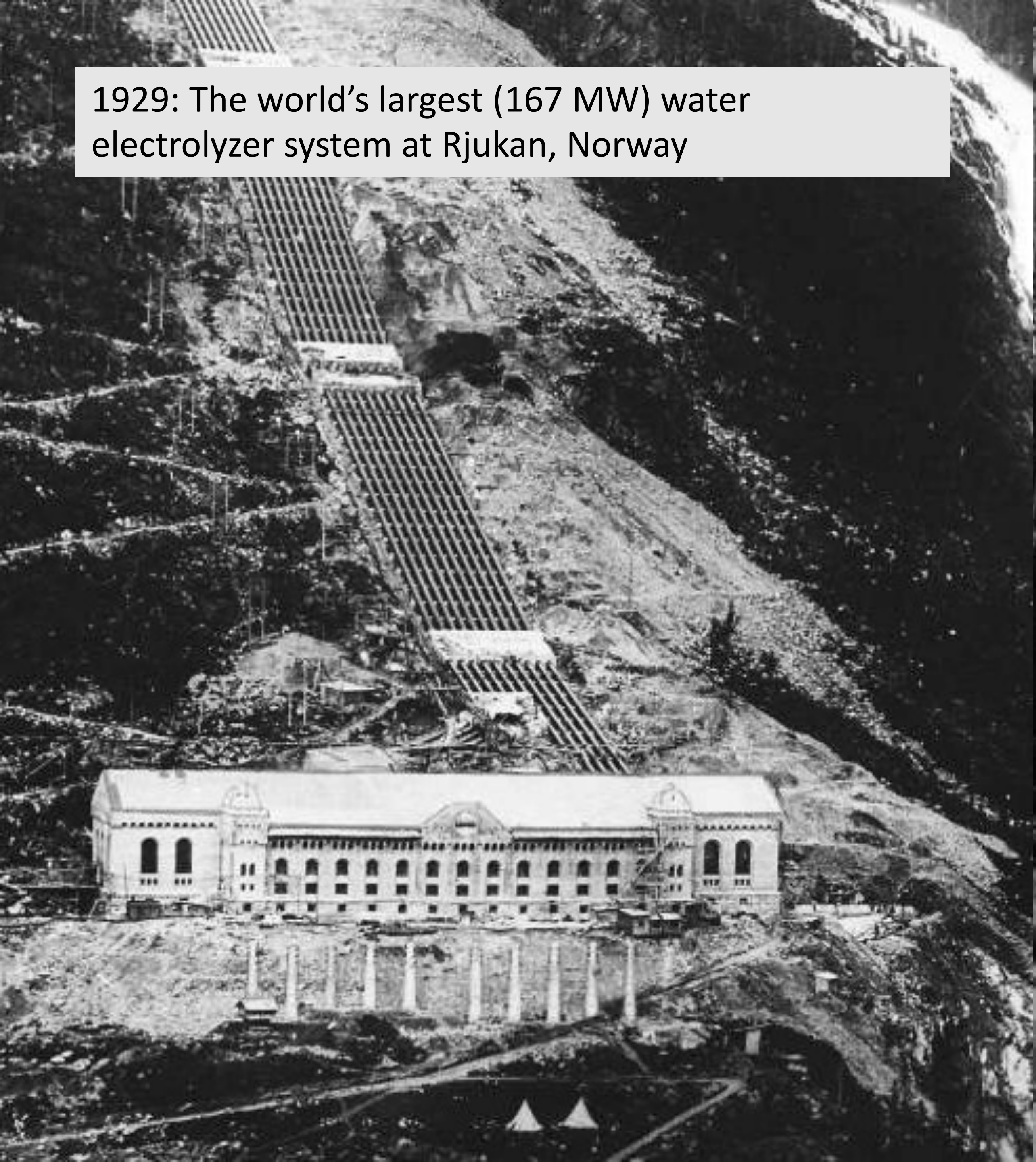
Manufacturing facilities in Norway, the US, and Denmark

Global sales network and offices

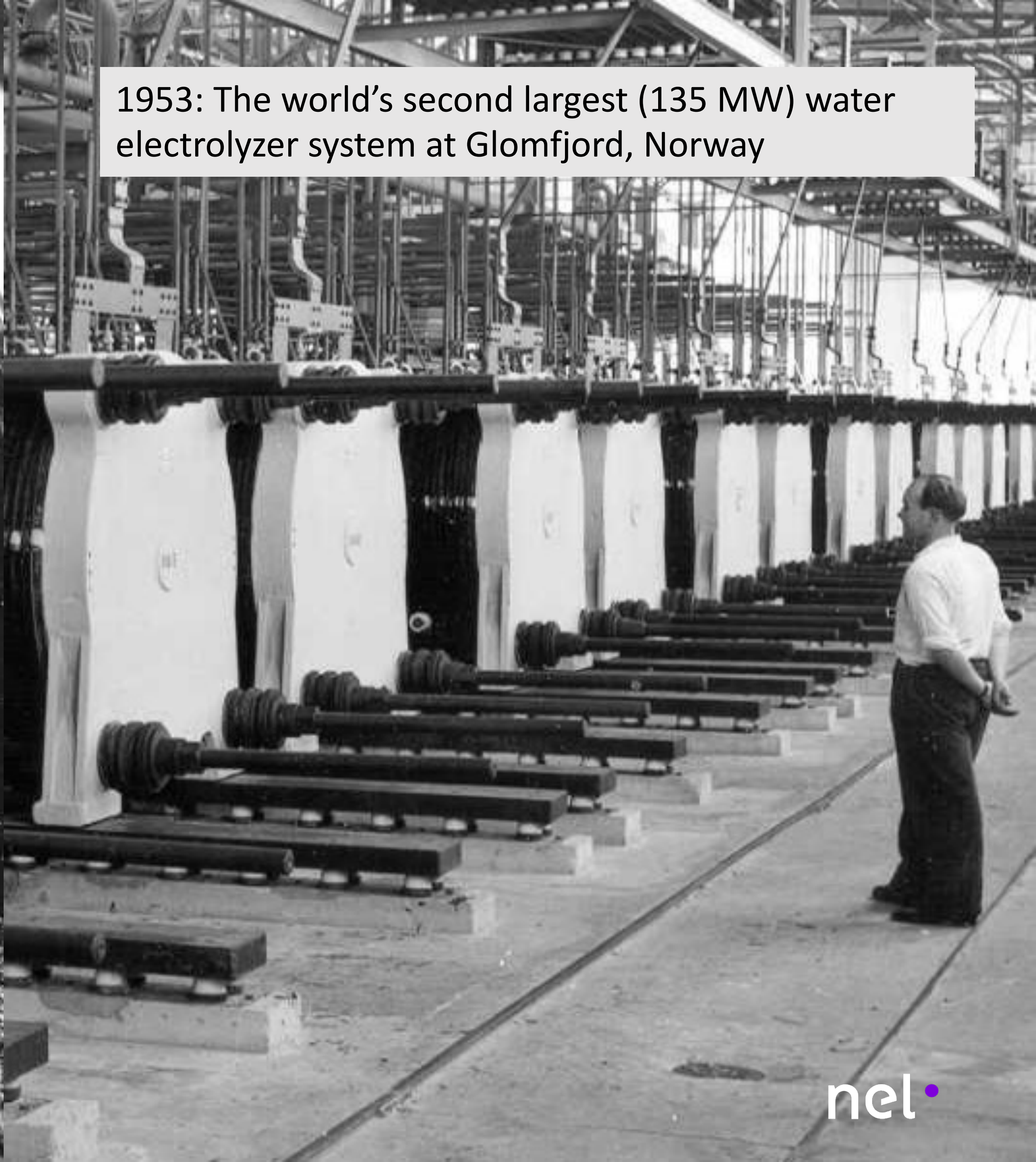
~575 Employees

Preferred partner with industry leaders

NOK 3.5 billion in cash reserves



1929: The world's largest (167 MW) water electrolyzer system at Rjukan, Norway



1953: The world's second largest (135 MW) water electrolyzer system at Glomfjord, Norway

nel

The world's only fully-automated electrolyser plant

- Large-scale production capacity of ~500 MW
- Capacity will be doubled to 1 GW. Can be expanded to ~2 GW
- Expansion at existing manufacturing plant in Wallingford, Connecticut
- Site selection process for a new 4 GW manufacturing facility in the US
  - expected to be concluded in 1H 2023
- A concept for fully-automated electrolyser facilities is key when scaling up production

Making green steel with Nel's hydrogen technology

- 4,5 MW alkaline electrolyser to HYBRIT pilot
  - Replacing coal with green hydrogen
  - First fossil-free steel production in August 2021

- 20 MW alkaline electrolyser to Ovako's steel recycling
  - The world's first to use hydrogen and oxygen in the heating process
  - Hydrogen production expected to start in Q2 2023
  - Conversion to green hydrogen will halve CO2 emissions from current levels

number one by nature

nel

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The fossil-free future

Thomas Hörnfeldt
VP Sustainable Business

SSAB

Strong globally and locally

MORE THAN

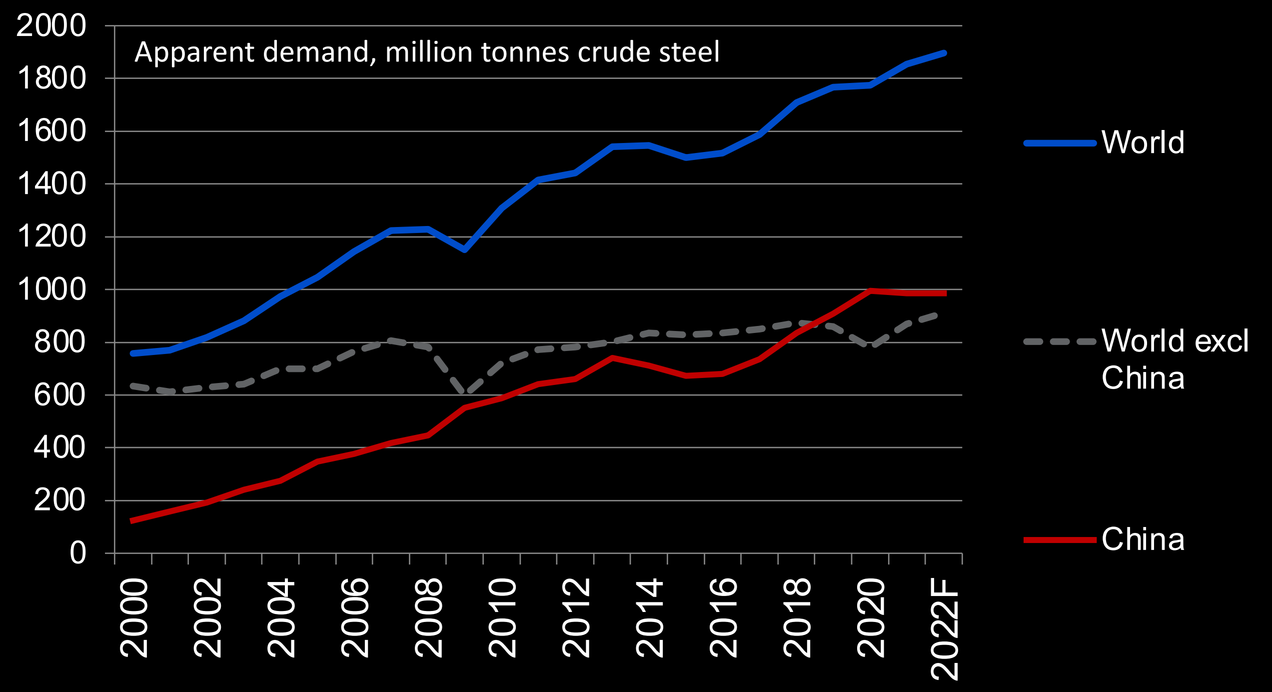
150

COUNTRIES OF
SALES COVERAGE

SSAB

STEEL CONSUMPTION INCREASING

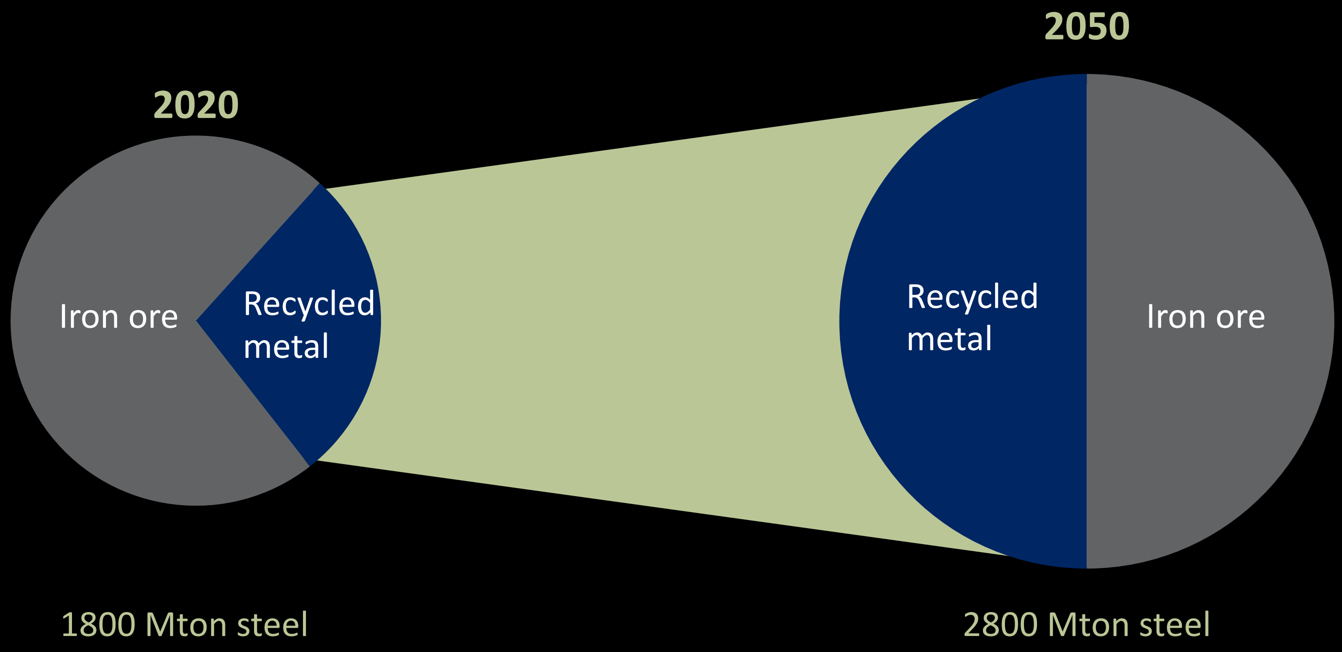
- Standard of living
- Urbanisation and infra structure
- Transportation and production



Source: worldsteel Short Range Outlook

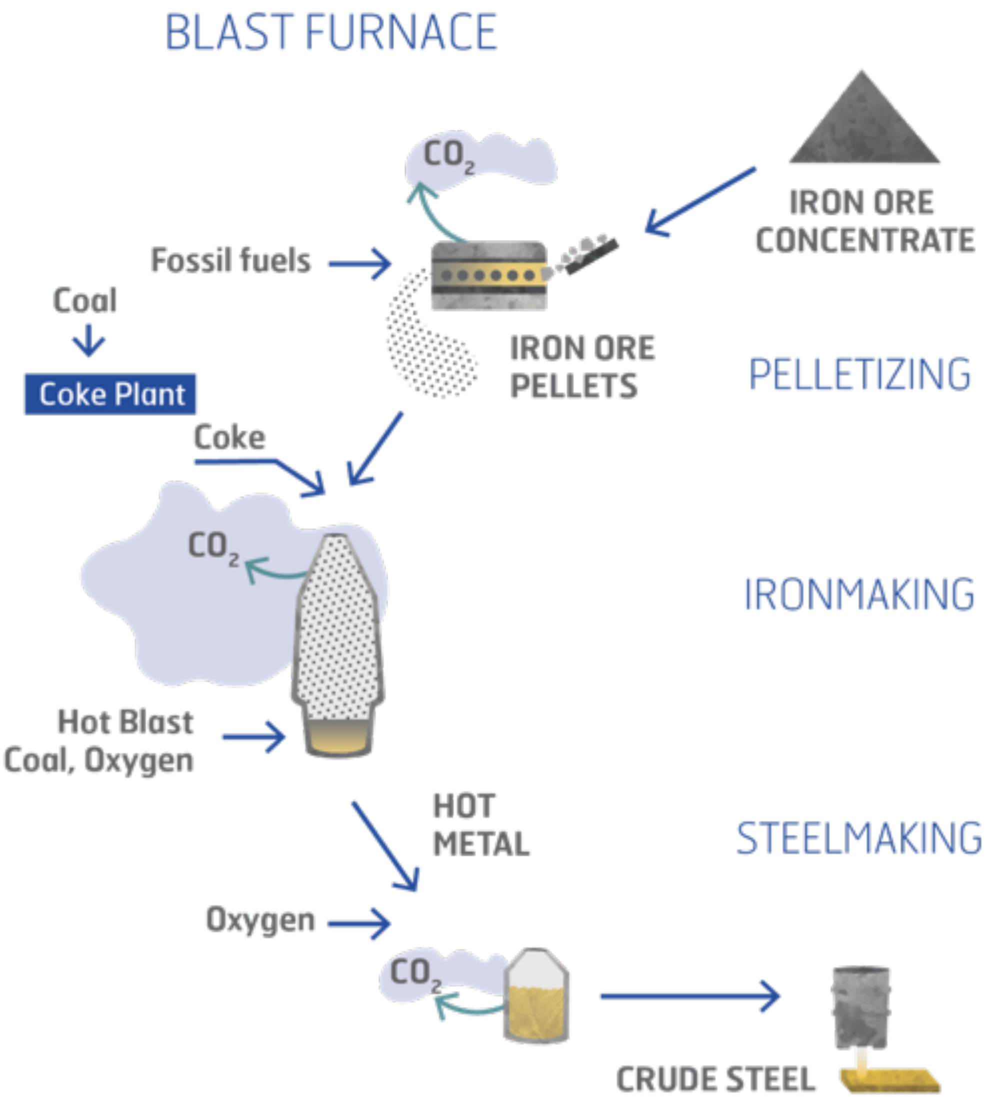
SSAB

RECYCLING IS NOT ENOUGH

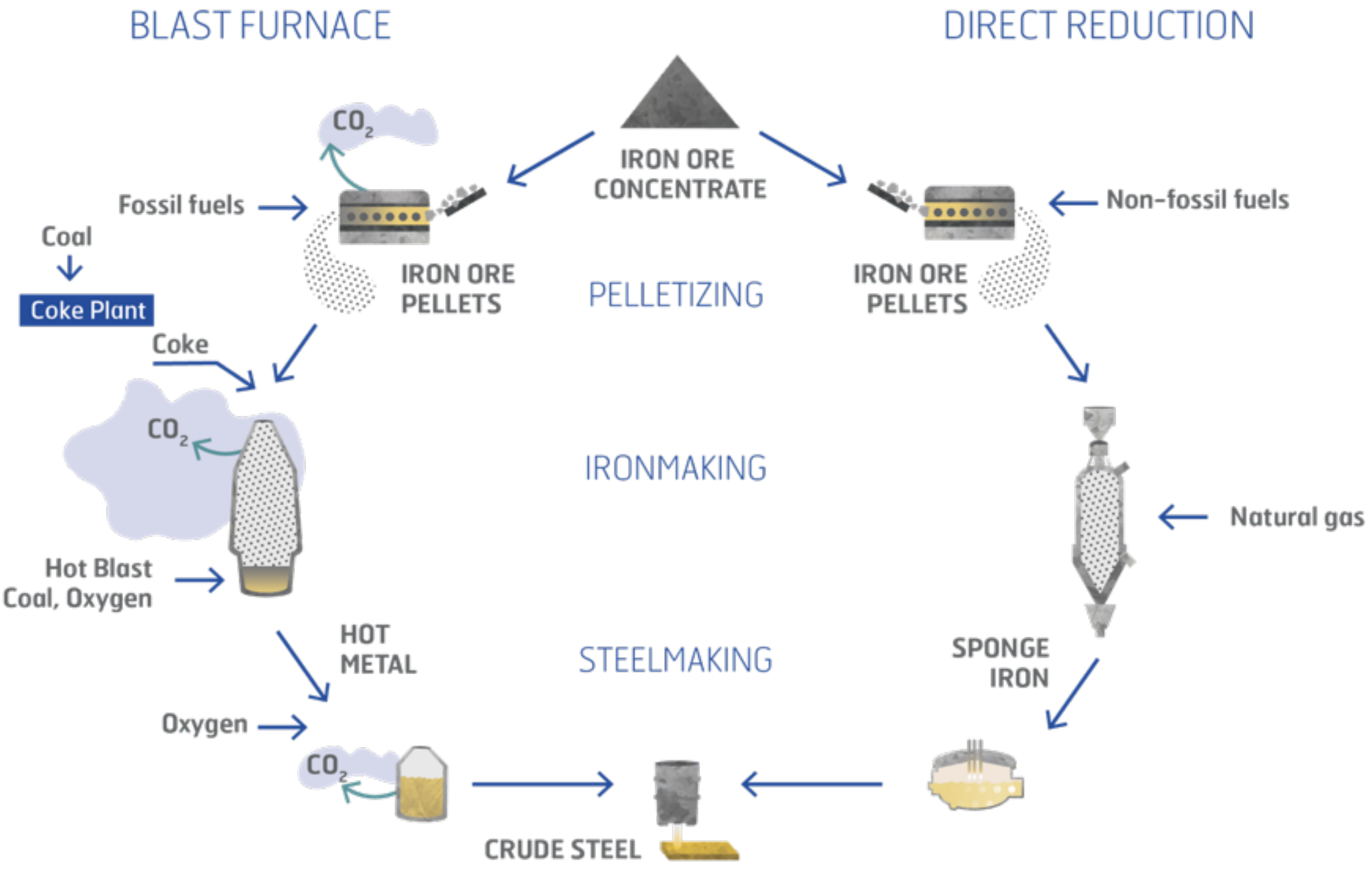


The HYBRIT technology

Two ways to make steel from iron ore today



Two ways to make steel from iron ore today



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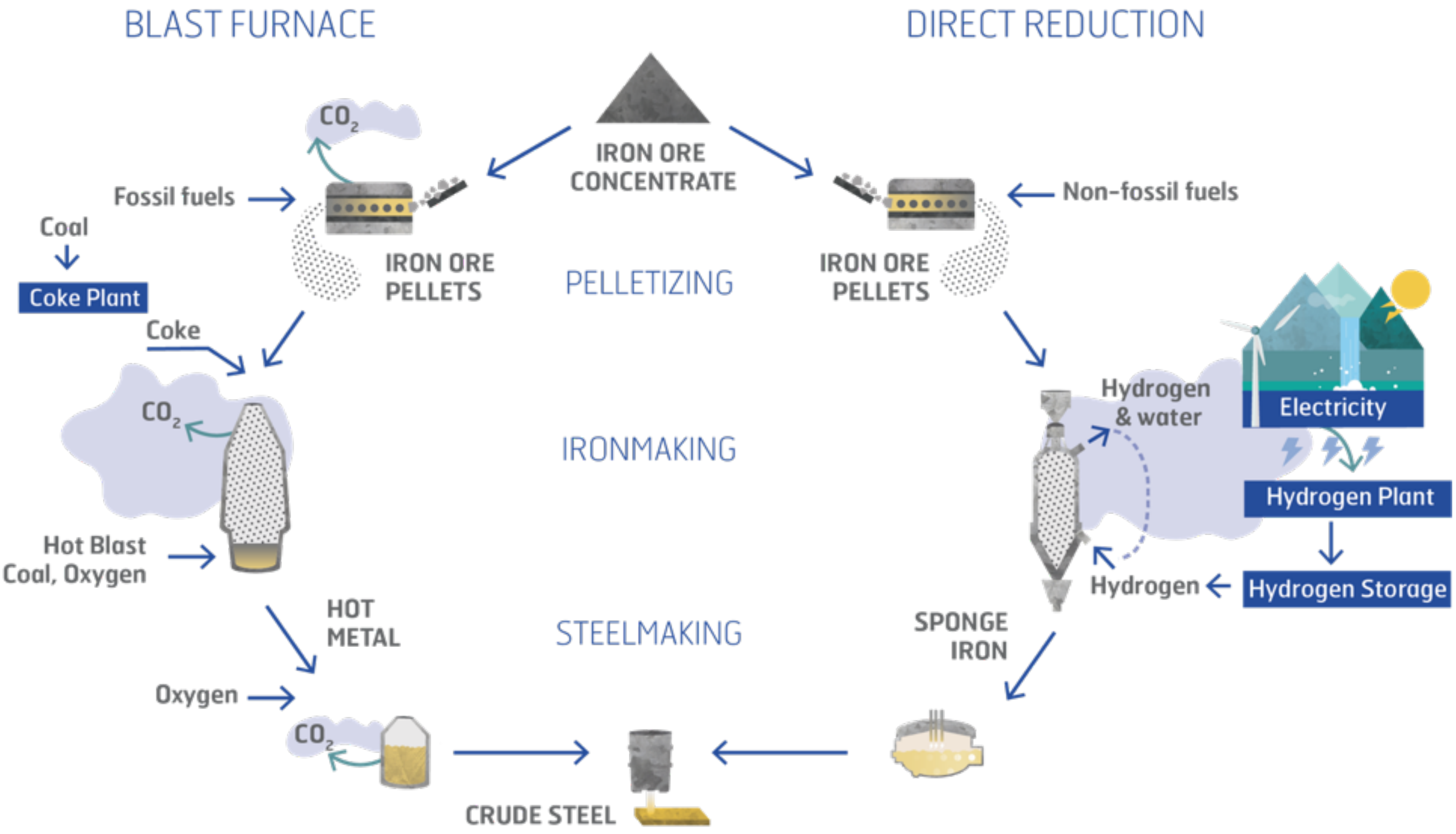
HYBRIT – Fossil-free steelmaking



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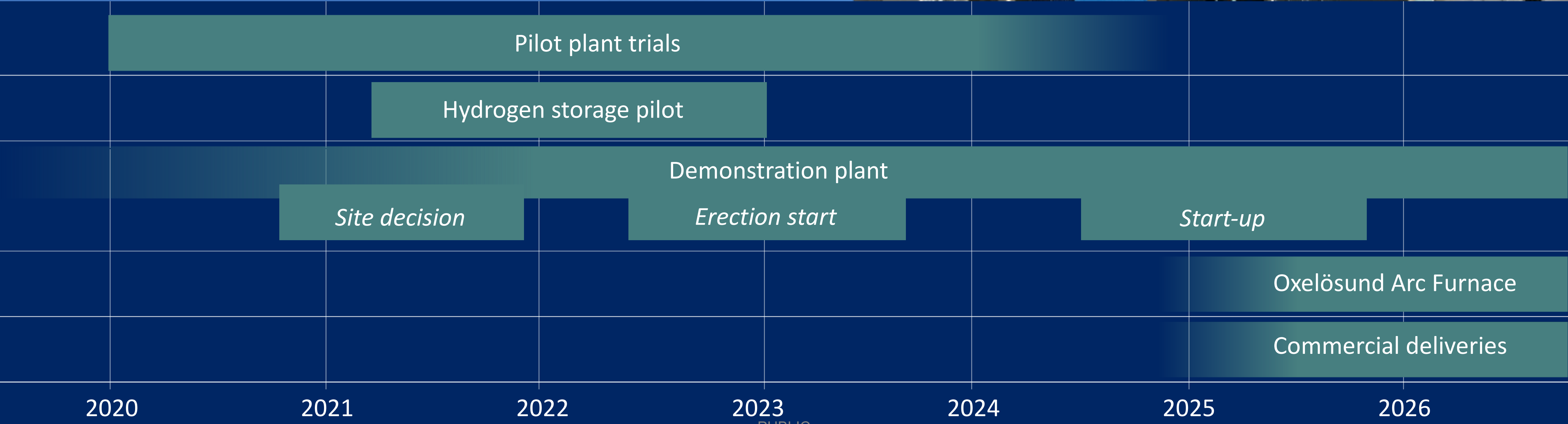
HYBRIT Pilot & Demonstration plant

First products reaching
the market in 2026



World’s first production plant for fossil-free sponge iron

- Industrialization of HYBRIT technology
  - The world’s first production plant for fossil-free sponge iron
  - In Gällivare, northern Sweden

- The demonstration plant which will be ready in 2026
  - Production capacity of 1.3 million tonnes of fossil-free sponge iron
  - Goal to expand production to 2.7 million tonnes by 2030

- Gällivare gives industrial synergies
  - Integration with iron pellet making
  - Transportation and logistics
  - Electricity supply and energy optimization

The first fossil-free steel delivered in July 2021

Cooperation with selected companies

VOLVO
VOLVO GROUP

VOLVO

Mercedes-Benz

Polestar

faurecia

Autoliv

shape CORP

CARGOTEC
HIAB · KALMAR · MACGREGOR

PEAB

Lindab

Epiroc

ALFA LAVAL

“We are leveraging innovation and collaboration to address the climate crisis. We are honored that SSAB will collaborate with us in our endeavors to produce a truly climate-neutral Polestar car by 2030”
says Thomas Ingenlath, CEO at Polestar.

“SSAB is showing the way in manufacturing quality steel without carbon dioxide emissions. SSAB’s innovative solutions will be invaluable in helping us decarbonize our manufacturing processes and the materials we use”

German financial paper ”Handelsblatt” September 2021

CLIMATE FRIENDLY INDUSTRY

Daimler is on its way to CO2-lean production – Swedish producer delivers green steel

The automaker is driving the decarbonisation of its supply chain: Starting 2026 Daimler will be sourcing CO2-free steel from SSAB in Sweden.

Translation by SSAB

Mercedes-Benz ”Ambition 2039” – carbon neutral in 2039

The first fossil-free automotive steel

► Laser cutting fossil-free steel at Mercedes-Benz AG in Sindelfingen

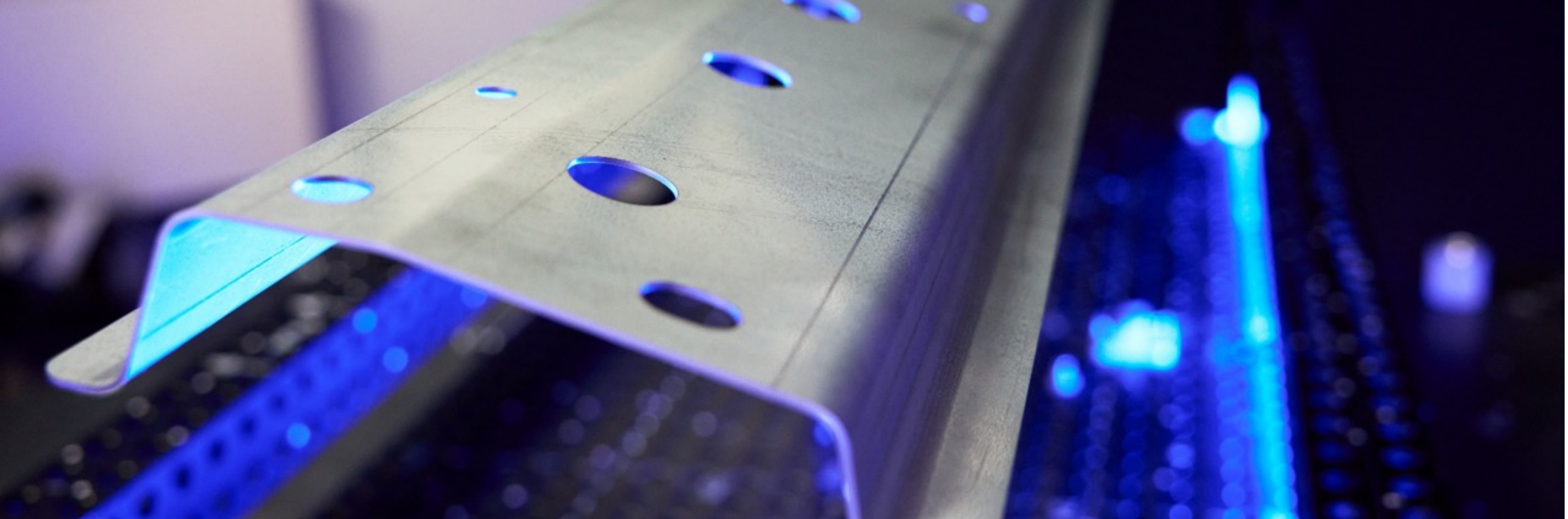
► A fossil-free steel using the HYBRIT technology

► A cold rolled 1500 martensitic steel

► A first delivery of fossil-free prototype sheets to an automotive OEM

The same properties as conventional material

- ▶ First automotive prototypes manufactured in two designs
- ▶ Seat cross-member and reinforcement for upcoming car line
- ▶ All tested properties confirm same properties as serial material



Want to know more?

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SSAB
A stronger,
lighter and more
sustainable world
PUBLIC

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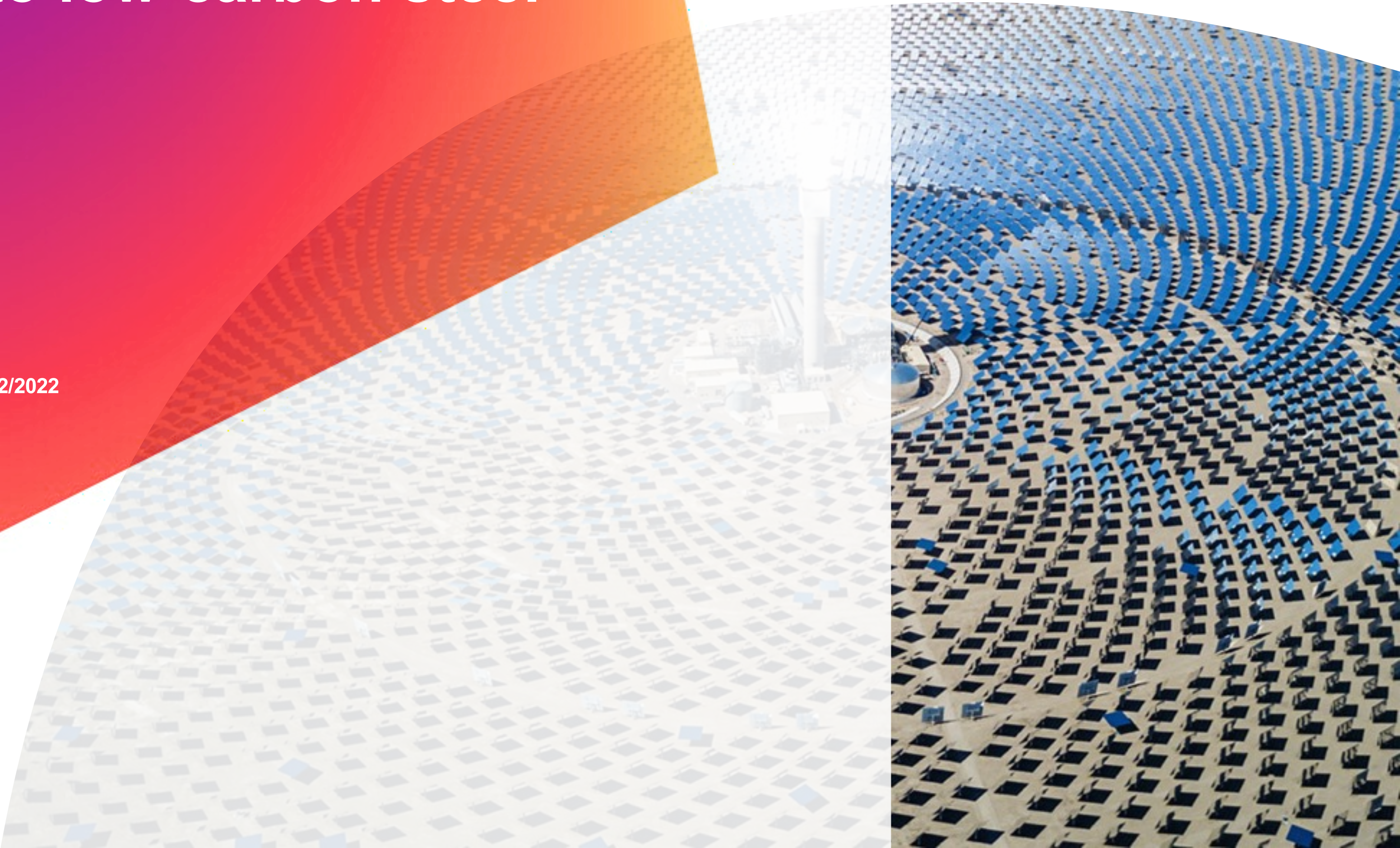
Low-Carbon Hydrogen: The enabler to low-carbon steel production



ArcelorMittal

Stéphane Tondo

Kallanish Commodities Webinar – 07/12/2022

Steel is critical to the transition to a carbon neutral, circular economy

Integral to the renewable energy revolution

A core material in the transition to electric vehicles

Supports the next generation of high-performance buildings

Facilitates emerging market infrastructure development

We are committed to decarbonising steel production

ArcelorMittal

-35%

Scope 1 & 2 CO_2 emissions by 2030 across Europe

Net zero

CO_2 emissions by 2050

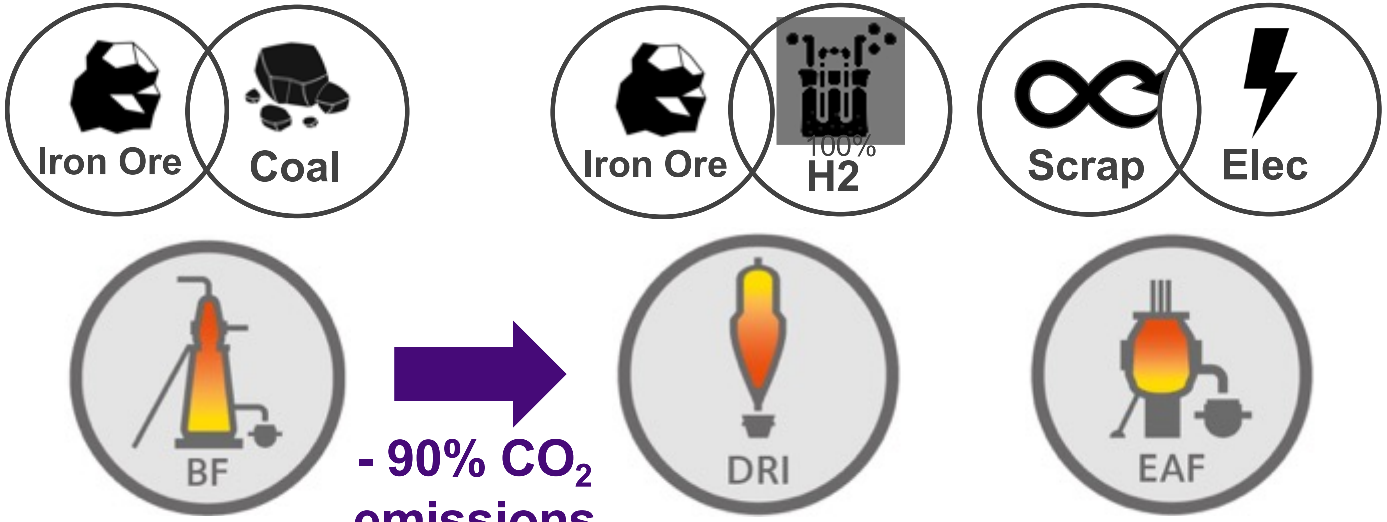
SBTi

Committed to setting science-based targets aligned with 1.5°

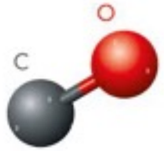
What is the Role of Hydrogen in Steel Production?

From Iron Ore to Iron

As reductant (Chemical agent) in DRI: replacing Coal or NG



- 90% CO_2
emissions



Carbon Based

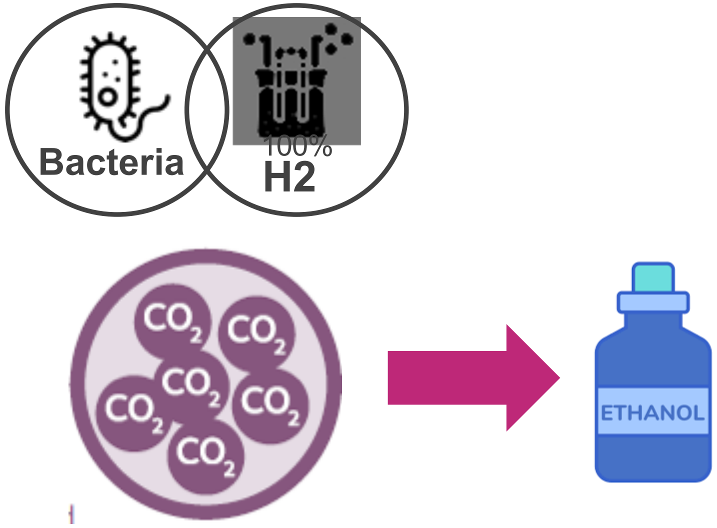
$FeO + CO \rightarrow Fe + CO_2 + CO$

Hydrogen Based

$FeO + H_2 \rightarrow Fe + H_2O + H_2$

From CO_2 to Ethanol

A chemical agent used to combine with CO2



Hydrogen Based

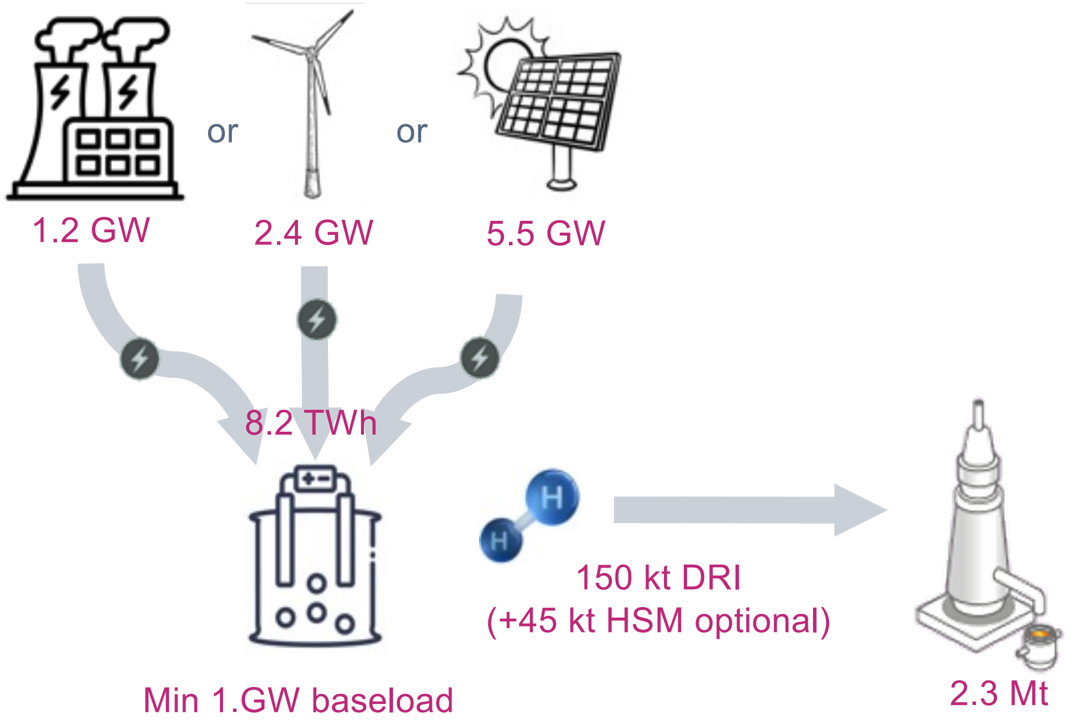
$2CO_2 + 6H_2 \rightarrow C_2H_5OH + 3H_2O$

H_2 is not intended to be used as Fuel

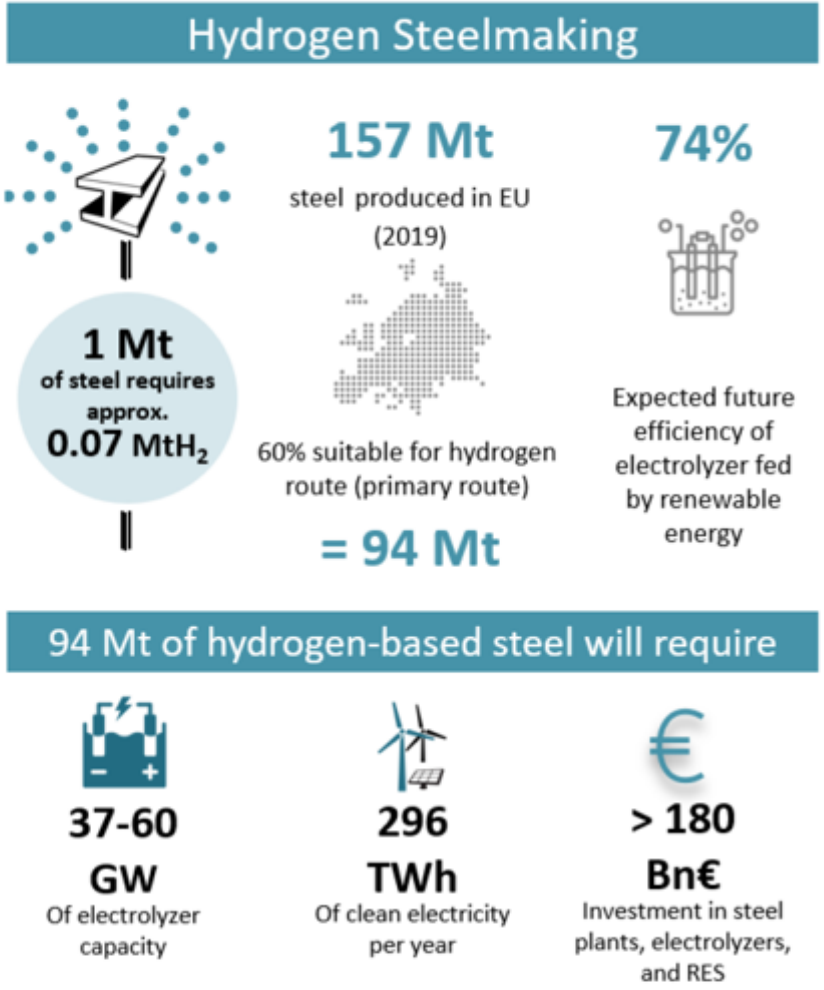
ArcelorMittal

How much hydrogen will be needed?

Decarbonized Steel Production requires massive volumes of Hydrogen



Requiring massive investments in decarbonized electricity and electrolyzers



rcelorMittal

Source: Carbon steel production report – European Parliament Research Service – April 2021

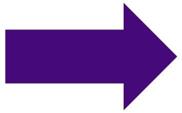
By when will hydrogen be needed for the steel industry?

By 2030, most of EU's steel production will be decarbonized

Primary production: ≈ 56%

Secondary production : ≈ 44%

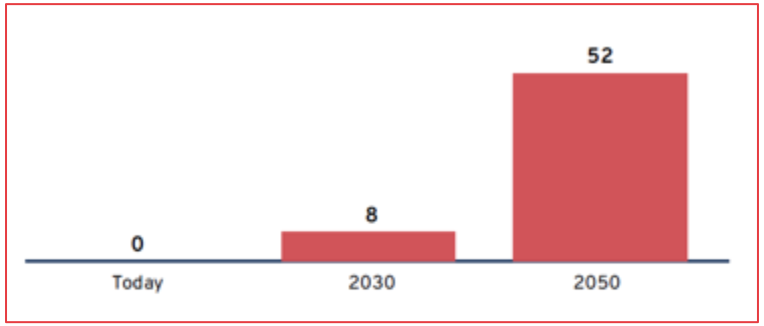
>50%



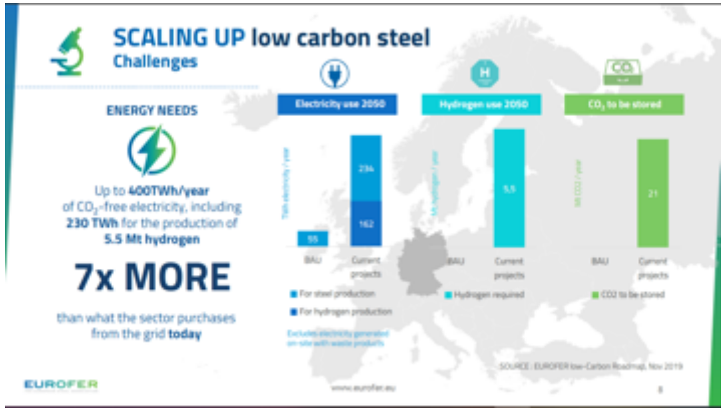
2025-30

Primary transformation Boosting H_2 needs for steel between 2025 and 2030

MPP TM: 8Mt WW by 2050



Eurofer: 5,5Mt H2 by 2050



What are the Barriers to the use of Hydrogen in steel manufacturing?

Available

Production
Ramp-up vs needs ?
Prioritization?

Transmission
Pipelines for baseload !

Stable

Storage
Intermittency vs continuous !

Regulation
Correlation, TEN-T

Decarbonized

Green H2
power availability ?

Low-Carbon H2
Definition ?

Affordable

Competitiveness
Domestic & imports costs
International market

Incentives
Subsidies Mechanisms ?
CCfDs

Thank you !

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