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PRESENT AND FUTURE OPPORTUNITIES IN GREEN STEEL PRODUCTION: A “clean heat” perspective

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1414 Degrees Overview

SiBox technology: The future of clean heat

Adelaide-based publicly listed company (ASX:14D)

Focus on thermal energy storage for decarbonising hard-to-abate heavy industrial sector

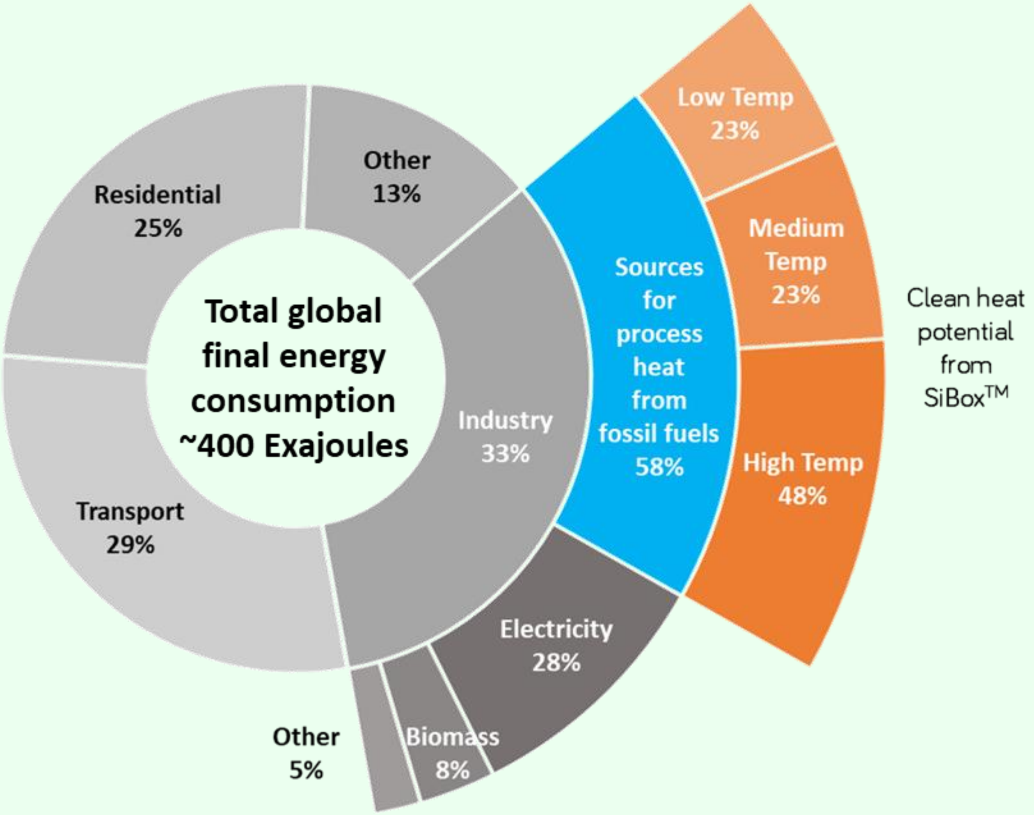
Major company partners for funding and production - Woodside, Refratechnik

Specialist R&D platform optimising efficiency and low cost of silicon technology

PART OF A BETTER FUTURE Woodside Energy

REFRATECHNIK

Clean industrial heat is needed



~45% of the world's energy related emissions come from heat

- There is a massive gap in the high temperature process heat market to replace fossil fuels with clean heat from renewable sources
- High temperature industrial heat has no commercial options to stop the use of fossil fuels
- 14D's technology is the most advanced storage technology able to replace fossil fuels at temperatures over 800°C

The 14D SiBrick is the building block of our technology

It harnesses the high temperature capabilities of silicon, to convert renewable electricity to zero-carbon heat for high temperature industries

14D SiBrick

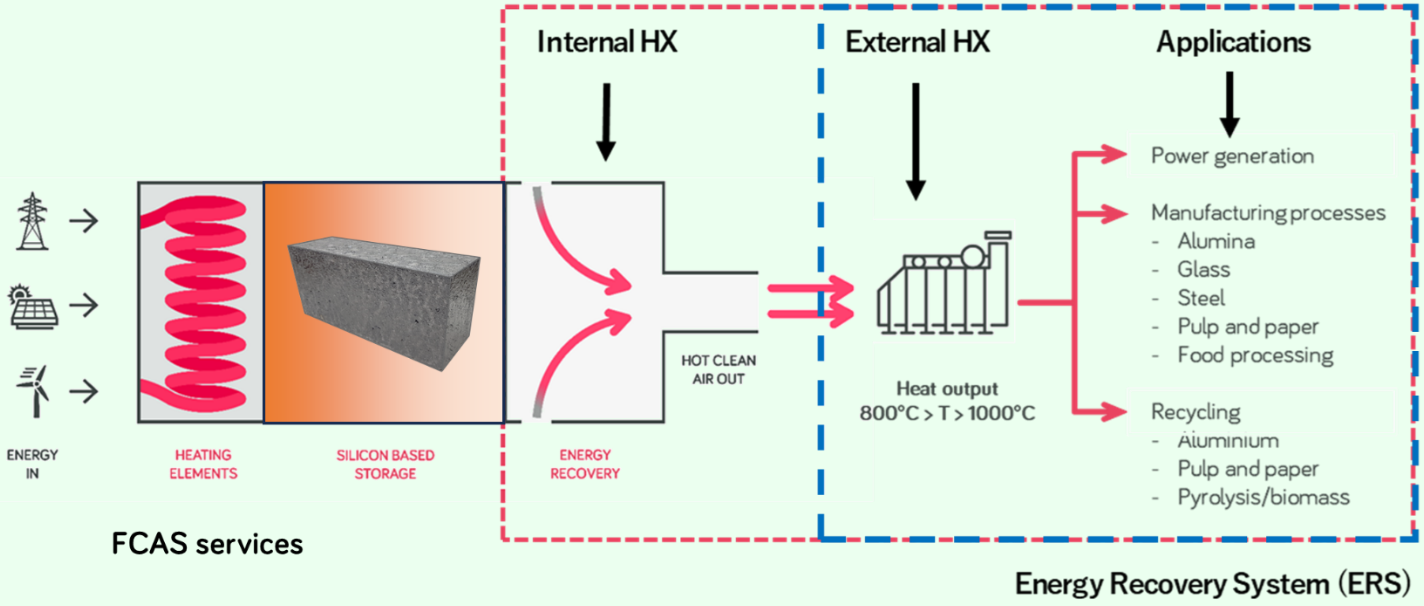
- Robust, modular/scalable
- Mass manufacturable
- High energy density
- High conductivity
- Up to 600 kWh/m^3

Scalability & Manufacturing

- Partnership with top-tier European manufacturer
- Leverage existing infrastructure to scale up
- Faster path to scale-up compared to other TES technologies
- Plant trials planned for mid 2024

14D Thermal Storage Projects

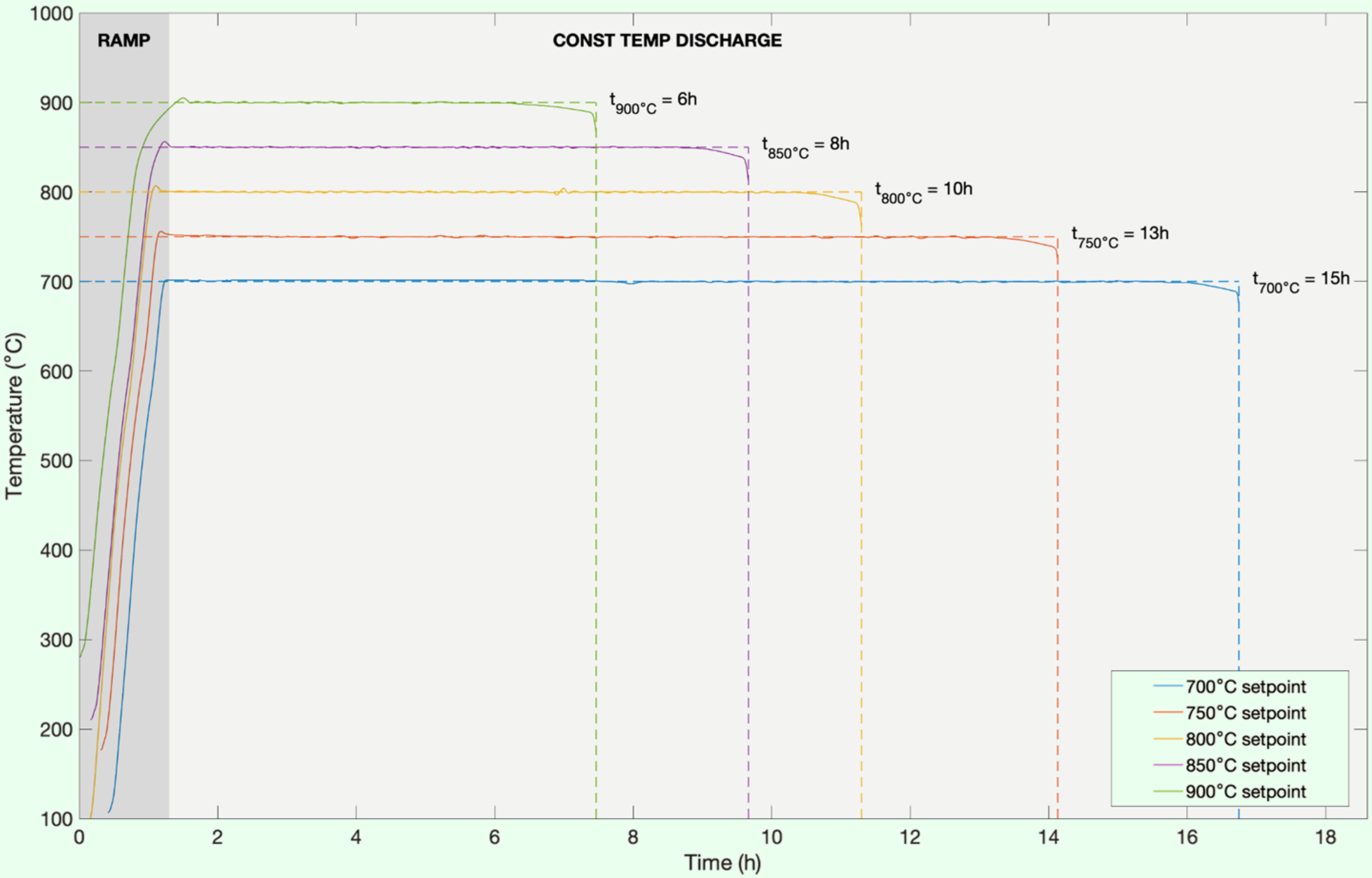
- **TESS-IND (2018):** Electrically charged 6 MWh-th storage coupled to 180 kW-e EFGT
- **GAS-TESS (2019):** Biogas powered 6 MWh-th storage coupled to 180 kW-e EFGT.



SiBOX® Demonstration Module (2023-ongoing)

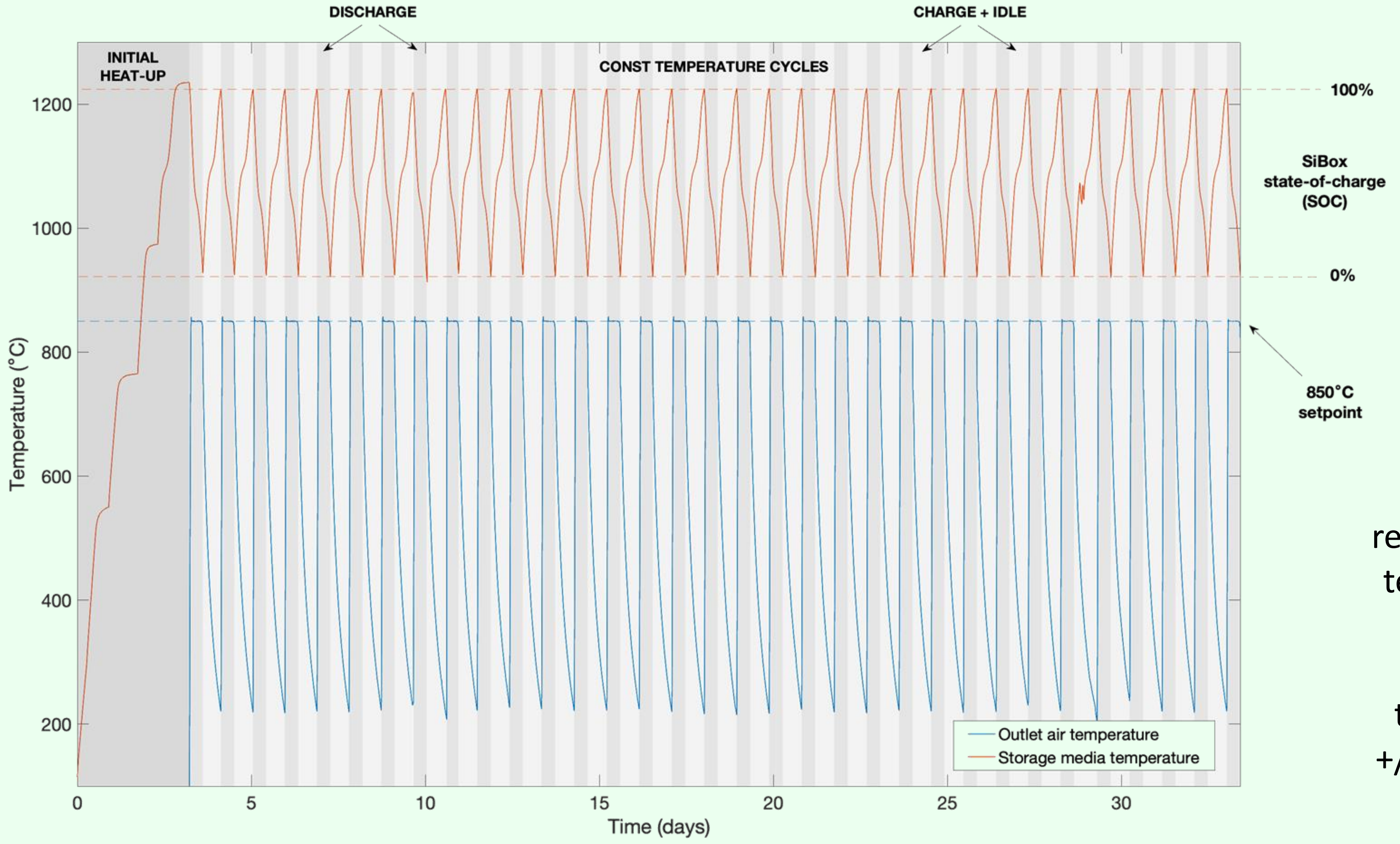
- Next-generation storage media and heat store design, 1 MWh-th storage. Operational since Jul ‘23
- Long duration storage. Several campaigns completed between 700–900°C with storage duration between 6–15h depending on outlet setpoint

SiBox Demonstration Module - Results



Outlet air temperature to the process. 5 different runs at various outlet temperature setpoints shown here.

SiBox Demonstration Module - Results

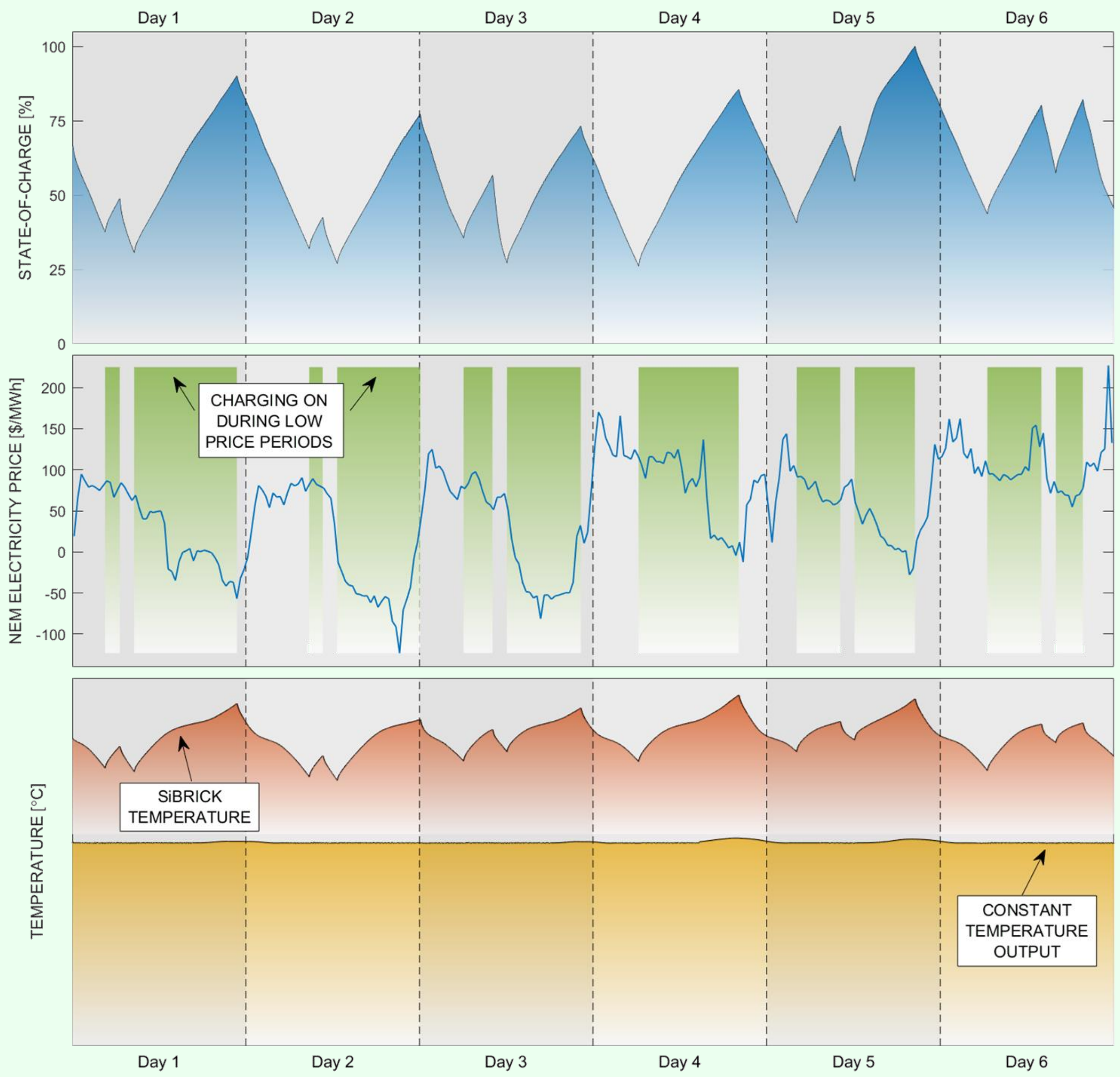


30-day continuous cycling results from SiBox with outlet air temperature setpoint of 850°C. One cycle per day. Temperature variation throughout each run is within +/- 2°C of setpoint temperature.

SiBox Demonstration Module - Results

Charge and discharge being decoupled enables the system to be run in simultaneous mode. The SiBox can provide 24/7 continuous heat to the process by charging intermittently when power prices are cheap.

Figure shows SiBox Demonstration Module operation for 6-days with continuous 24/7 heat output.



Case Study: Integration into DRI process

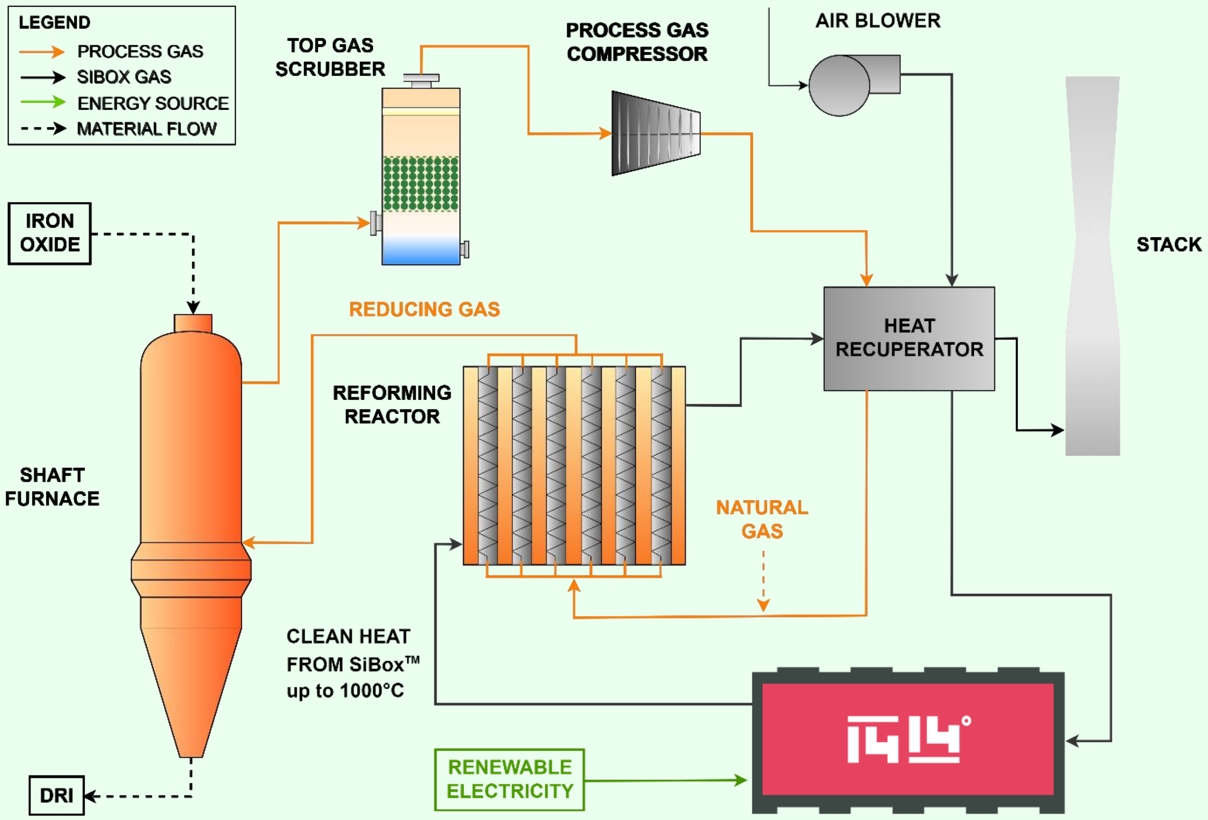


Figure 1: SiBox integration into conventional Direct Reduced Iron process; image adapted from conventional natural gas based DRI process, as an example, to include SiBox as a partial replacement for natural gas.

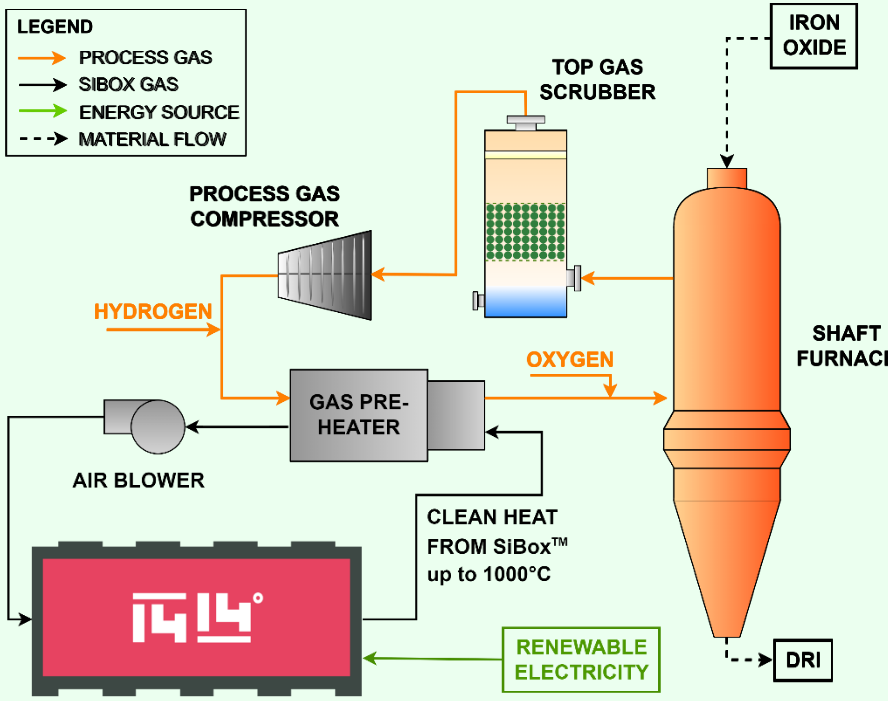


Figure 2: SiBox integration into a typical H_2-Direct Reduced Iron process; image adapted from H2-based DRI processes, as an example, to include SiBox as an alternative for direct electric or fuel-based heating.

H_2-DRI: ~75–100 MW clean heat can be integrated per million tonne of DRI produced

HILT CRC

Australian Government
Department of Industry, Science and Resources

AusIndustry
Cooperative Research Centres Program

Heavy Industry Low-carbon Transition Cooperative Research Centre

Over 50 partners, including, in Iron and Steel:

- Fortescue Metals Group
- Roy Hill
- Liberty GFG
- Grange Resources
- Primetals Technologies
- Magnetite Mines

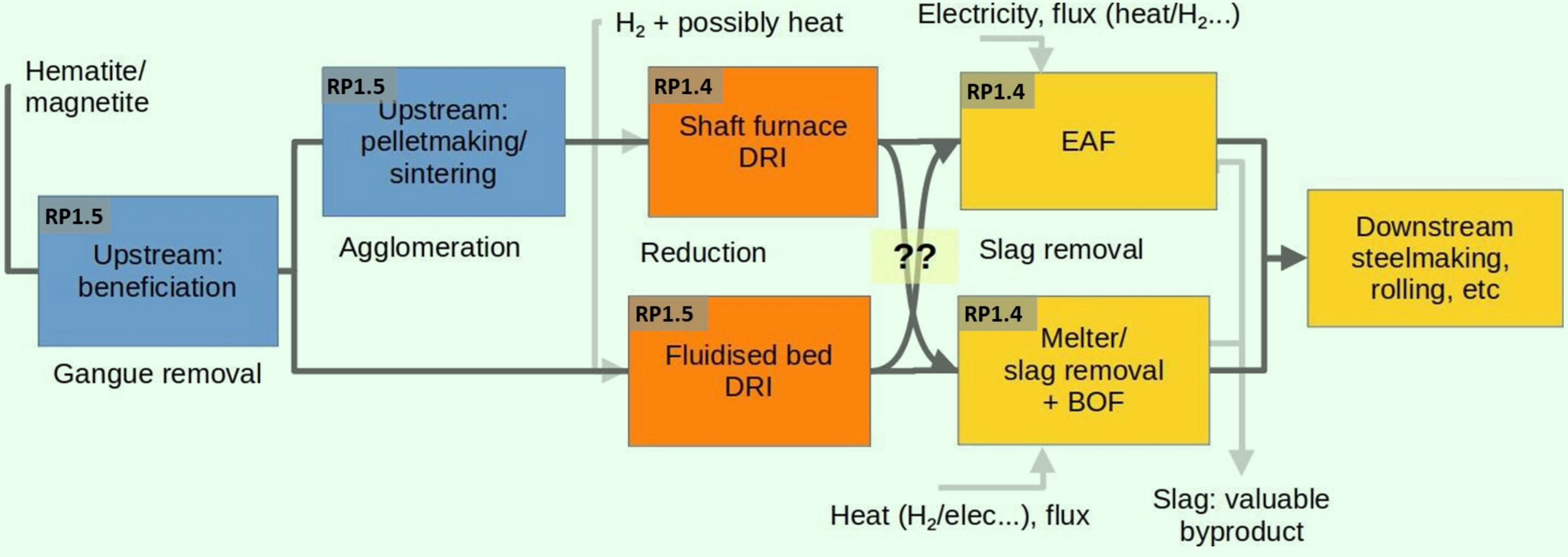
- Ten-year funding
- https://HILTCRC.com.au/

Three research programs:

- Process technologies (iron/steel, alumina, cement)
- Cross-cutting technologies (energy supply, CCU/S, fuels)
- Facilitating transformation (industry roadmaps, supply chains, community)

End-to-end modelling of green steel production

Hydrogen DRI pathways



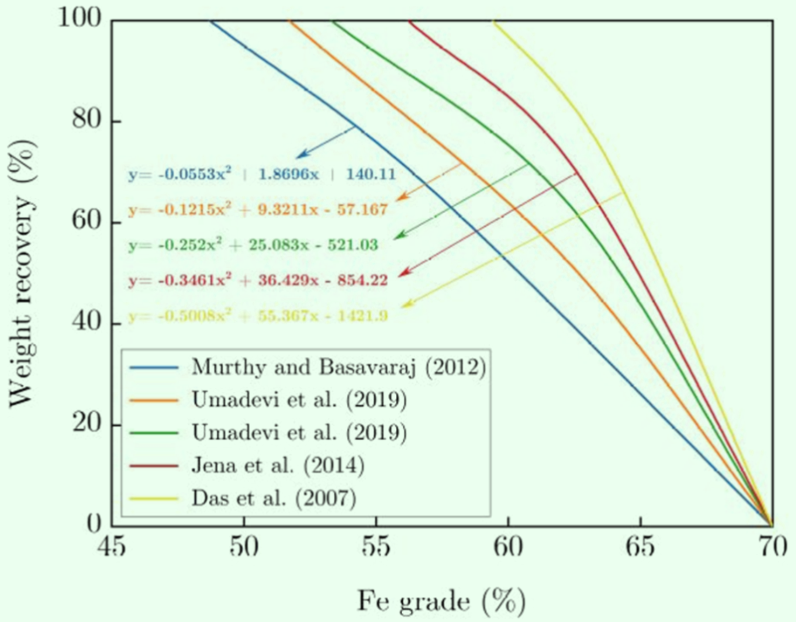
HSC Sim flowsheeting was used to link the beneficiation, pelletisation and pyro steps (DRI-EAF or DRI-smelter-BOF), with both fluidised bed and shaft furnace options considered for the DRI.

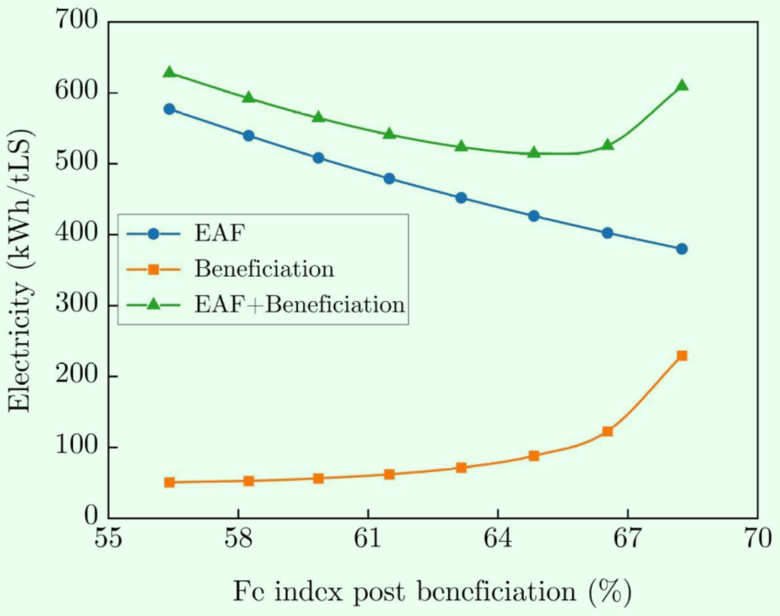
Of key interest was the resulting **liquid steel price** for **different ore grades** and levels of **beneficiation**.

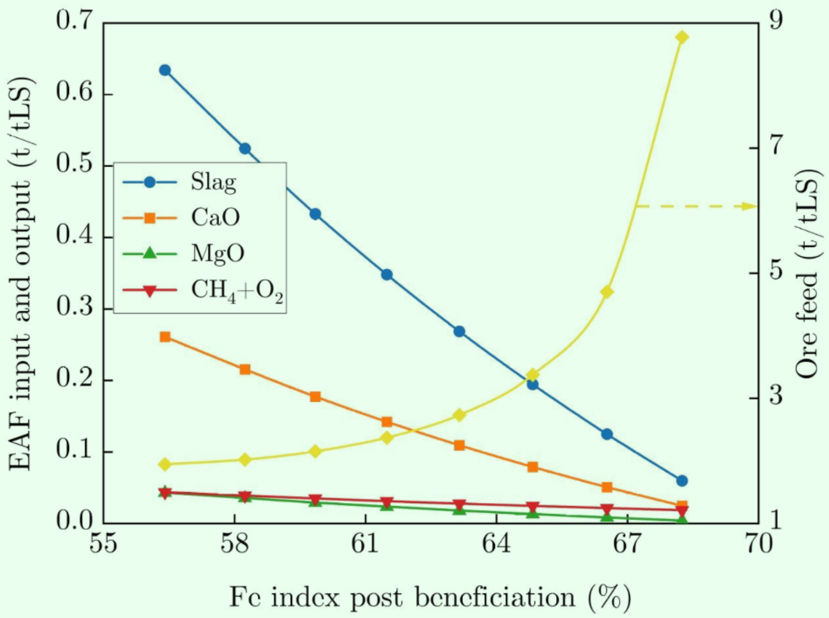
Key 'axes' of analysis

1. **FB vs SF** pathways primarily will be differentiated based on equipment cost and presence/ absence of agglomeration step.
2. **Beneficiation vs steelmaking** as ways to remove gangue; will be highly sensitive to the ore characteristics (goethite, hematite…)
3. **EAF vs melter BOF** (flux required as a function of gangue content)
4. **Low RE costs in Australia** versus elsewhere (input from other projects)

Beneficiation and effect on DRI-EAF main inputs/outputs



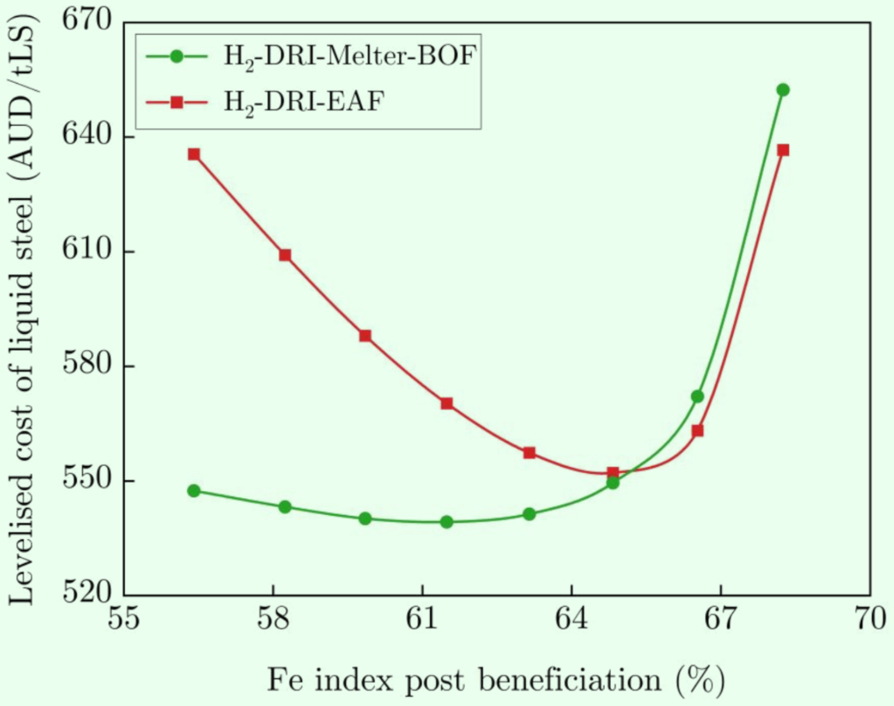


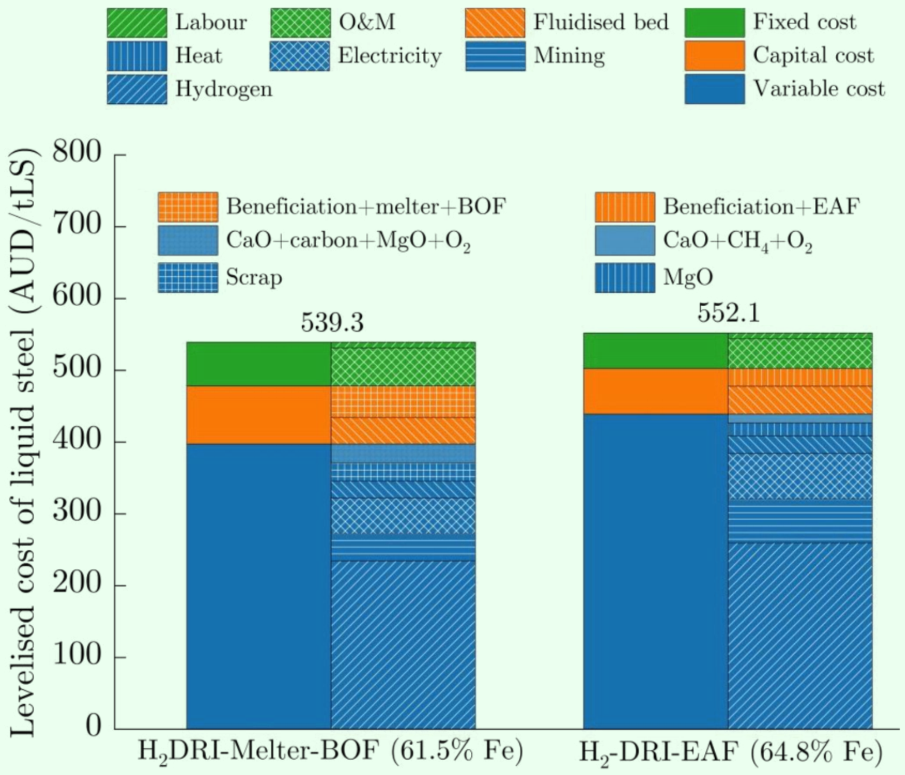


Yield decreases dramatically at higher levels of beneficiation.

- The **flux** charging, O_2 and CH_4 charging to the EAF decrease, and the resulting **slag** volumes decrease at Fe% is increased. This is balanced against the dramatically increasing **raw ore** feed into the lower-yield beneficiation process.
- Ultimately, increased **electricity** demand for crushing and screening outweighs the savings in EAF electricity consumption at higher levels of beneficiation.

Cost of LS: H_2-DRI-EAF vs H_2-DRI-smelter-BOF





When the melter-BOF pathway is compared to the EAF pathway, less beneficiation is required, and it provides marginal benefit in terms of levelised cost of liquid steel.

The less-beneficiated melter-BOF pathway saves cost in mining, but adds cost in flux, scrap and component capital costs. With optimal beneficiation, the melter-BOF pathway saves **~13 AUD/tLS (<2.5%)**

Key takeaways:

- Under present market conditions, we find that it is better to process **low-grade Pilbara ores** using smelter-BOF processes than it is to pay the premium for higher-grade ores
- Beneficiation up to ~61% is optimal, but only slightly reduces the cost of the resulting liquid steel*.
- At assumed energy prices (eg 3.5 USD/kg for H_2), we find that energy costs are more than half of the total steel cost. However, at current EU carbon tax levels (90 EUR/tCO2e), the process is already close to parity with BF-BOF.

** This is an initial evaluation, and many details remain to be refined and revisited.*

Integration of thermal storage in green steel production

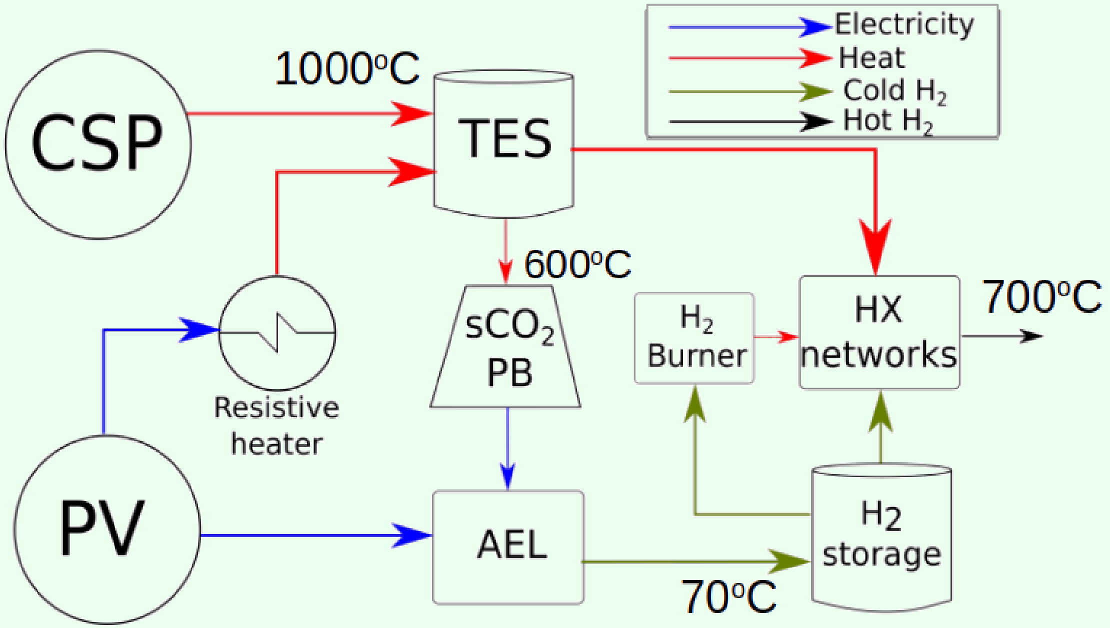
H_2 iron making – what about heat?

$Fe_2O_3 + 3 H_2 \rightarrow 2 Fe + 3 H_2O$

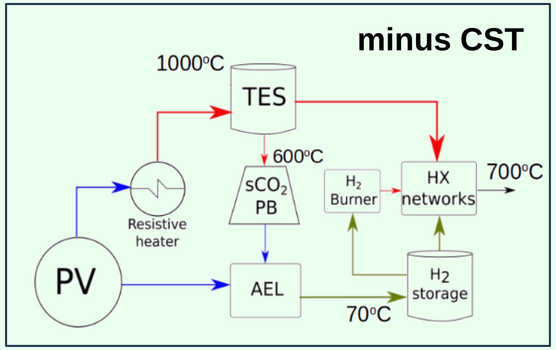
Production at 5 Mt/a would require:

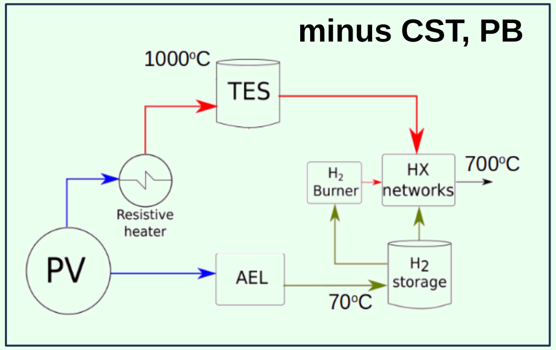
- 1.03 GW of **H_2** on an LHV basis
- 110 MW of **heating** to get the H_2 to reaction temperature
- What is the best way to supply ~1.1 GW of 'hot hydrogen'?

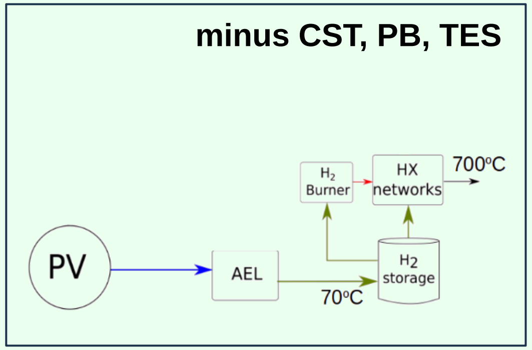
Starting point: green steel via reduction with hydrogen.



DRI Technology providers have indicated that direct electrical heating of the reducing gas is a possibility.







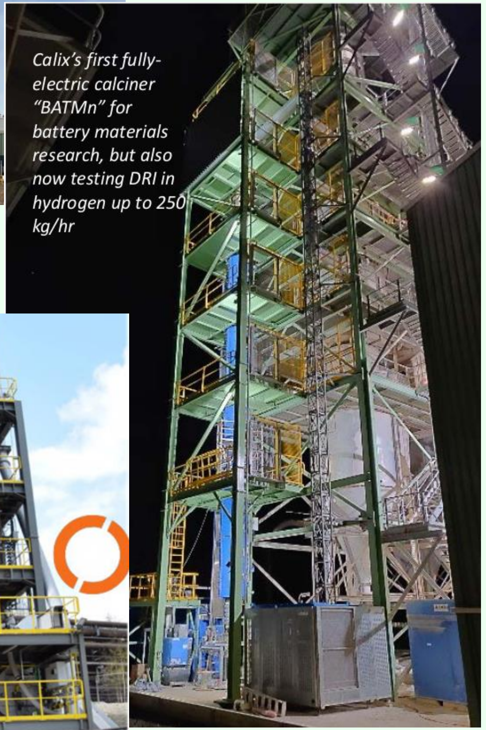
Key takeaways:

- We examined alternative systems to supply green ‘hot hydrogen’ (700°C) for a HYFOR-like DRI process. **Can be adapted for other DRI processes as well.**
- Using TES for heat supply to H_2 DRI facilitated a significant reduction in overall energy costs. TES was assumed to be particle-based storage at 1000°C for this initial investigation. **Detailed study with 1414 Degrees’ SiBox system is part of the on-going project.**
- The best source of electricity input was photovoltaics, rather than solar-thermal. This is because most of the energy runs through an electrolyser, and the **cost of electricity is more critical than the cost of the heat.**
- Again, these were initial evaluations. Optimal configurations will change with altered operating temperature and component costs. **Detailed integration feasibility, including strategies to avoid particle sticking, radiative heating and comparison with other storage technologies like SiBox is on-going.**

Conclusions

Conclusions

- **Smelter-BOF pathway unlocks lower-grade ores:**
  - For lower-grade hematite-goethite ores, the smelter-BOF processing pathway is highly appealing. The smelter achieves similar product with much less flux, obviating the driver for higher-grade ore (or intensive beneficiation).
- **Energy storage is crucial for cost reduction:**
  - H_2-DRI processes can be operated more cheaply if thermal energy storage is combined with hydrogen storage to ride through the 'dark doldrums'.



Courtesy: HYBRIT, CALIX and Primetals

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