DEPARTMENT OF IRON RANGE
RESOURCES & REHABILITATION

The Sweden-US Clean Hydrogen Delegation Trip Recap
Wednesday, November 13, 2024

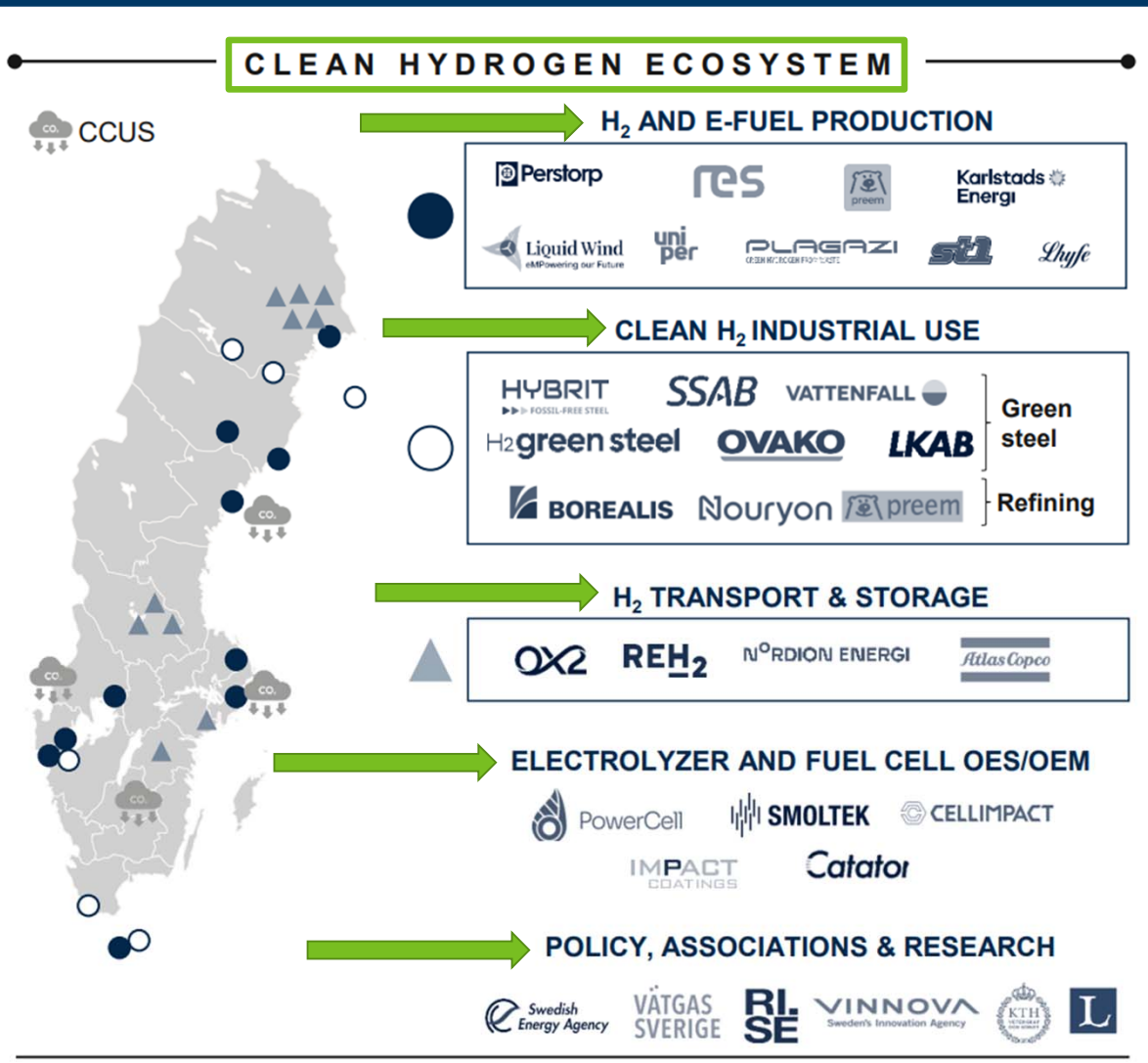
THE SWEDEN-US CLEAN HYDROGEN DELEGATION

Sweden: Gothenburg and Stockholm, June 10-13th, 2024

Welcome & Introduction to the Swedish clean hydrogen market, policy and energy landscape

Gothenburg June 10, 2024

Left to Right:
Frank Kohlasch, MPCA
Gregg Mast, CEEM
Nate Long, DEED
Ambassador Ramanathan
Jason Janisch, IRRR
Rachel Johnson, APEX


CLEAN HYDROGEN ECOSYSTEM
CCUS
H2 AND E-FUEL PRODUCTION
Perstorp
res
preem
Karlstads Energi
Liquid Wind
uniper
PLAGAZI
st1
Lhyfe
CLEAN H2 INDUSTRIAL USE
HYBRIT
FOSSIL-FREE STEEL
SSAB
VATTENFALL
H2green steel
OVAKO
LKAB
Green steel
BOREALIS
Nouryon
preem
Refining
H2 TRANSPORT & STORAGE
OX2
REH2
NORDION ENERGI
Atlas Copco
ELECTROLYZER AND FUEL CELL OES/OEM
PowerCell
SMOLTEK
CELLIMPACT
IMPACT COATINGS
Catator
POLICY, ASSOCIATIONS & RESEARCH
Swedish Energy Agency
VÄTGAS SVERIGE
RI. SE
VINNOVA
Sweden's Innovation Agency
KTH

The 4-day program* will explore collaborations and foster knowledge exchange with sectors such as transportation, green steel and power-to-X as well as policy

Monday, June 10th	Tuesday, June 11th	Wednesday, June 12th	Thursday, June 13th
GOTHENBURG		STOCKHOLM	
Suggested arrival to Gothenburg, Sweden	**Green hydrogen for refining** Site visit to refining cluster with projects to scale up green hydrogen for chemical input, petrochemical as well as E-fuel projects Perstorp preem BOREALIS	**Policy and incentives** Government Offices of Sweden Meeting with representatives from Swedish parliament and government agencies to understand opportunities	**Pioneering the green steel industry** Discussions with Sweden's innovative steel industry, paving the way for industrial decarbonization with 3 large scale green steel projects under way HYBRIT FOSSIL-FREE STEEL H2green steel OVAKO
Clean hydrogen market Swedish Energy Agency Introduction to the Swedish clean hydrogen market, policy and energy landscape	**Scaling up Power-to-X** Liquid Wind Discussion with Europe's leading developer of commercial scale e-fuel facilities	**Renewable energy** OX2 VATTENFALL Renewable developers' role in enabling large scale hydrogen projects and opportunities within Sweden	
Fuel cells PowerCell Site visit to a leading fuel cell producer's state of the art facility	**Climate neutral port** PORT OF GOTHENBURG Site visit to Gothenburg Port with ambitious targets to transition to a climate neutral port with solutions such as hydrogen	**Hydrogen infrastructure** NORDION ENERGI Connecting Sweden's hydrogen market with a pipeline	**Research and innovation** CHESS KTH The future of clean hydrogen technology and Sweden's innovative ecosystem
Heavy duty hydrogen VOLVO Discussion and matchmaking with Volvo's innovation hub	**Refueling infrastructure** hydri Building out a Swedish hydrogen refueling infrastructure to enable decarbonization of heavy-duty transport	**Seminar and round table discussion on clean hydrogen** Hosted by RI.SE VÄTGAS SVERIGE With participation from the broader Swedish hydrogen ecosystem, including solution providers, developers and end-users	*Joint dinner and reception*
Dinner with Hydrogen Sweden	*Travel to Stockholm by train*		

Notes: *meetings are preliminary and subject to change pending cancellations or changes by meeting target

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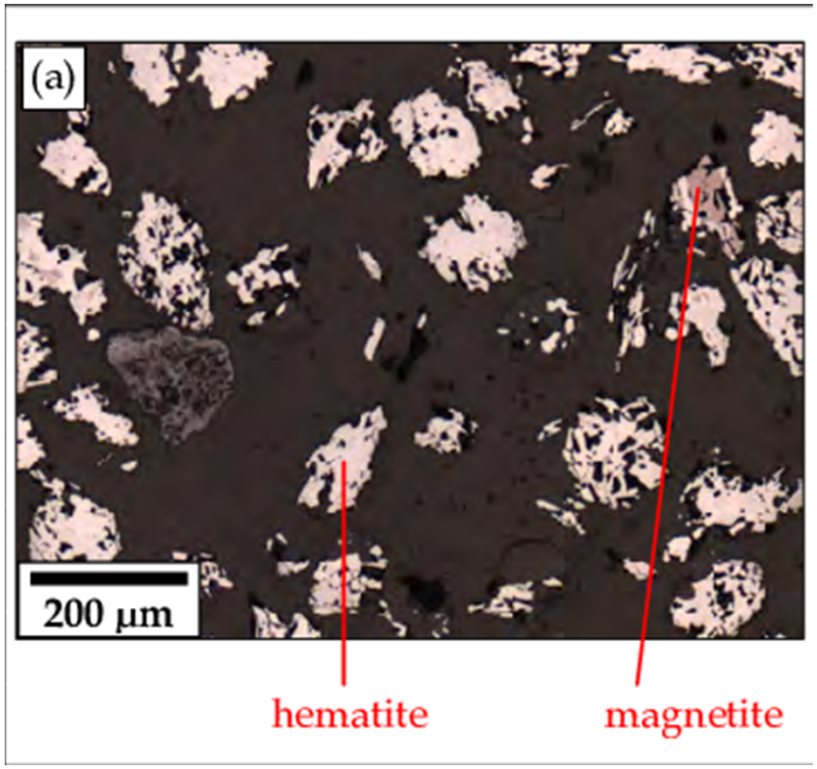
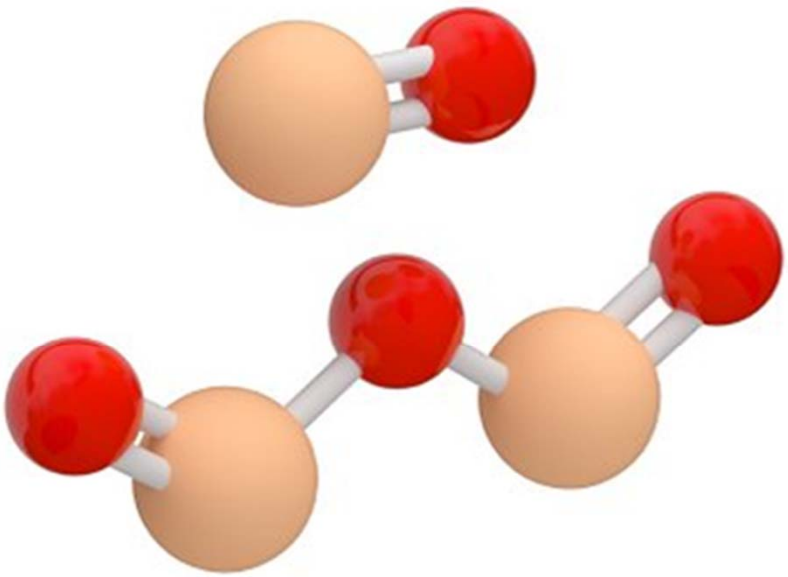
Green Steel 101

Crushing and concentrating mechanically separate iron-oxide particles from non-iron bearing particles



The iron is still chemically bonded to oxygen when concentrating and pelletizing is complete.



Iron Oxide

Ironmaking
(blast furnace)

Iron

Ironmaking is the most CO_2 intensive step

CO_2 emission intensity during the steel making process

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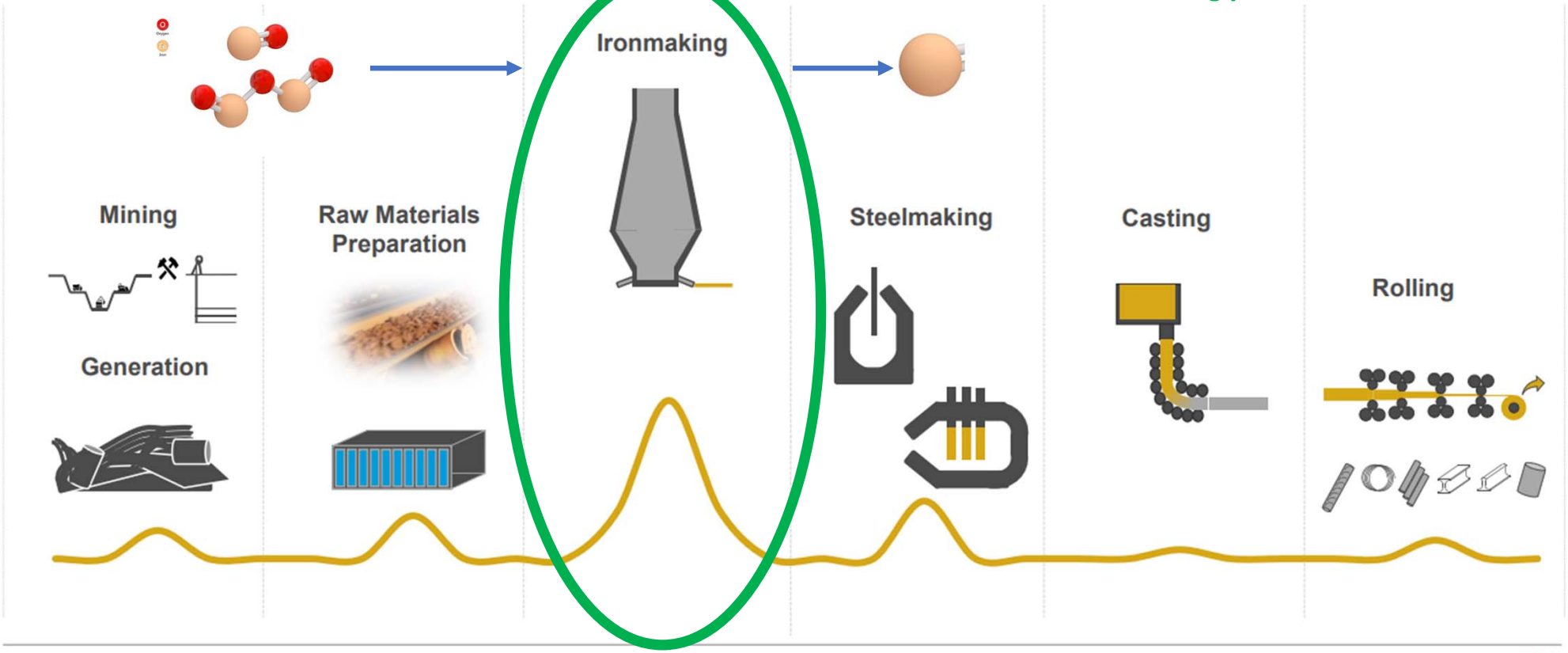
CO_2 emission intensity during the steel making process

Green Steel is all about reducing carbon-dioxide emissions in the ironmaking process



Standard steelmaking now (BF-BOF process)

$$Fe_XO_X + C + energy = Fe + CO_2 + slag$$

- Fe_XO_X: Any type/quality of iron ore should work
- C: Coke is both the reductant and energy source
- CO_2: Coke-based reduction creates the most CO2 emissions

Slag formation during hot metal production means a variety of ore grades can be used with minimal impact on quality (but significant impact on emissions)
BOFs currently have the highest flexibility when it comes to raw material selection

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- Blast Furnace Iron Making
  - 1.5 to 2.5 tons of CO2 produced per ton of steel
  - 1.3 tons of taconite pellets required per ton of steel
  - 0.3 tons of scrap per ton of steel
  - Produces the highest purity iron product

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Scrap-based EAF steelmaking now

Fe + energy = Fe

- EAFs cannot transform iron ore. They only 'refine' existing pure iron units from other sources
- Electrical energy to remelt scrap or other iron units

Old steel in – new steel out. You need iron units from past steel production or other current ironmaking processes for EAF
- Scrap availability and quality?
- Other iron units availability and embodied emissions?

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- Electric Arc Furnace Iron Making
  - 0.3-0.5 tons of CO2 produced per ton of steel
  - 0.4 tons of virgin iron units per ton of steel (usually pig iron and hot-briquetted iron (HBI)
  - 0.8 tons of scrap steel per ton of steel
  - Purity depends on iron unit mix

Standard steelmaking now (BF-BOF process)

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Future hydrogen steelmaking "Green steel"

$Fe_XO_X + H_2 + energy = Fe + H_2O$

- Only high-quality "DR-grade" iron ore will work well
- Hydrogen from 'green' sources
- No carbon emissions – just water vapor

Direction reduction means no hot metal production & no slag formation. Narrow range of iron ore types acceptable. Limited flexibility. Quality in – quality out.

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- energy: Direction reduction means no hot metal production & no slag formation. Narrow range of iron ore types acceptable. Limited flexibility. Quality in – quality out.
- $Fe + H_2O$: No carbon emissions – just water vapor

- Green Steel Iron Making
  - 0.2 tons of CO2 per ton of Iron
  - ~1.3 tons of iron DRI pellets per ton of steel
  - ~0.3 tons of scrap per ton of steel
  - High purity iron – mix dependent
  - Finished steel costs 20-40% more than current BF / EAF steel

Summary

Iron Making Technology	CO2e Emissions / Ton of Iron	Iron Ore Pellets / Ton of Iron
Blast Furnace	1.5-2.5*	1.3
Electric Arc Furnace	0.3-0.5	0.5
Green Hydrogen Furnace	0.1-0.2	1.3

* Implementing carbon capture and sequestration may further reduce emissions

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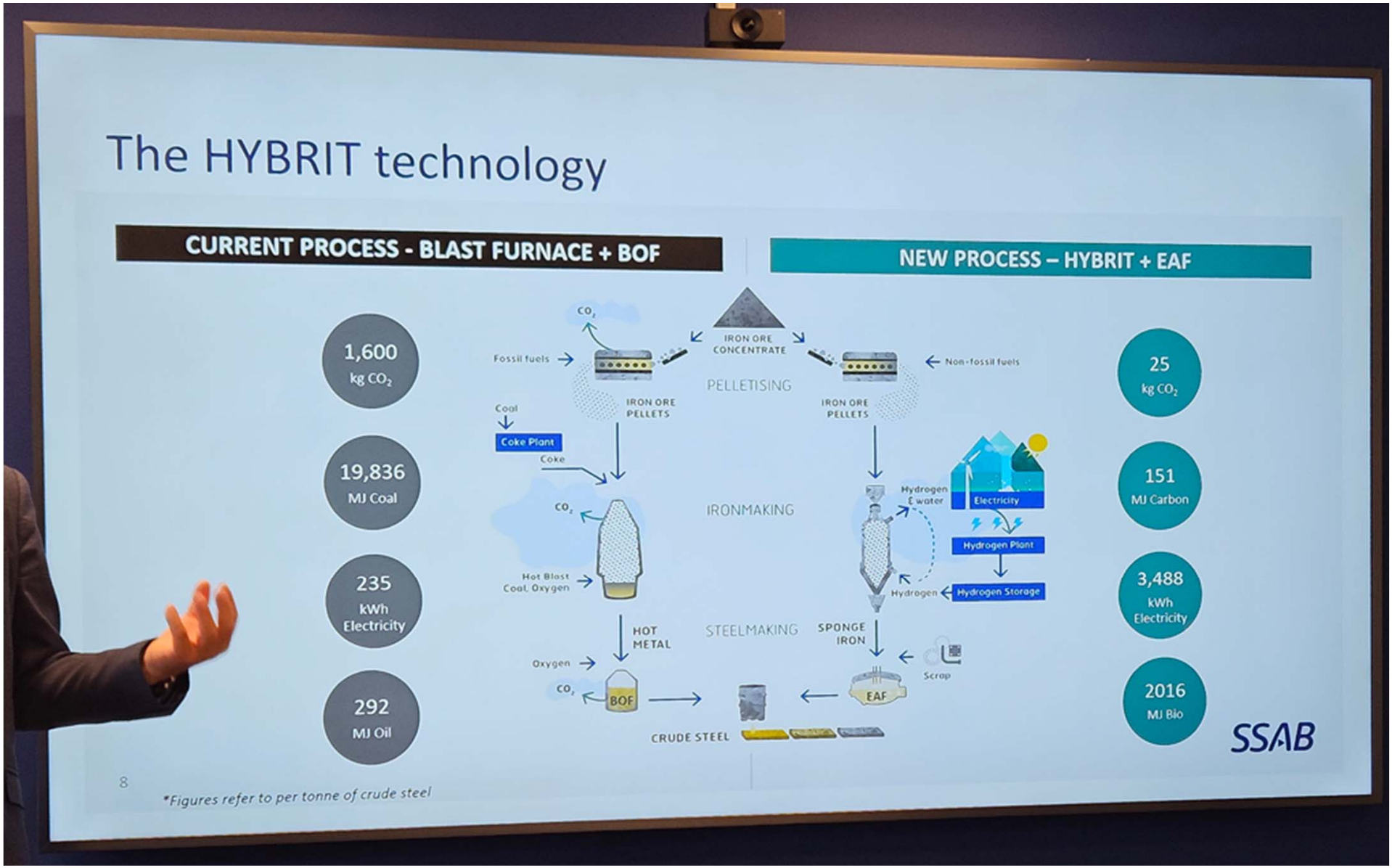
Swedish Green Steel Makers –SSAB and H2GreenSteel

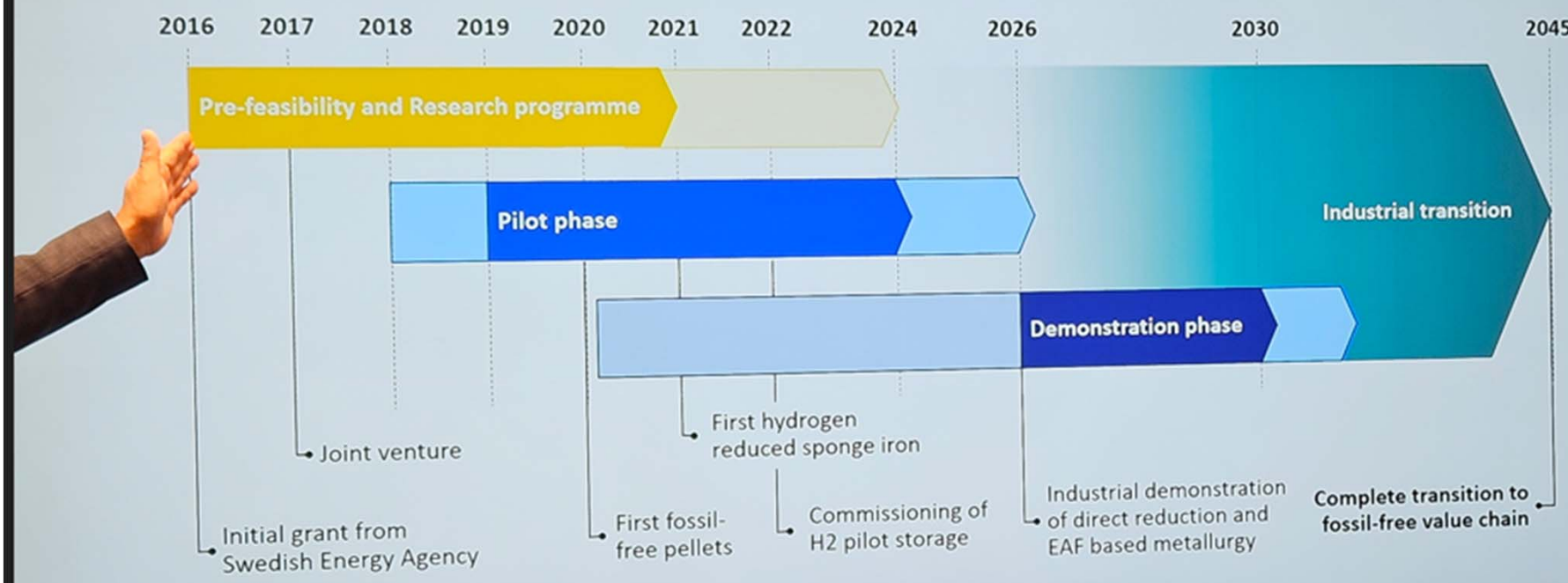
SSAB

A piece of fossil-free sponge iron with the Hybrit pilot plant in the background. Credit: Hybrit

The HYBRIT technology



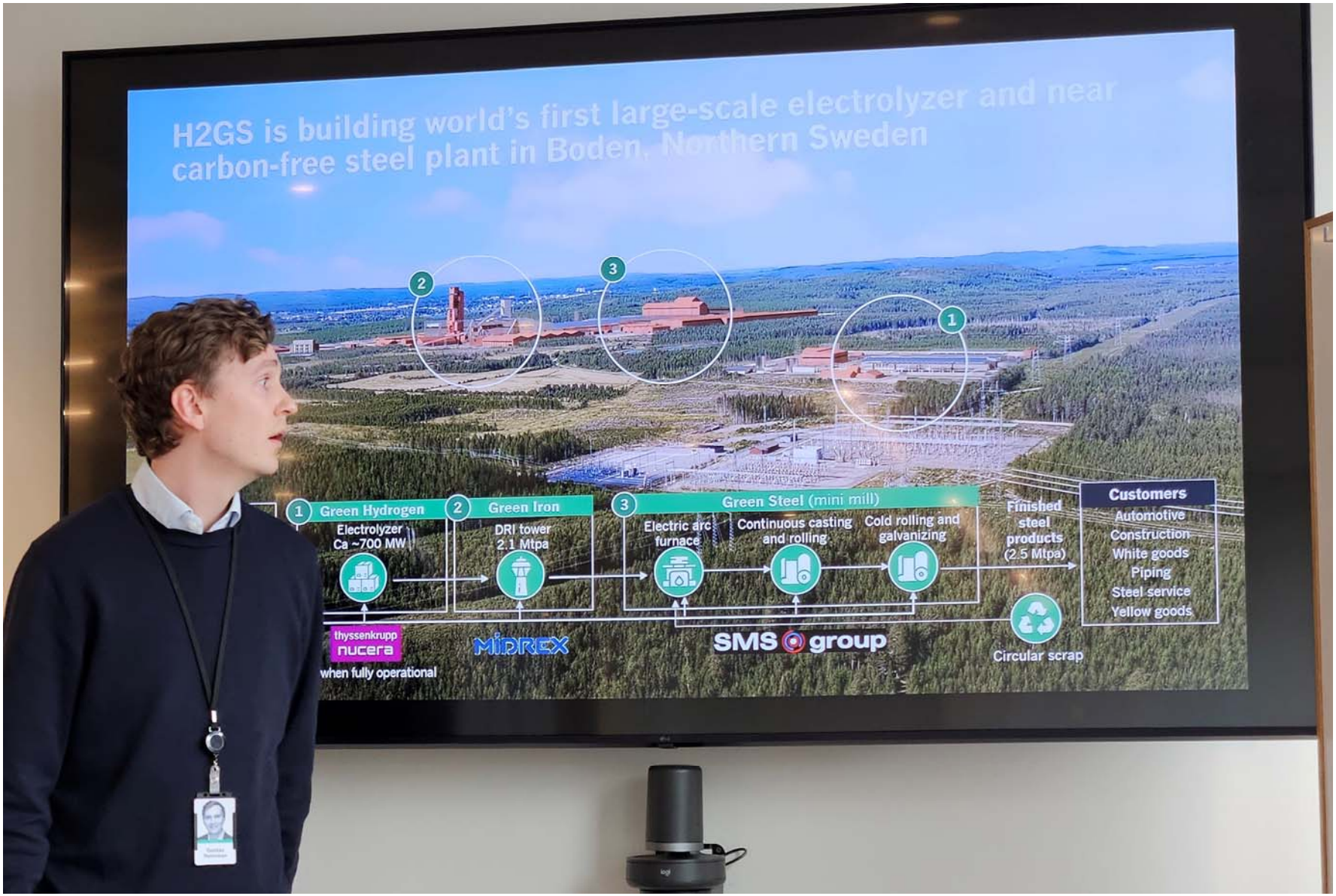
HYBRIT timeline – From technical development to complete transition 2045



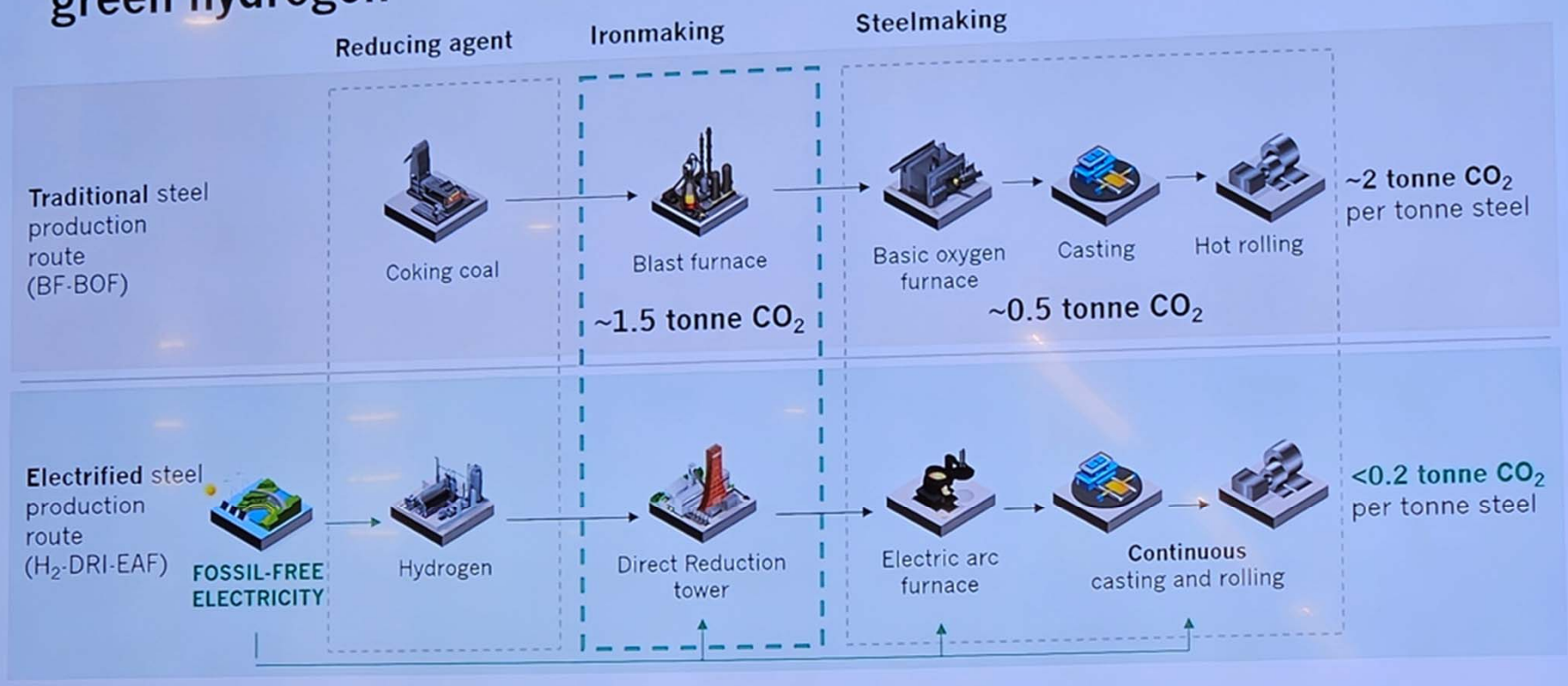
SSAB additional comments

- Need help on permitting process, grid connection, and new electricity sourcing – most challenging aspects in US.
- Also need favorable policy framework and level playing field (CBAM?)
- Awarded up to $500M by Department of Energy to build green steel plant in Mississippi and upgrade EAF in Iowa.

H2 green steel


H2GS is building world's first large-scale electrolyzer and near carbon-free steel plant in Boden, Northern Sweden
1 Green Hydrogen
Electrolyzer
Ca ~700 MW
2 Green Iron
DRI tower
2.1 Mtpa
3 Green Steel (mini mill)
Electric arc furnace
Continuous casting and rolling
Cold rolling and galvanizing
Finished steel products (2.5 Mtpa)
Customers
Automotive
Construction
White goods
Piping
Steel service
Yellow goods
thyssenkrupp nucera
when fully operational
MIDREX
SMS group
Circular scrap

95% decarbonization potential in steelmaking by applying green hydrogen



H2GreenSteel wants to grow outside of Sweden

- Looking for other locations in the world – Canada, Brazil, Iberia, US

- Criteria for future locations
  - Abundant green energy
  - Price of green energy
  - Stability of energy supply

- Concerns with US as a location
  - No baseload of green energy
  - Poor logistics of iron ore
  - Political/regulatory framework uncertainty (45v?)
  - Permitting / state aid concerns

- H2G have a preferred location in the US (I'm thinking Texas)

- Quebec / Brazil – you can replicate what is being done in Sweden

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Overall Take-Aways

Sweden Green Steel Key Take-Aways

1. Sweden has developed significant experience and knowledge in hydrogen-based steelmaking. To leverage this knowledge, partnerships should be created and strengthened.
2. Competitive supply of large amounts of 100% green electricity is critical to successful green steel production.
3. SSAB HYBRIT technology will be licensable and may be a path forward for a green iron/steel maker.
4. Minnesota is not currently the first choice for Swedish green steel manufacturers to establish a US footprint. We are working to change that.
5. Working with local iron-ore miners to invest in green-iron production critical to our regional success. DRI pellets at Cliffs and USS are a significant first step.
6. Work led by NRRI / NREL on the Green Steel / Industrial Decarbonization initiative is another important step.

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THANK YOU

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