

Hybrit Pilot Project: Melting HDRI with 0% Carbon

Scrap supplements and alternative ironmaking 10
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*Gunilla Hyllander, Pär Ljungqvist, Niklas Kojola,
Joel Carlsson, Hedda Pousette*

100% CARBON-FREE STEEL



SSAB



LKAB



VATTENFALL

Hydrogen Breakthrough Ironmaking Technology

for a fossil-free future

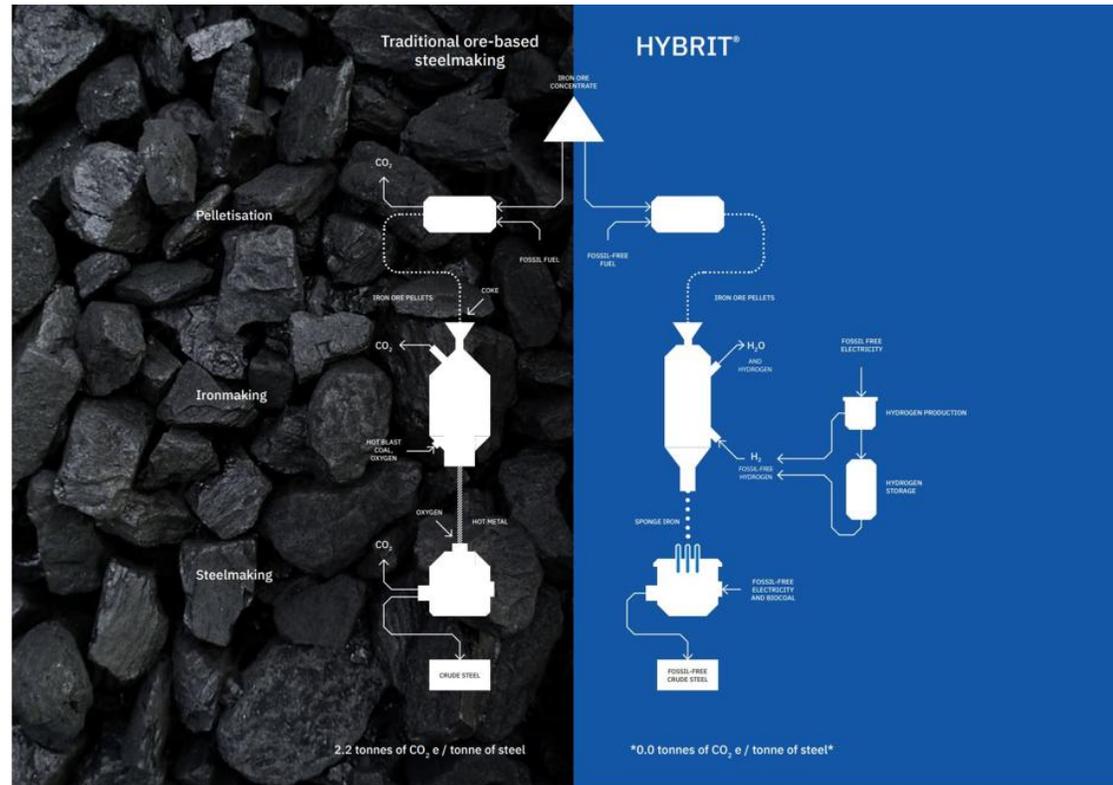
HYBRIT eliminates CO₂ from the iron and steel industry

2,2
ton CO₂/ton
steel

Average blast furnace
process

1,6
ton CO₂/ton
steel

State-of-the-art
blast furnace
process

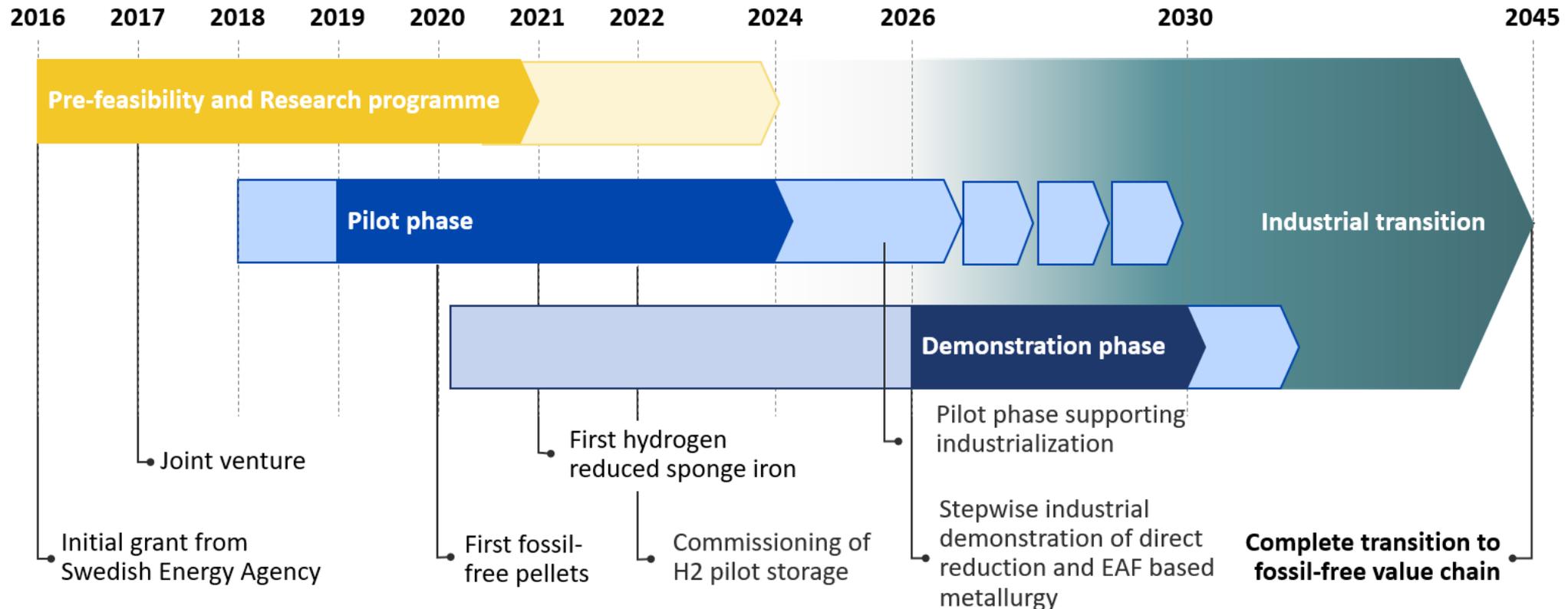


0,0*
ton CO₂/ton
steel

HYBRIT
Hydrogen based
direct reduction
process

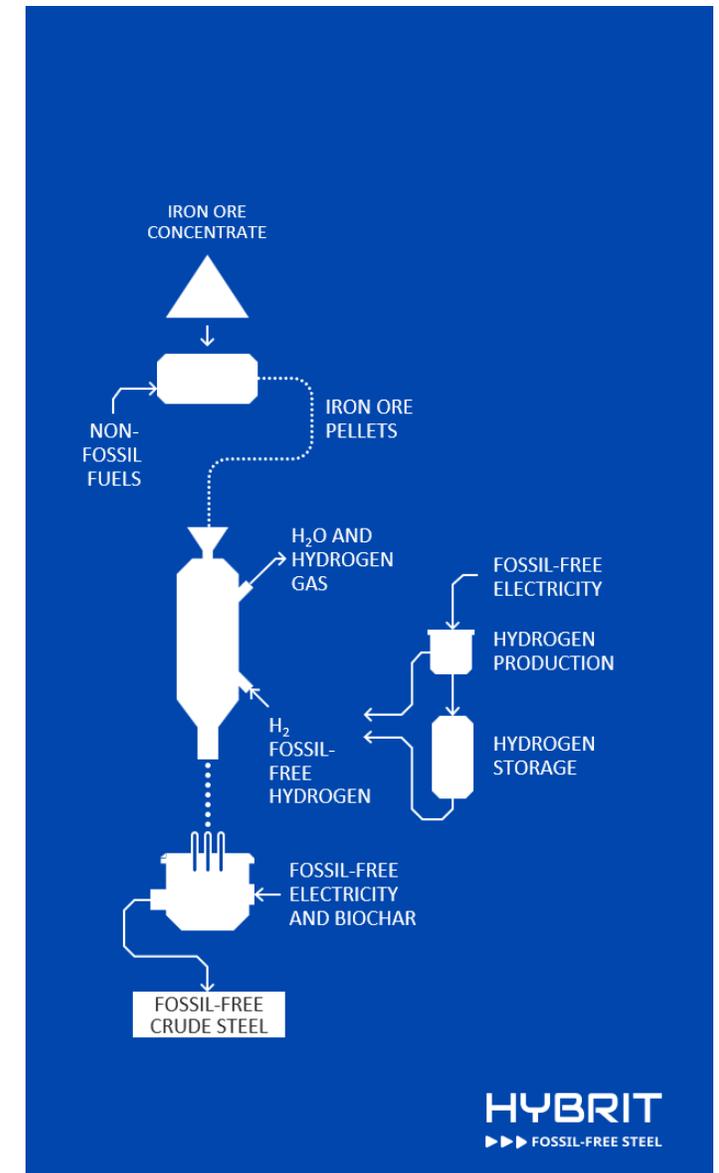
*The process produces small emissions of carbon dioxide from the consumption of graphite electrodes and the addition of slag formers in the electric arc furnace. These emissions are less than 0.05 ton of CO₂ e/ton of steel which is rounded to 0.0 ton of CO₂ e/ton of steel. Typical value for ore-based steelmaking with blast furnace technology is 2.2 tons CO₂ e/ton of steel.

HYBRIT timeline – From technical development to complete transition 2045



Verified development at each step

- Fossil-free production of iron ore pellets
- Hydrogen-based direct reduction on a semi-industrial scale
- Provides a competitive iron and steel value chain
- Melting of fossil-free iron raw material in an electric arc furnace in co-operation with Swerim
- Hydrogen production and storage
- Industrial process practice established
- Innovation on time and within budget



Verification across the value chain

- From ore to steel



IOP production
with bio-oil



H2 sponge iron
production



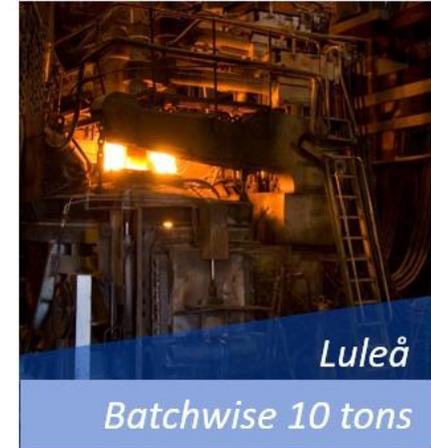
Hydrogen
production



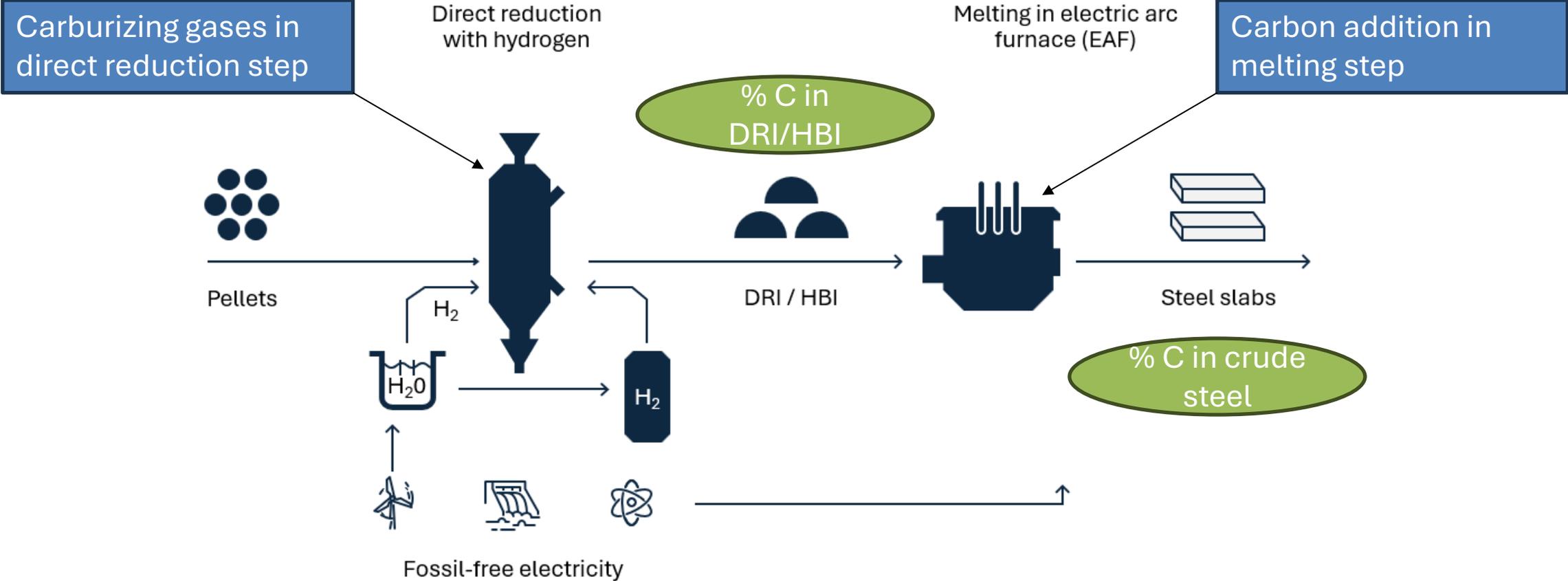
Hydrogen storage
in lined rock cavern



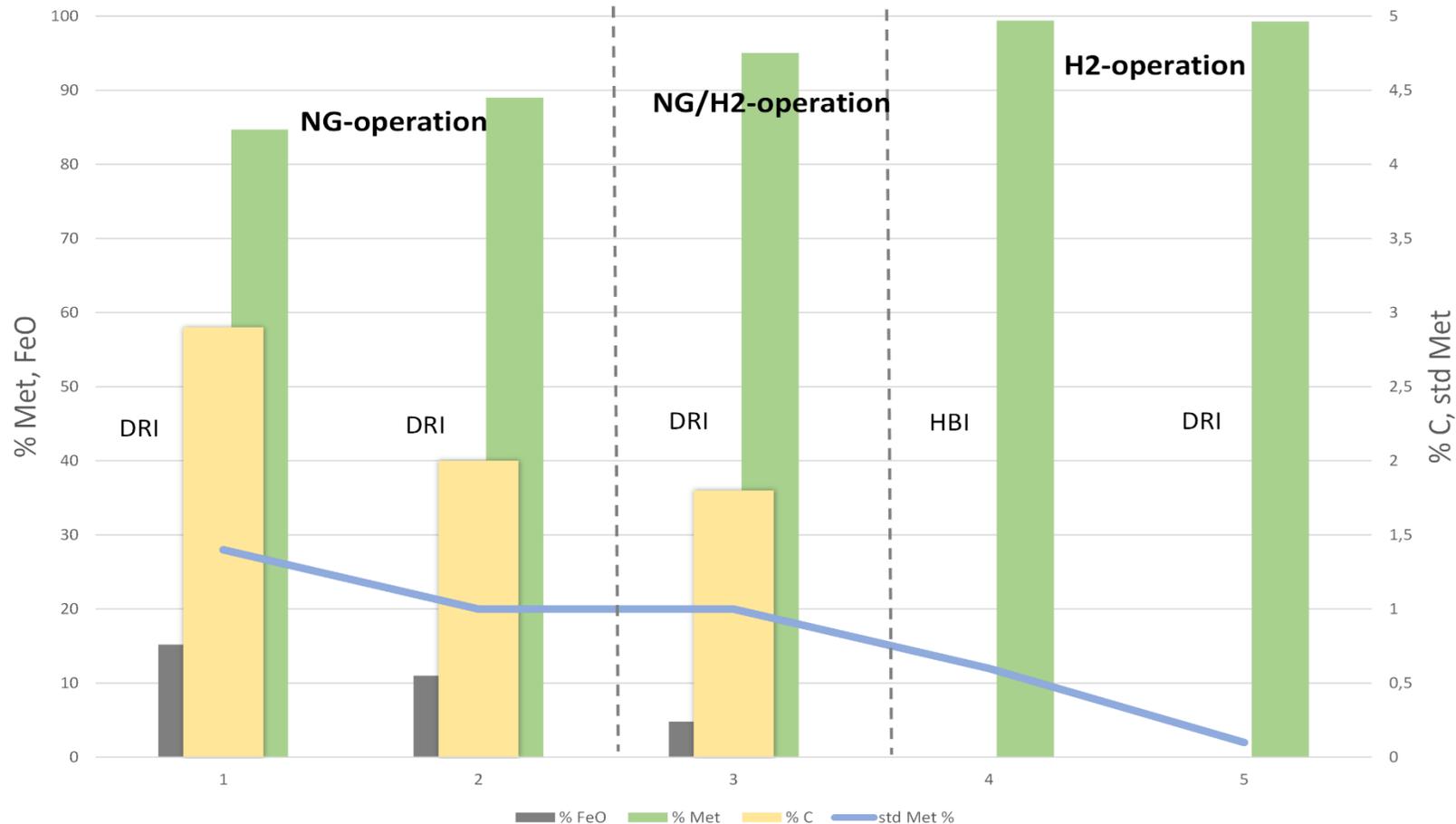
Melting in electric
arc furnace



Role of carbon in different process steps – is it possible to minimize it?



Hydrogen content during reduction - affects pilot DRI product quality



Extensive pilot testing focusing on process settings for hydrogen based direct reduction

- Including testing of different kinds of carburization
- Ingoing **reduction gas temperature** to the shaft between 550 – 1030 °C
- **Operating pressure** between 2 to 4 barg
- **Production rate** between 0,8 to 1,4 t DRI/h
- **Residence time** for reduction have been varied in a wide span
- **175 process points** with hydrogen reduction have been evaluated in the pilot programme

Defined
process window
for transtion to
industrial scale

New sponge iron product with unique properties

Sponge iron pellets reduced with hydrogen have significantly better transport, storage and melting properties compared to sponge iron reduced with conventional natural gas-based processes.

- Low iron oxide content and 0% carbon give the sponge iron robust mechanical properties.
- Tests also show that the product has very good and stable chemical properties.
- A high degree of metallisation (98-99%) means that there is very little iron oxide remaining.



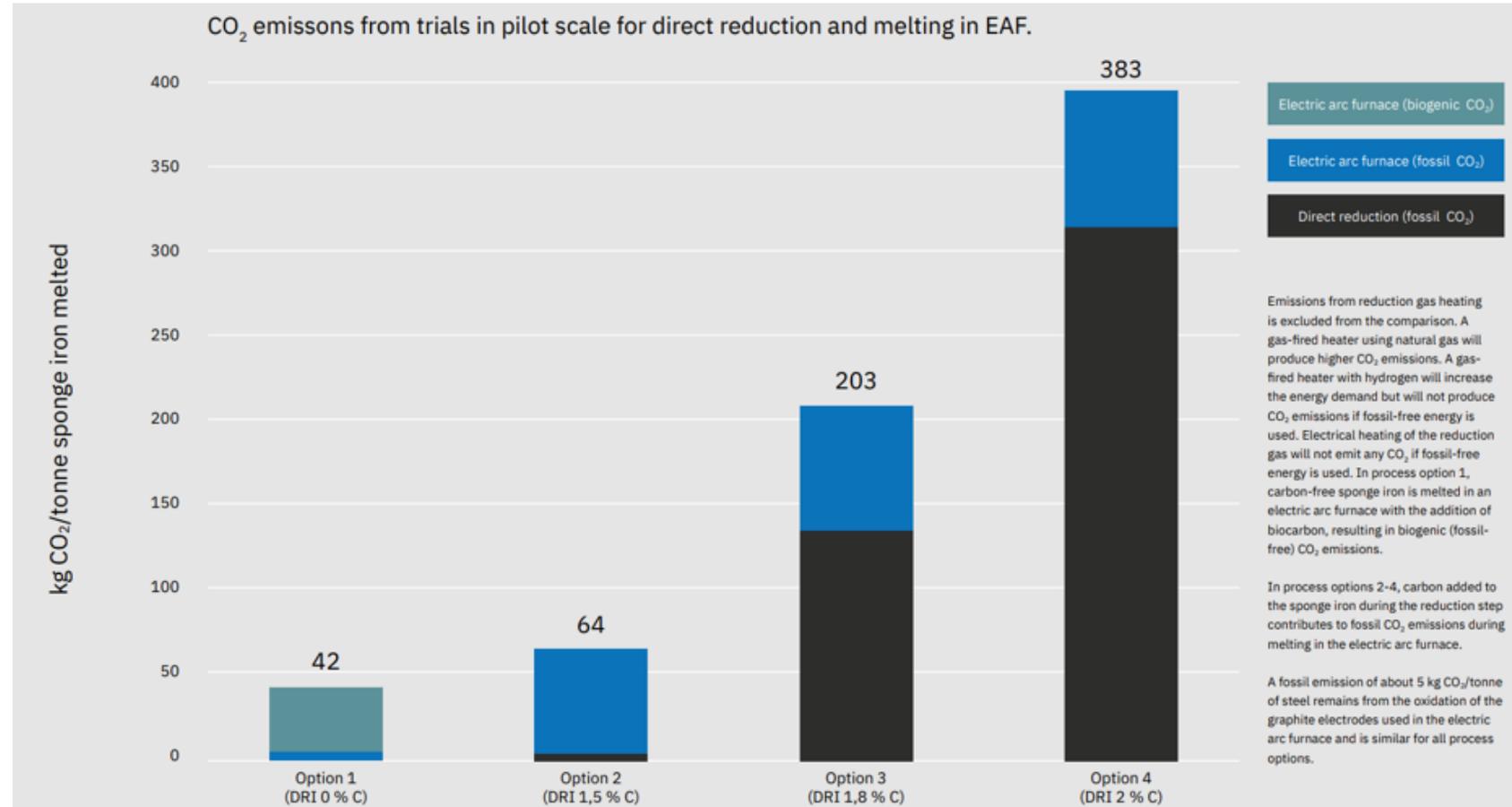
Sponge iron and melting

- DRI and HBI has been produced from NG and H₂ operations, in wide range of compositions
 - Metallization degree
 - Carbon contents
- Melting trials in EAF have been conducted in order to establish best operational practice with hydrogen reduced DRI and HBI.
 - More than 400 melts
 - 12 different materials have been tested
 - Different DRI and HBI incl commercial HBI
 - Varied metallization degree and carbon content



HYBRIT makes fossil-free iron and steel a reality

1. Direct reduction of iron ore pellets using hydrogen only. Biocarbon is fed to the electric arc furnace during the melting of the sponge iron. **This is the main option of the HYBRIT process.**
2. Direct reduction of iron ore pellets using hydrogen only, but the sponge iron is carburised after the reduction step using, for example, natural gas.
3. Direct reduction of iron ore pellets using mainly hydrogen, but the sponge iron is carburised during the reduction process
4. Direct reduction of iron ore pellets using conventional technology based on natural gas.



As a reference: State-of-the-art blast furnace process emits 1,6 ton CO₂ / ton steel

Melting of carbon-free sponge iron into fossil-free steel



Pilot trials in Swerim's electric arc furnace

- Continuous weekly operation
- 12 weeks total testing time
- More than 400 trial melts
- More than 1000 tonnes of steel have been produced

A fossil-free process for melting carbon-free sponge iron has been developed and is ready for full-scale implementation.

Varied parameters in melting carbon-free sponge iron into fossil-free steel

Ingoing iron carriers:

- Sponge iron (DRI)
- Hot briquetted iron (HBI)
- Scrap

Chemical properties:

- Degree of metallization
- Carbon content

Adding method:

- (Batchwise during start-up)
- Continuous feeding

Carbon carriers:

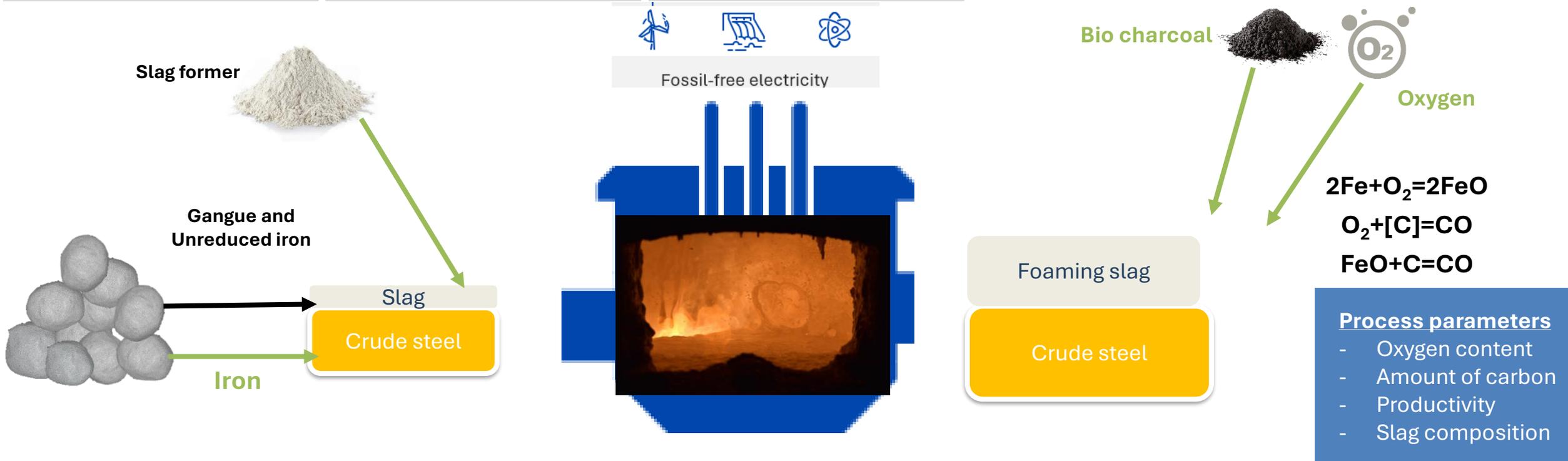
Biocarbon with different size fractions

Addition methods:

- Injection
- Top feeding

Chemical properties:

- Volatile fraction
- Carbon content



Process parameters and process window

▶ Process parameters have been varied

- FeO i slag (%)
- Bath temperature (°C)
- Feeding rate (t/h)

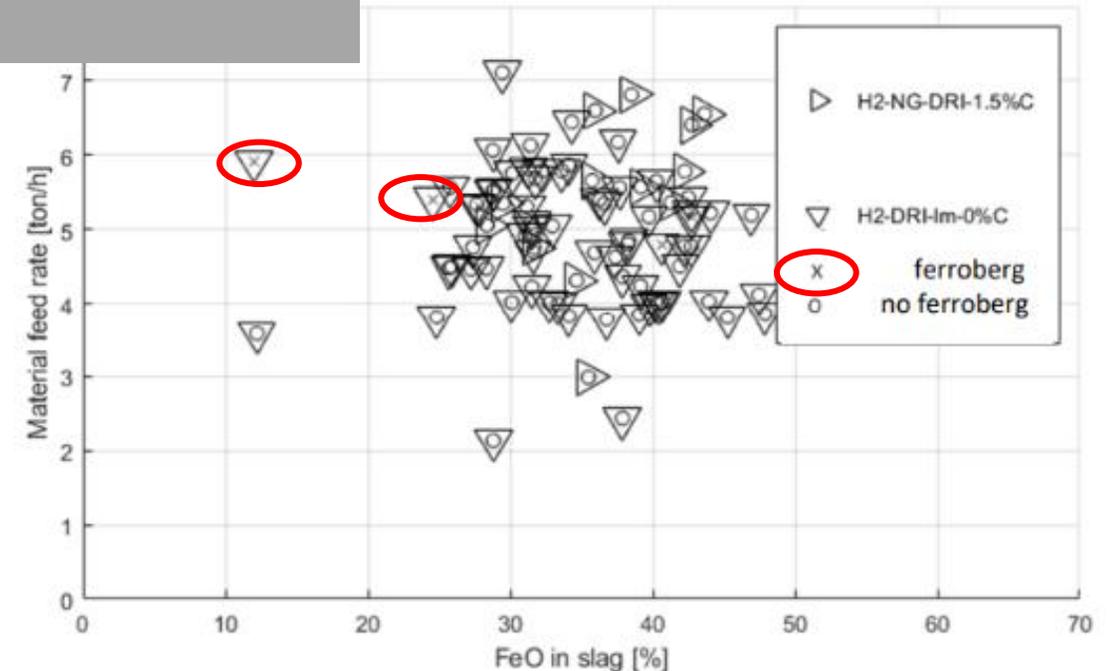
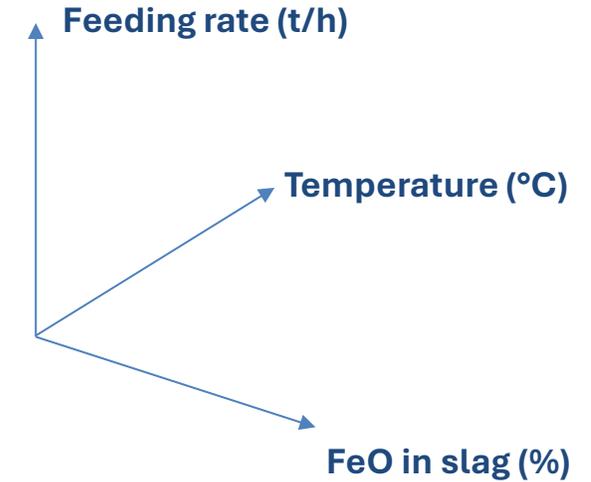
▶ Within the process window:

- Good foaming slag
- Good productivity – no ferrobergs
- Stable process, stable melting temperature and slag chemistry

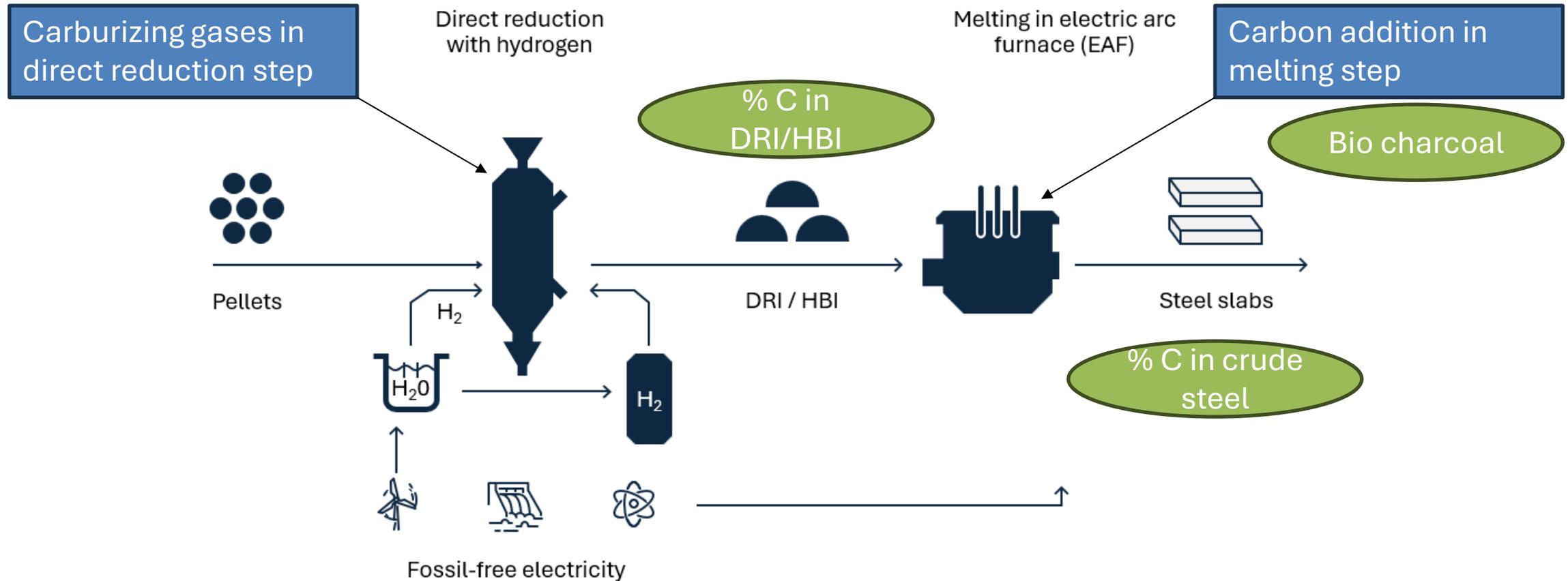
The graph shows a variety of EAF heats in terms of feedstock

- C-free DRI or 1.5% C DRI
- FeO in slag (%) and DRI feed rate (ton/h)

For each heat it is indicated whether a ferroberg was formed or not



Role of carbon in different process steps – is it possible to minimize it?



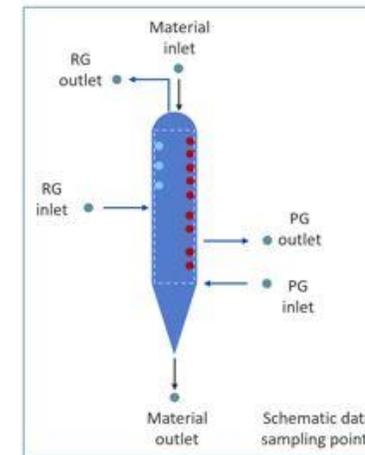
The main results of the pilot program

- HYBRIT has developed technology that enables efficient fossil-free steel production - 0.0 tons of CO₂ e/tons of steel*
- The choice of process settings and technologies has been validated through pilot scale trials throughout the value chain from ore to steel.
- The value chain is based on a new sponge iron product with unique properties.
- Technical risks have been reduced.
- Innovation on time and budget
- IP protection including patent applications

*Including scope 1 and scope 2.

HYBRIT Development platforms

Models of pellet, reactor and process



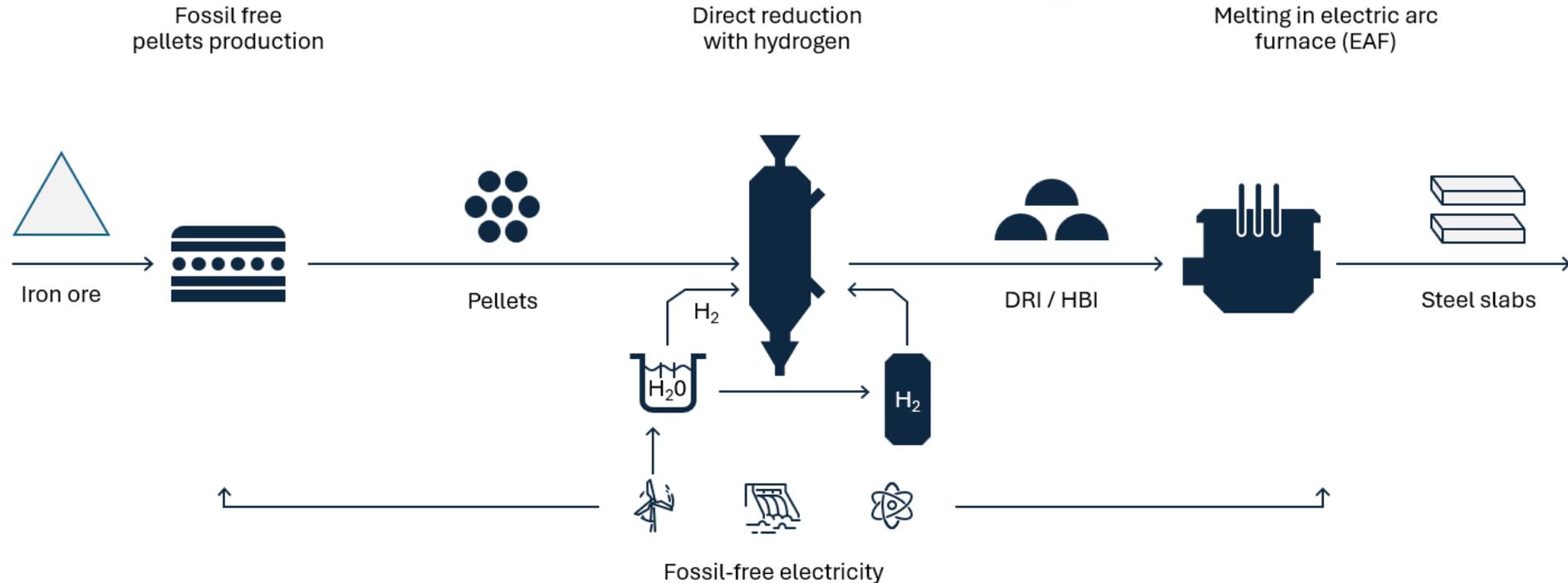
Pilot trials



Lab experiments



HYBRIT[®] develops a new value chain with ambition to eliminate CO₂ emissions



Value chain analysis

The overall value chain analysis shows that the **best overall efficiency** is achieved when the iron ore is **reduced with hydrogen** in the reduction step and then melted into crude steel together with a **minimal biocarbon addition** in the electric arc furnace

Competitive production is verified

▶ Security and safety:

- Since start of operations in 2020 – no incidents have occurred that have compromised the safety of staff or the plants

▶ Environmentally friendly production:

- Focus on fossil-free production in all process steps – extensive measurements and sampling have been carried out

▶ Intermediate commodities:

- Energy, raw material and additive requirements have been optimized

▶ Productivity:

- Productivity has been maximized for a competitive production cost – the unique properties of H-DRI have been defined and optimized

▶ Stability

- Process have proven to be robust – only small variations in results and implementation

▶ Product quality

- The final fossil-free crude steel product meets or exceeds the applicable quality requirements



**Pilot trials in
semi-industrial
scale**



**Prototypes in
industrial scale**

HYBRIT – For a fossil-free future

Developed technology that enables efficient fossil-free steel production

0.0

Tonne CO₂e / tonnes of steel*

- ▶ Validated through pilot scale trials throughout the value chain
- ▶ A new sponge iron product with unique properties
- ▶ On time and budget
- ▶ IP protection sought