Innovation in Decarbonisation of the Steel Industry – Australian Perspective

NIM Webinar January 2025

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What is Green Steel? Ironmaking?

Iron ores are reduced to **Iron** (Fe + impurities) before making steel:

1. **Iron Oxide + C + Flux = Iron(l) + Slag + CO/CO_2** **90-95%**
2. **Iron Oxide + Natural Gas = Iron + Water + CO/CO_2** **5-10%**
3. Iron Oxide + H_2 = Iron + Water <1%
4. Iron Oxide + electrons = Iron + Oxygen Lab.
5. Iron Oxide + Reactive Metal = Iron + RM Oxide Lab.

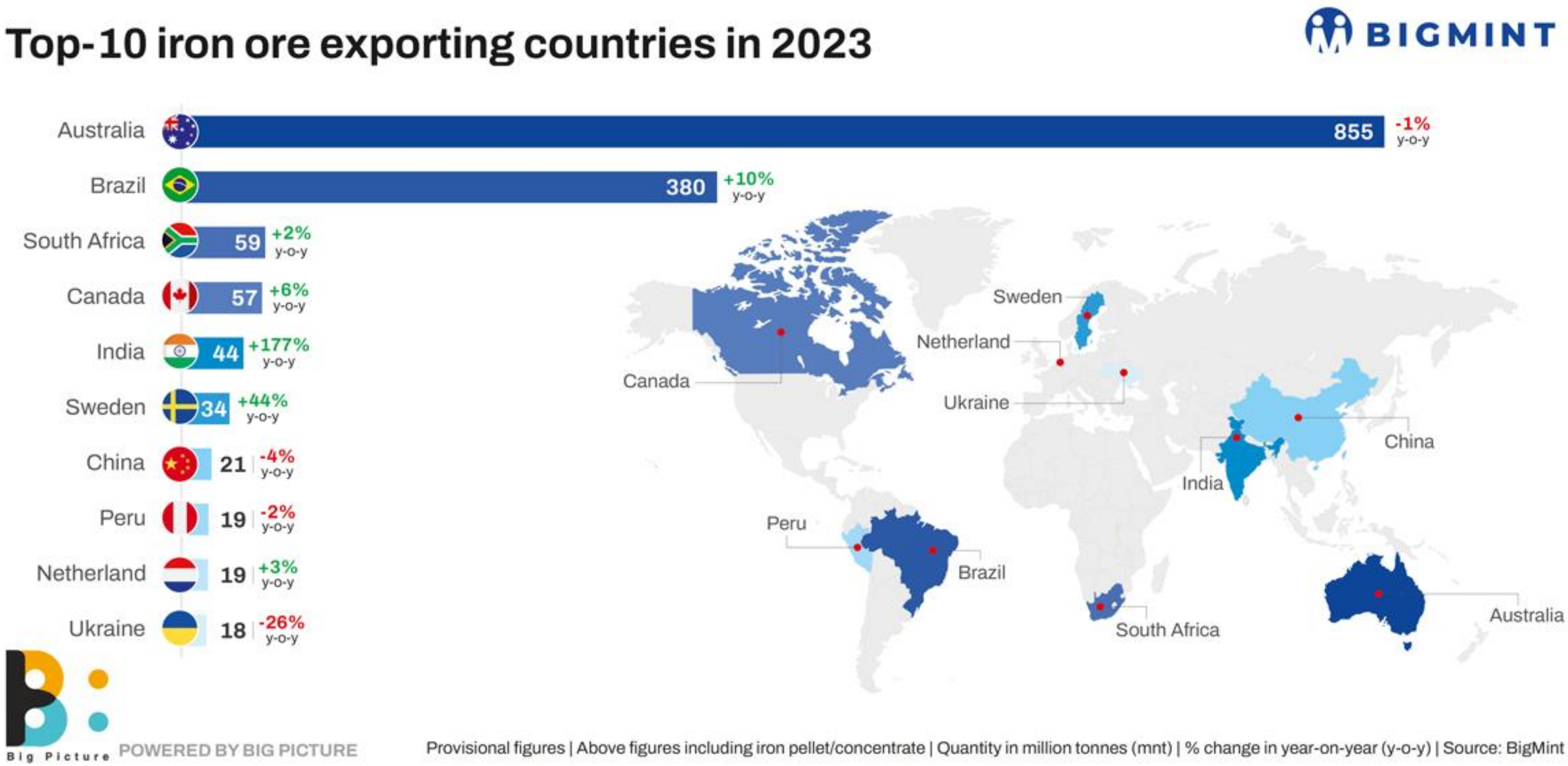
Phase the first two routes into the final three

Replace C and NG with “sustainable sources”

Utilise Carbon Capture and Storage technology

Who makes steel?

Where does the ore come from?



Iron Ores

Hematite (70 wt.% Fe)	Fe_2O_3
Magnetite (72 wt.% Fe)	Fe_3O_4
Siderite	$FeCO_3$
Goethite	$FeO(OH)$

High grade ores (65 wt.% +) – less than 10% of current supply

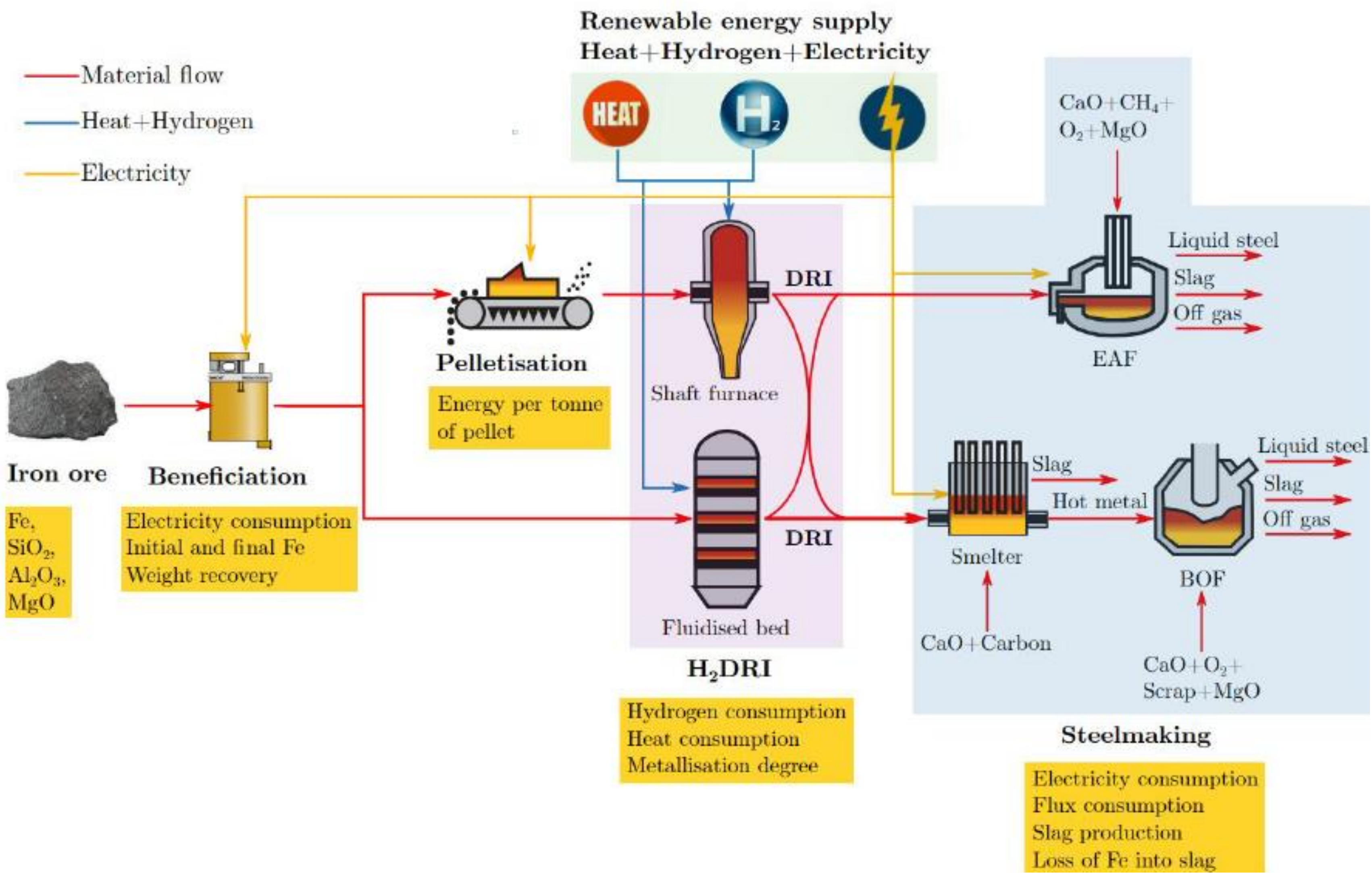
Low grade ores (30-62 wt.%)

Silica and alumina will increase slag volume

Phosphorus and sulphur costly to remove

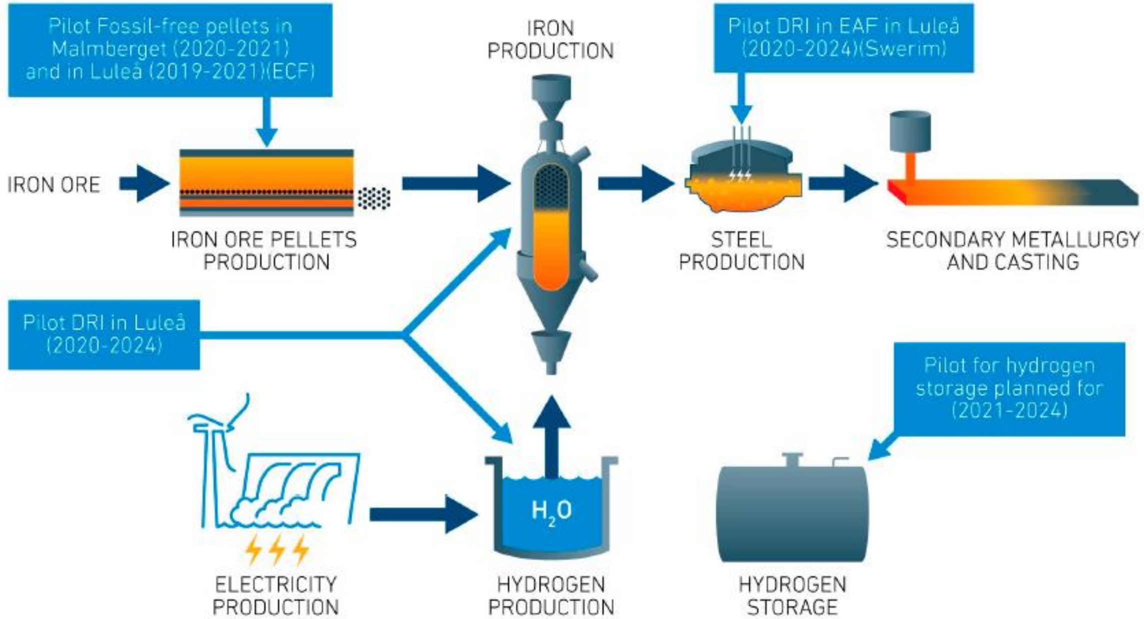
Images from www.mii.org

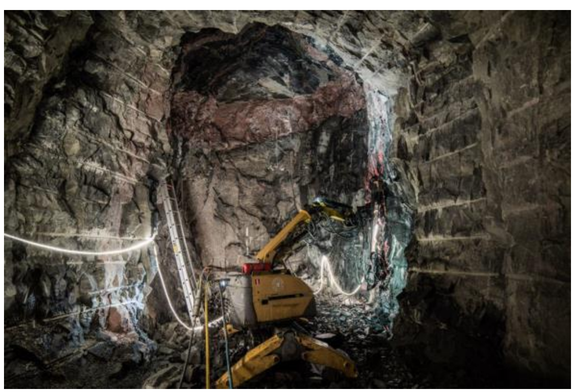
Pathways & Iron Ore Quality – Major Routes

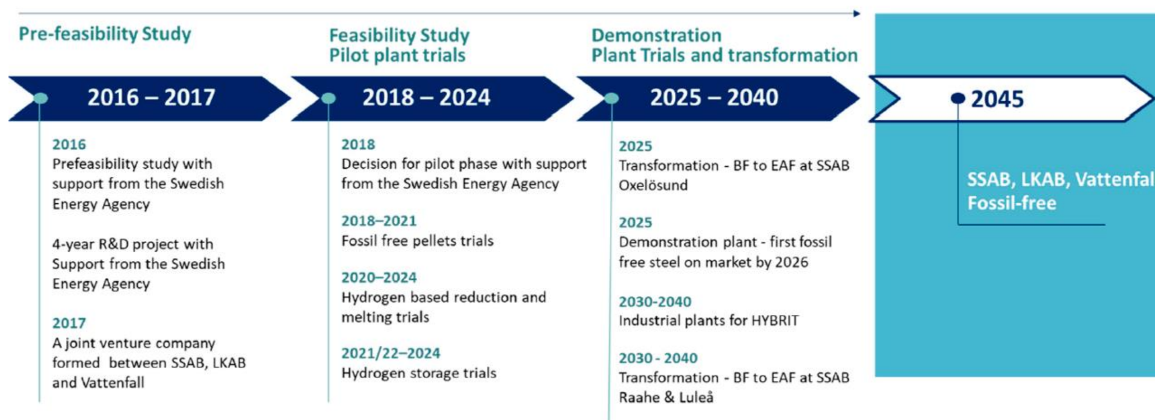


Pye et al., HiTemp4 Presentation, October 2024

Swedish Hydrogen Strategy Hybrit

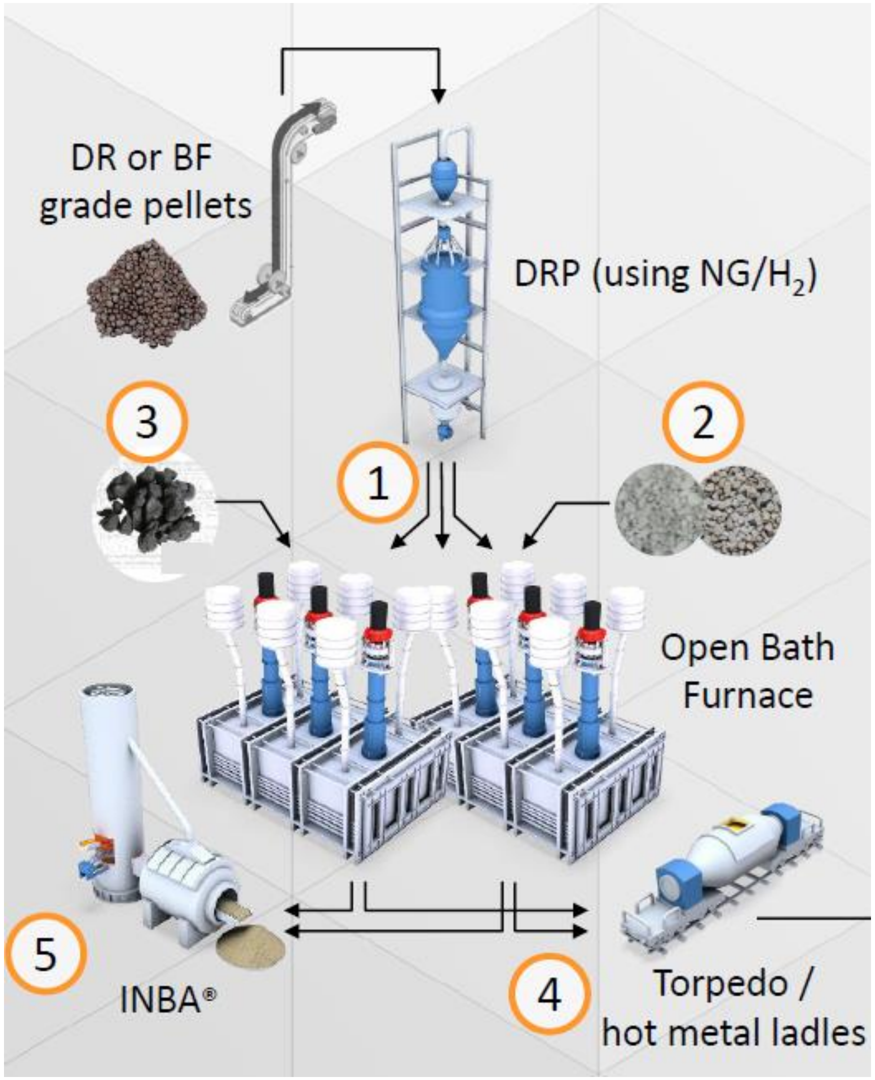


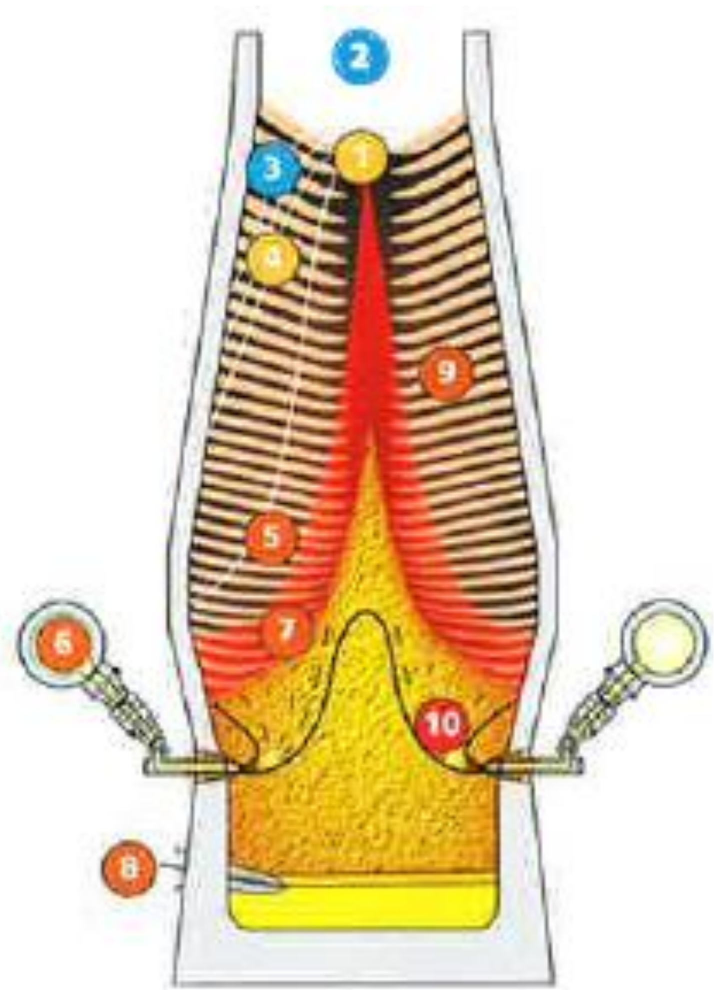




Pei et al., Metal 2020

Processing of Low Grade Ores ?





Graphic from SMS Presentation at EOSC October 2022 and Geerdes et al. 2009

RP 1.014 Electric Smelting for Australian Ores

De-risking of electric smelting furnace for Australian ores, Geoff Brooks (Swinburne/CSIRO)

Aims:

a) How does the gangue content of the iron ore effect performance of the ESF in terms of productivity, energy usage, metal chemistry and attractiveness of the slag as cement feedstock?

b) How does the form of the DRI level of carbon and operating temperature of ESF effect the productivity, energy usage, metal and slag chemistry?

c) Can waste oxides and scrap be easily incorporated into the ESF process?

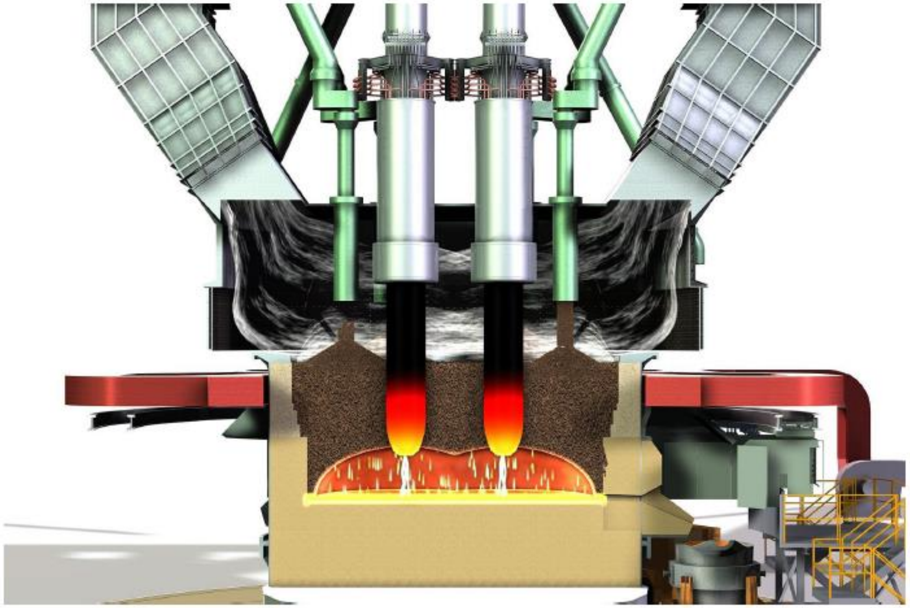
d) What is impact on the techno-economics of processing Australian iron ores through H2 DRI-ESF route?

Approach:

Mixture of modelling, high temperature experimentation, pilot plant/industrial data and techno-economics

Status:

- Agreement sent to partners for review and signature
- Planned start date: 7 October 2024
- Planned completion date: 7/09/2027



Images from https://www.sms-group.com/de-de/plants/electric-smelters-and-submerged-arc-furnaces

Where is "Green" Steel up to?

Hydrogen DRI most likely route to "Green Steel" because:

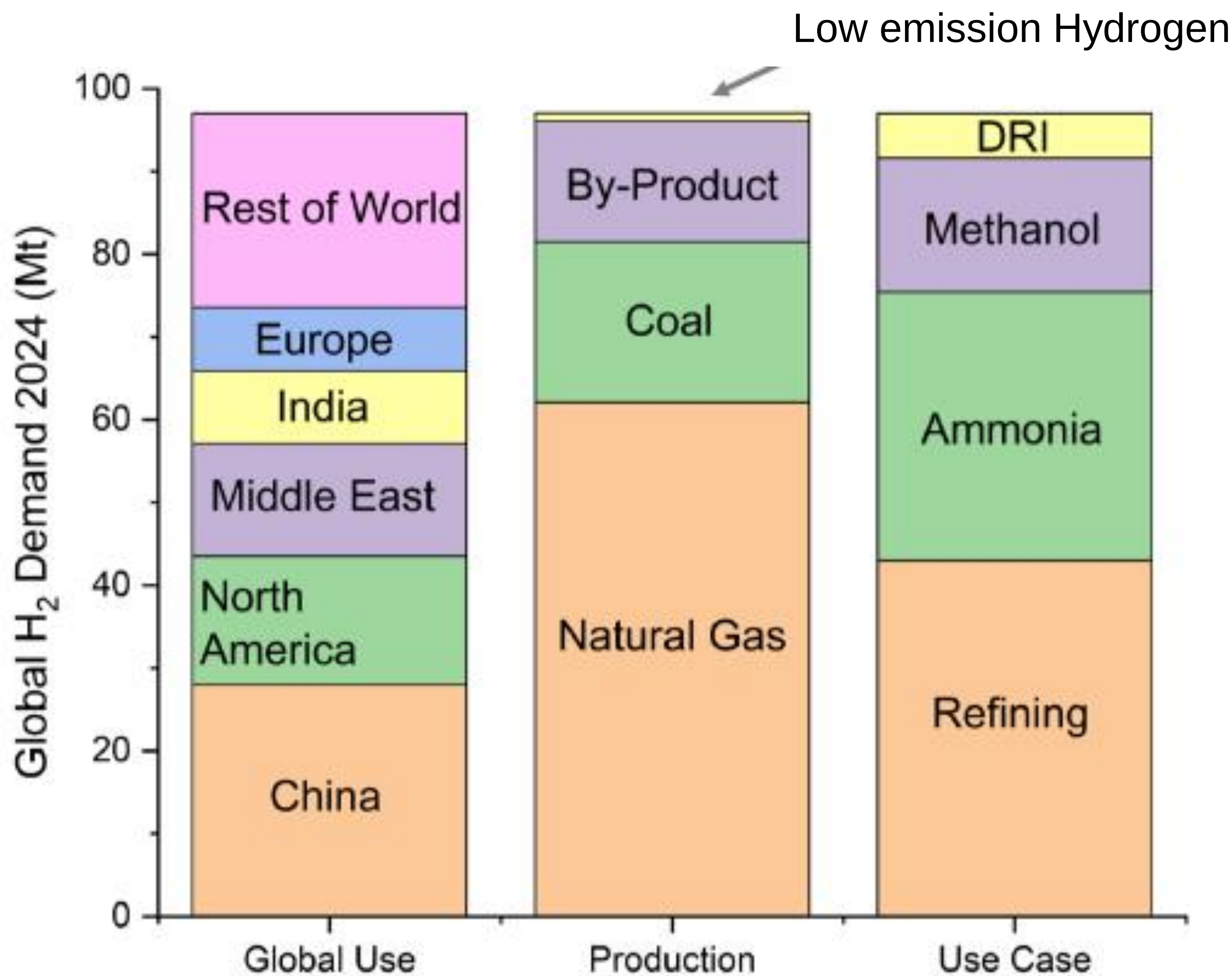
a) Difficult (impossible?) to replace large amounts of coke/coal in existing Blast Furnace technology

b) Linking carbon based ironmaking with Carbon Capture & Storage not demonstrated to date and requires depleted oil wells and/or suitable geology near plant

c) Biomass routes require steady/affordable supply of "sustainable" biocarbon – partial solution?

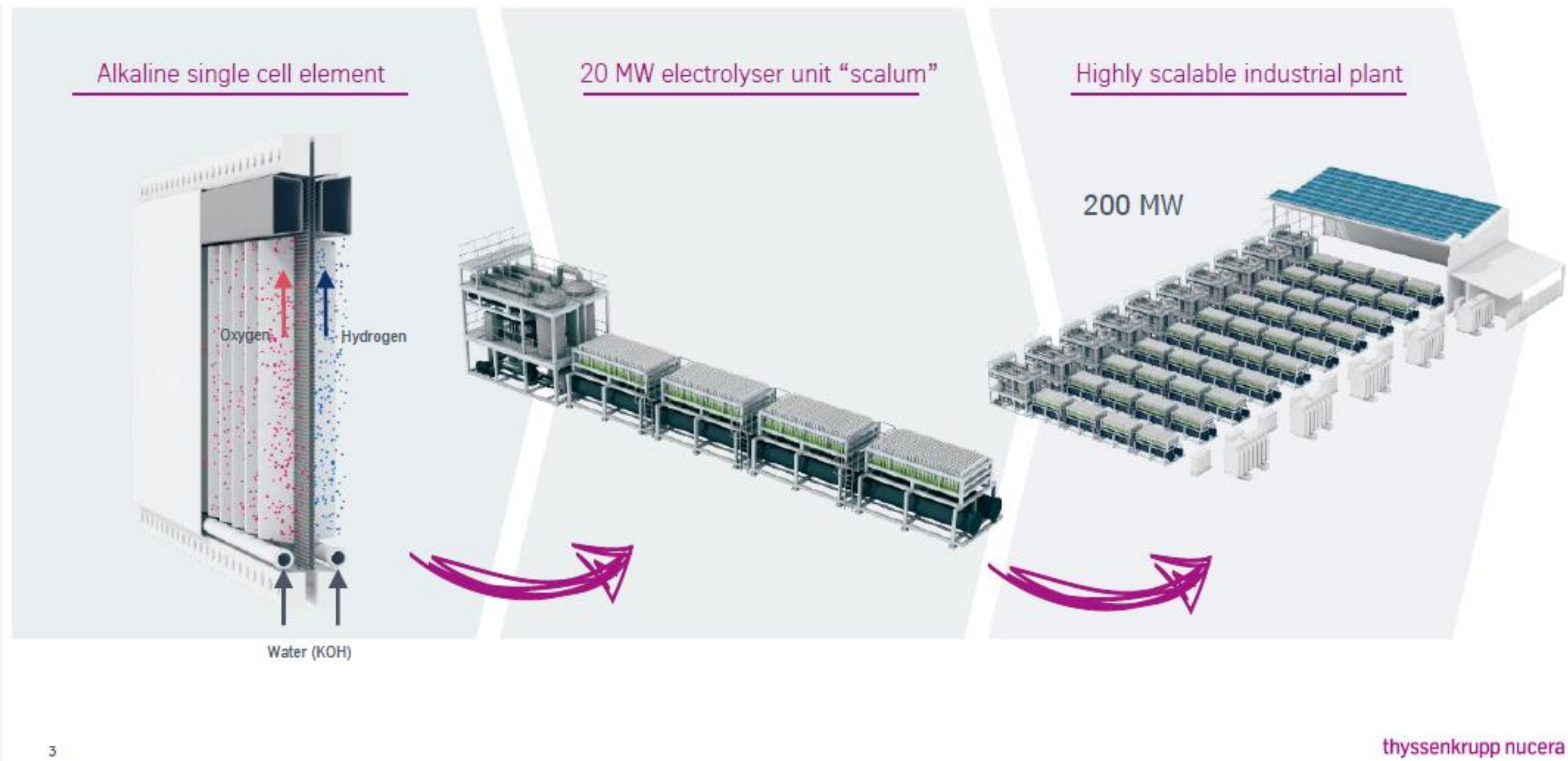
d) Electrolysis/Metallothermic routes are a long way from commercialisation

Global Supply of Hydrogen



IEA, 2024, Global Hydrogen Review 2024
IEA, 2023, CO2 Emissions in 2023

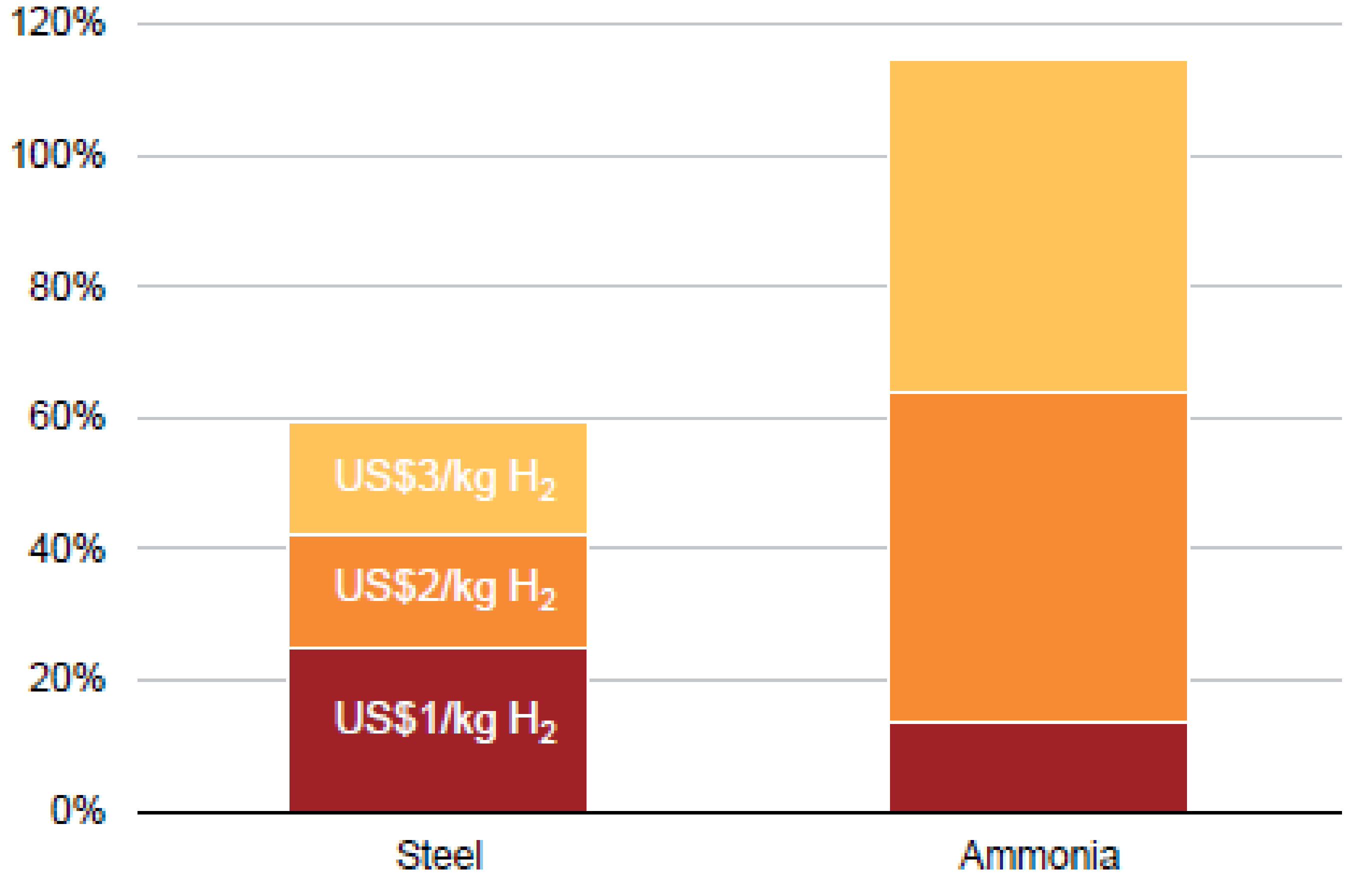
Scale up of Green Hydrogen Production



Thyssenkrupp nucera, HiTemp4, October 2024

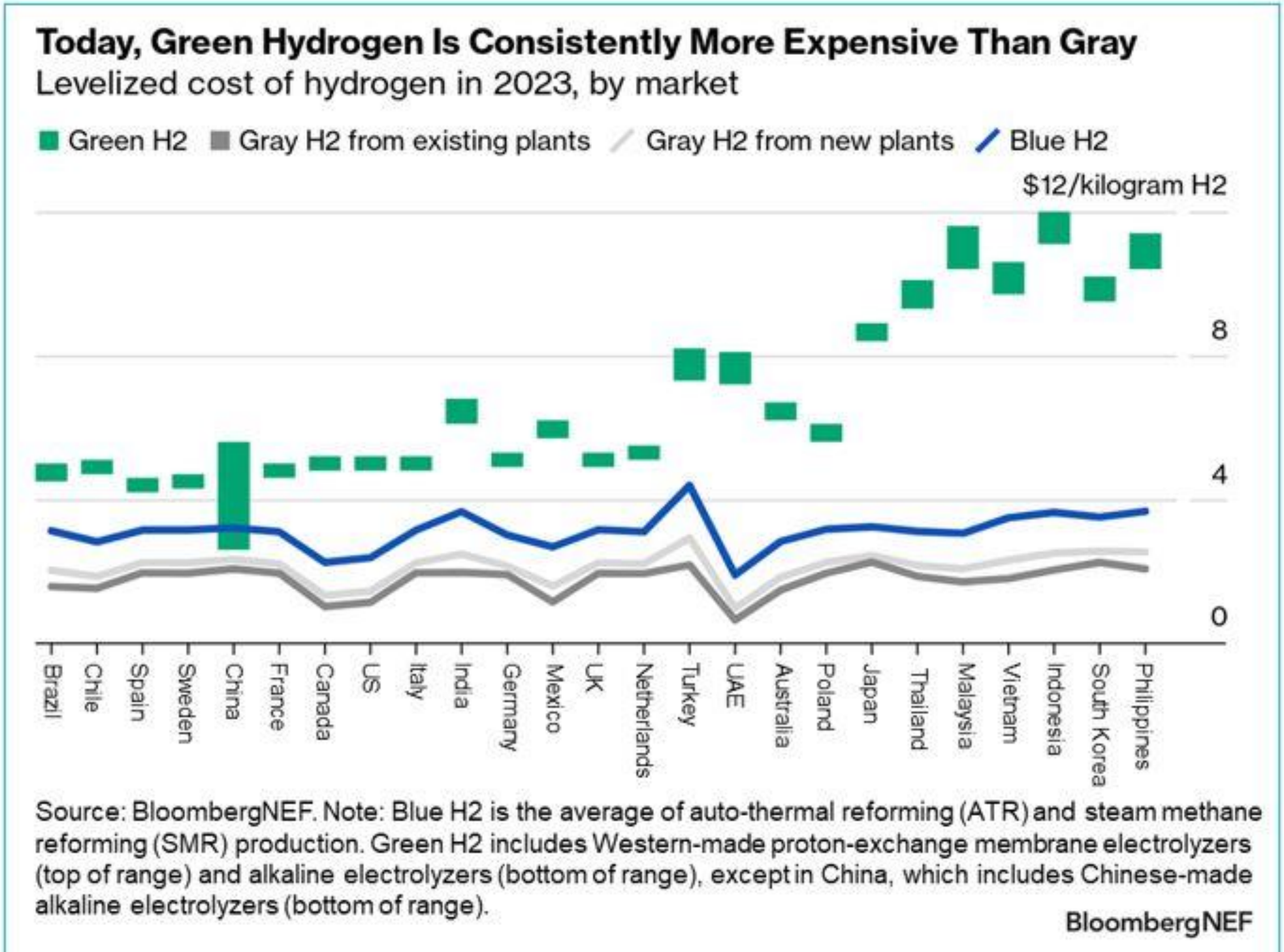
Figure 2.2: Green steel is more cost-competitive than green ammonia in the near-term

'Green premium' (additional cost of hydrogen-based product over cost of fossil fuel-based product) for Australian-made green steel and green ammonia

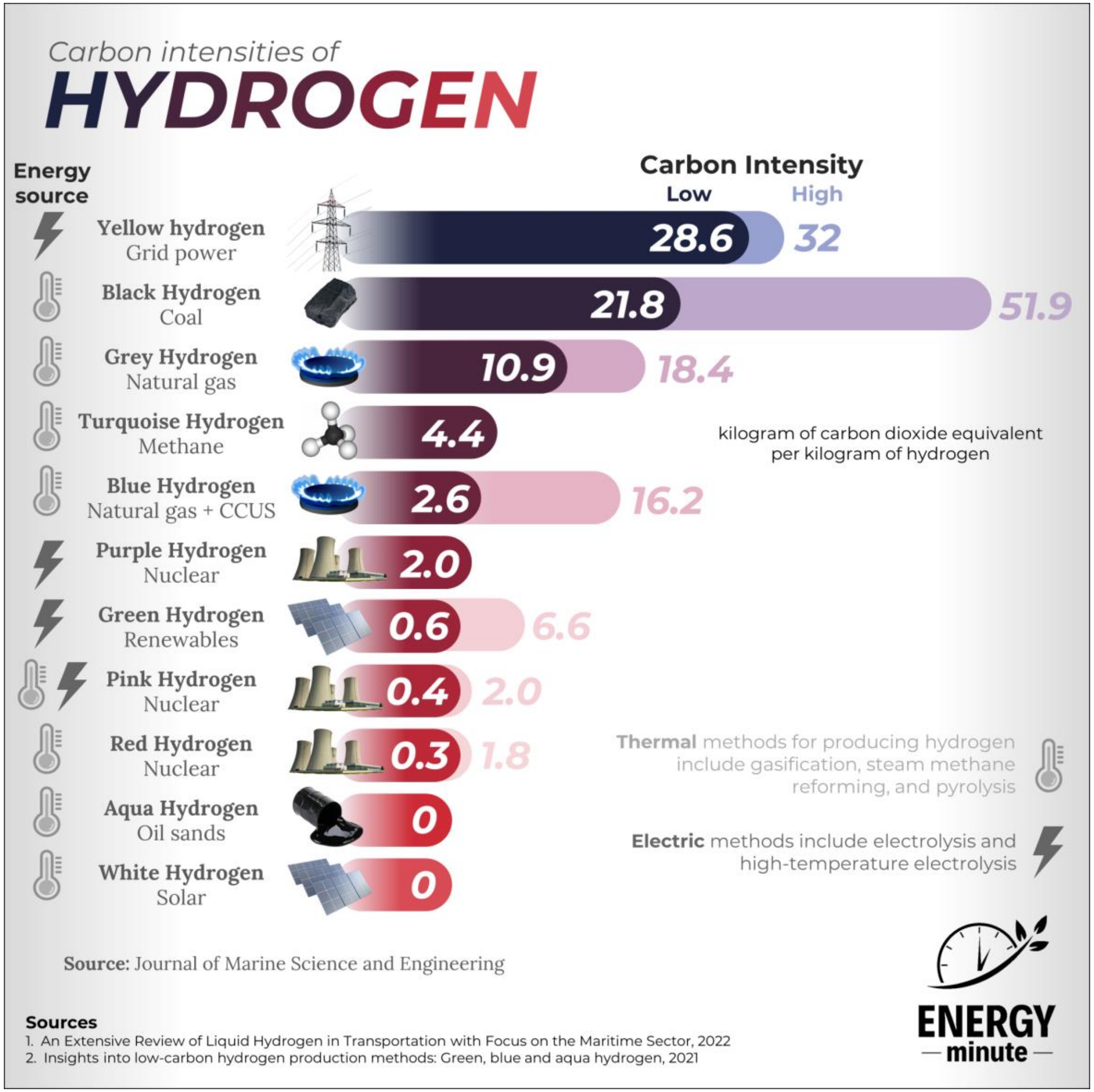


Start with Steel, Grattan Institute, May 2020

Current Cost of Hydrogen



Does Hydrogen need to be Green?



Challenges for Hydrogen DRI

a) Suitable supply of renewable energy (GW scale required)

b) Current low scale of Green Hydrogen production (MW scale)

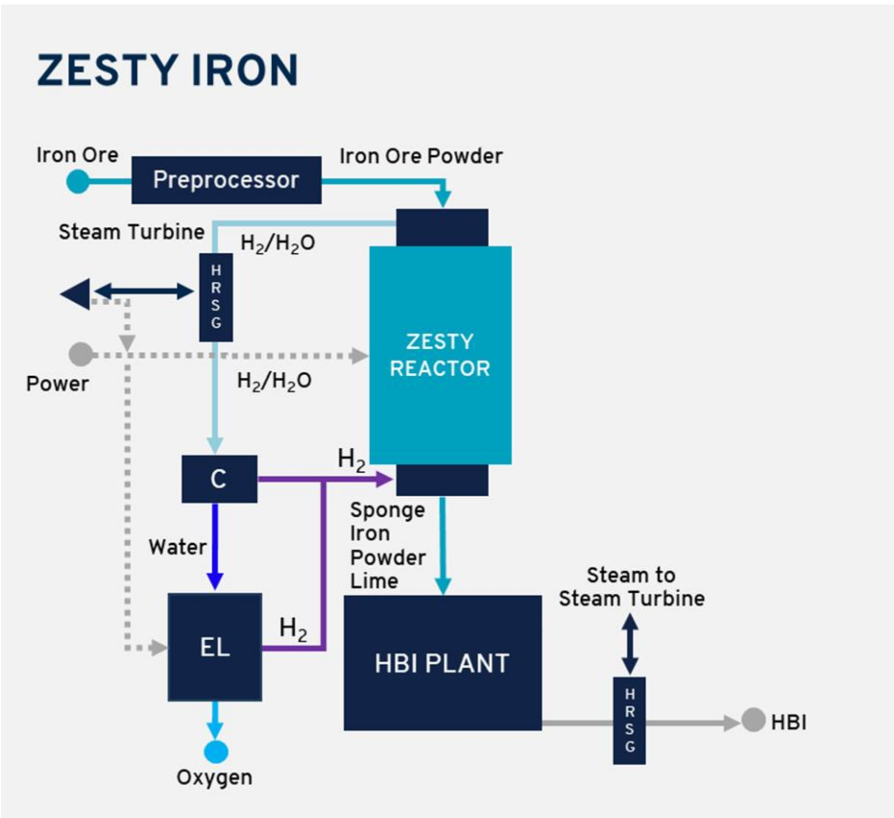
c) Concern with cost and supply – nervous investment environment

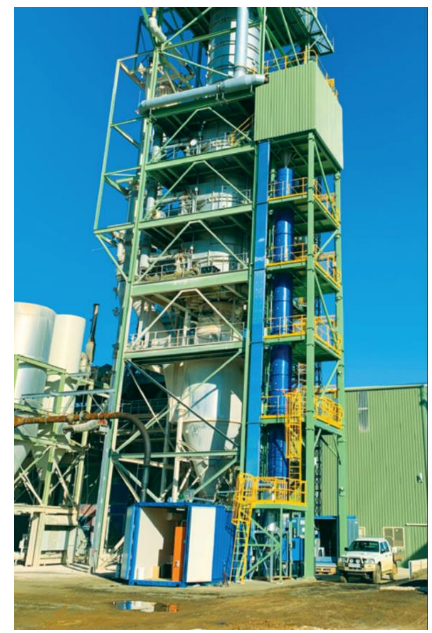
d) Processing of lean ores in existing technology – how will they perform?

e) Will it be necessary to agglomerate and/or grind these ores before feeding into H_2 DRI processes?

Australian Initiative - Calix ZESTY Process

Calix ZESTY - New Hydrogen DRI Process
Iron Ores Fines/Hydrogen Gas Flash Smelting
Electrical Heated Reactor – Renewable Energy
Testing underway in Bacchus Marsh Facility
Building on experience in calcining kilns





Boot-Handford et al. Metec 2023

Australian Initiative - Calix ZESTY Process

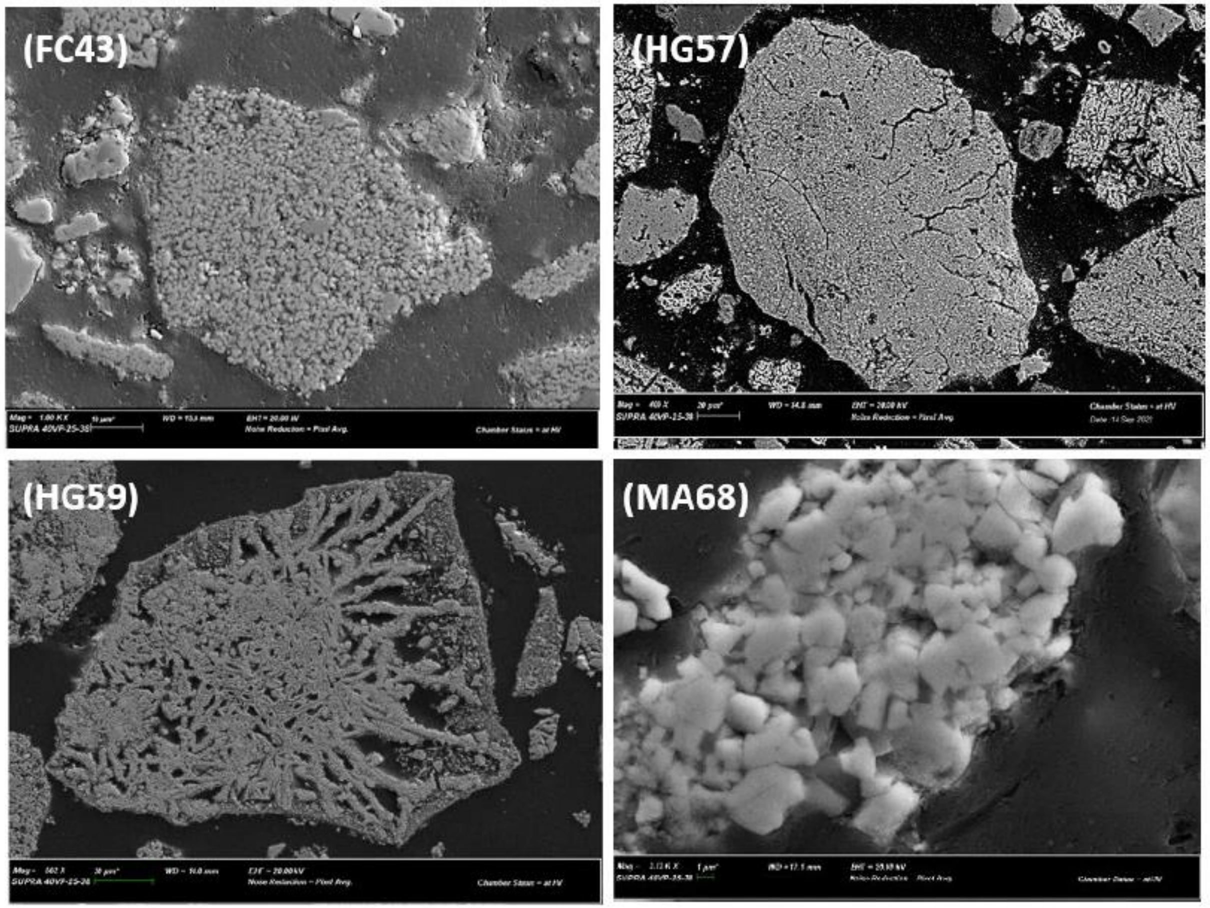
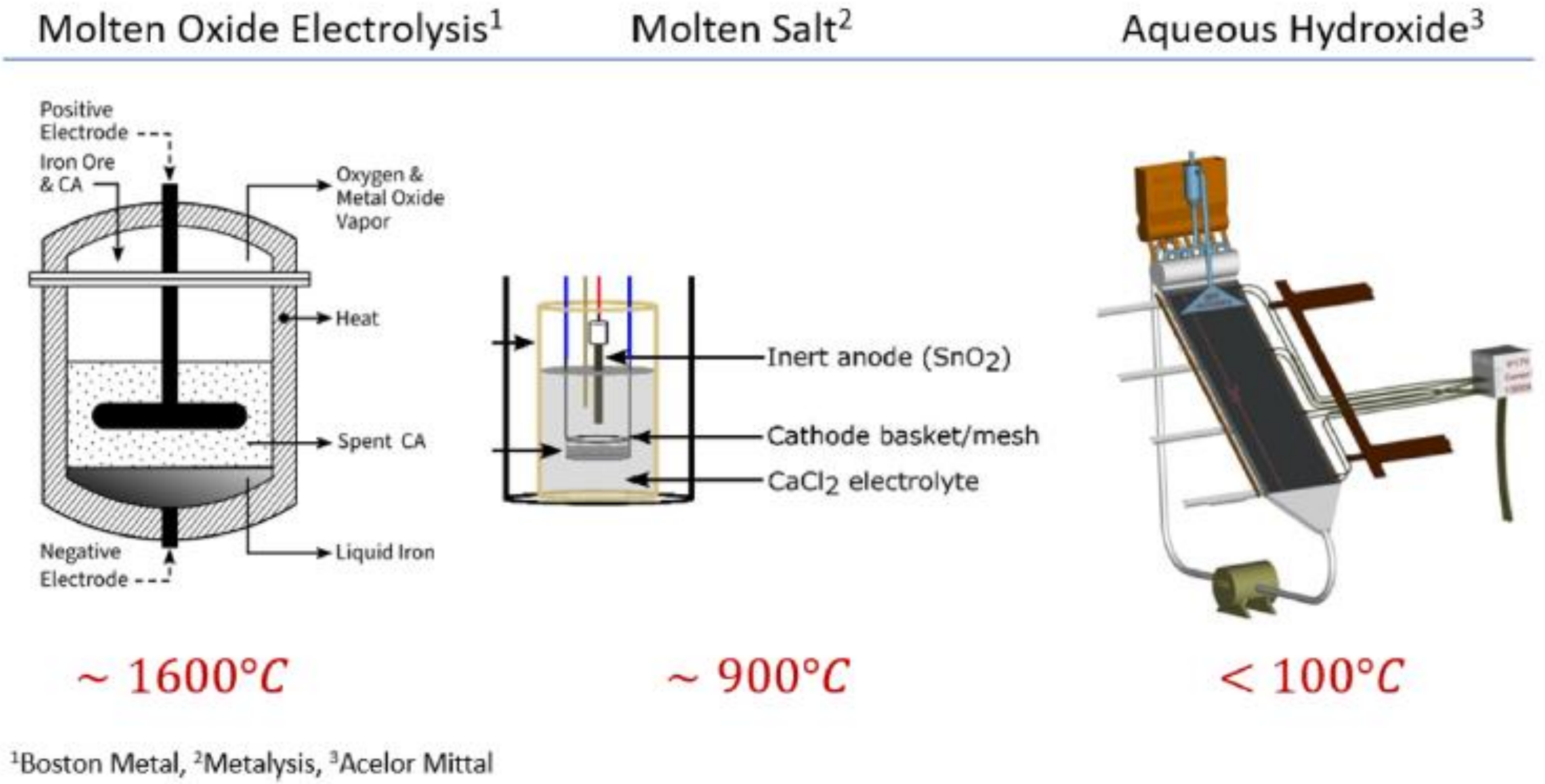


Figure 4: Typical SEM images of ZESTY processed iron ores: closed and open pores were observed in FC43, HG57, HG59, while MA68 showed denser structure (ore type = various; wall temperature = 950°C; feed rate = 60 kg/h; H2/ORED stoichiometry = 2).

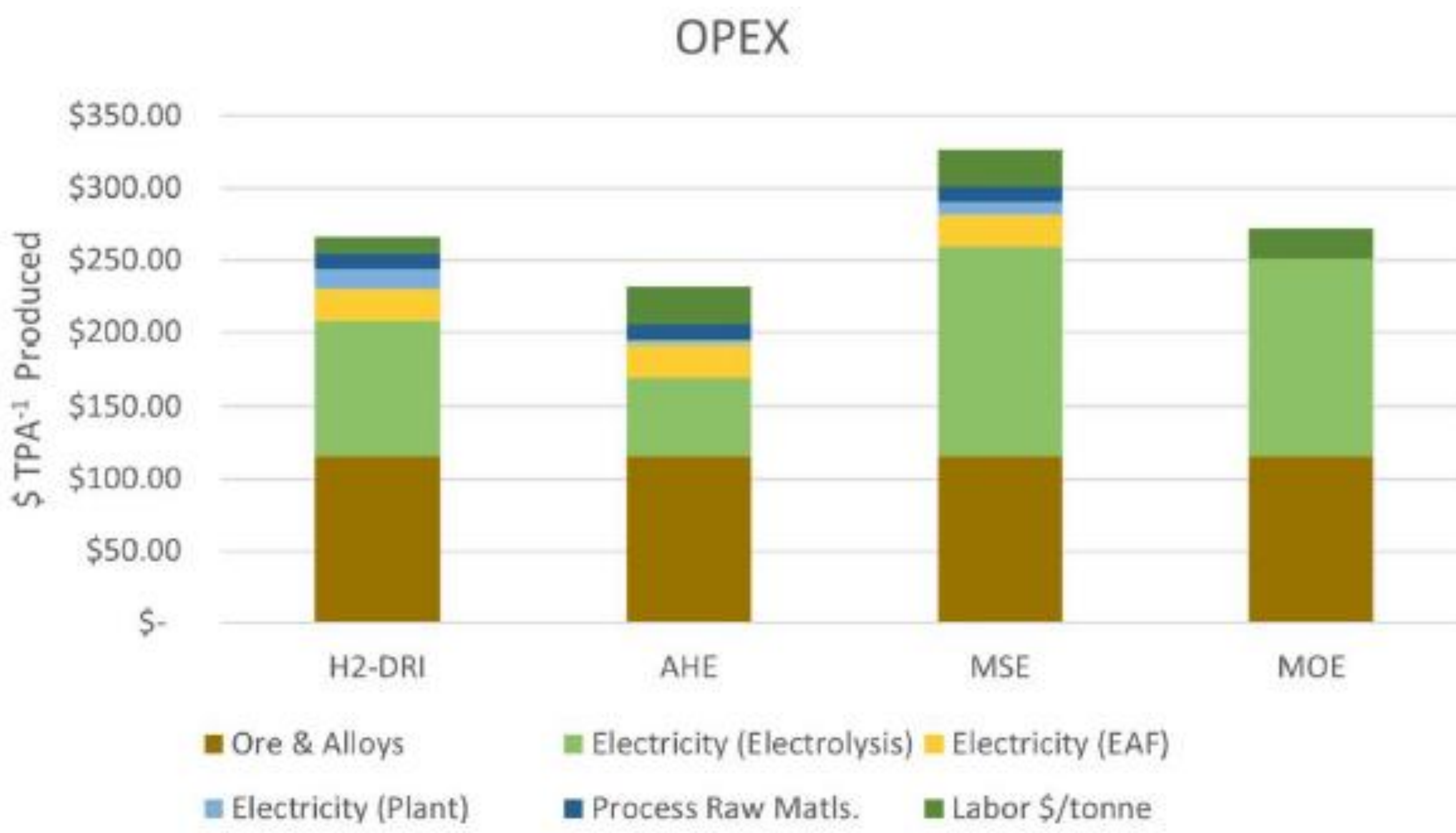
Boot-Handford et al. Metec & 6th ESTAD 2023

Alternative Decarbonization Routes: Electrolytic Routes



Humbert et al., J. Sustain Metallurgy 2024

Molten Oxide Electrolysis – Operating Costs



Humbert et al., J. Sustain Metallurgy 2024

Molten Oxide Electrolysis – Anode Materials

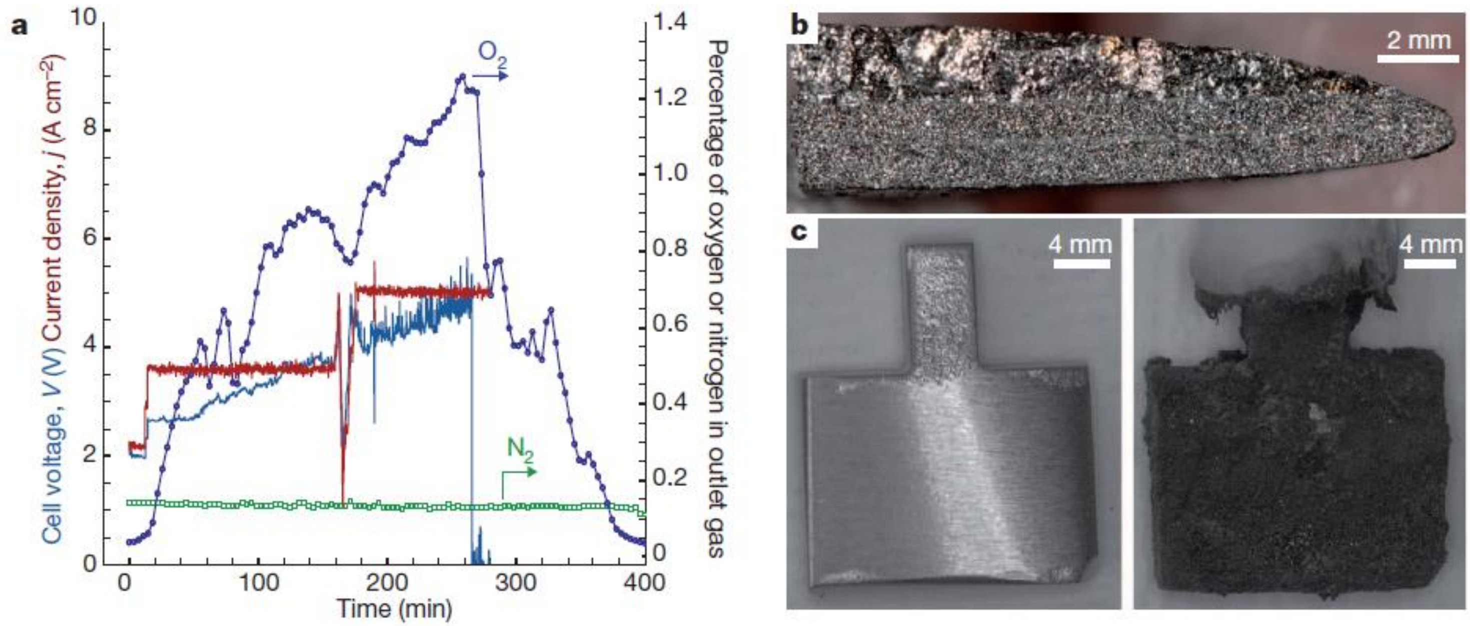


Figure 1 | Electrolysis experiments demonstrate metal and oxygen production with a macroscopically stable $Cr_{90}Fe_{10}$ anode. **a**, Variation of the cell voltage (left axis) and oxygen and nitrogen content of the process gas (right) during constant-current electrolysis ($T = 1{,}565$ °C, 92,964 C). **b**, Fracture of the cathode deposit, showing the deposition of molten metal on top of the substrate. **c**, Macrographs of a $Cr_{90}Fe_{10}$ anode before (left) and after (right) electrolysis, showing the limited change in dimensions ($T = 1{,}565$ °C, 21,923 C).

Allanore et al, Nature 2013

Green Steel: The Big Picture

Hydrogen based ironmaking has impetus (particularly in EU)

Cost/Scale of Green Hydrogen is major issue

Processing of high gangue ores? Electric Smelters?

Australian become a Green Iron exporter?

Future of electrolysis, metallothermic & biomass options ?????

Time for Innovation & Risk