Hybrid Heating And Energy Management Systems For Industrial Decarbonisation

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IMPERIAL

calix zesty by calix

BACKGROUND

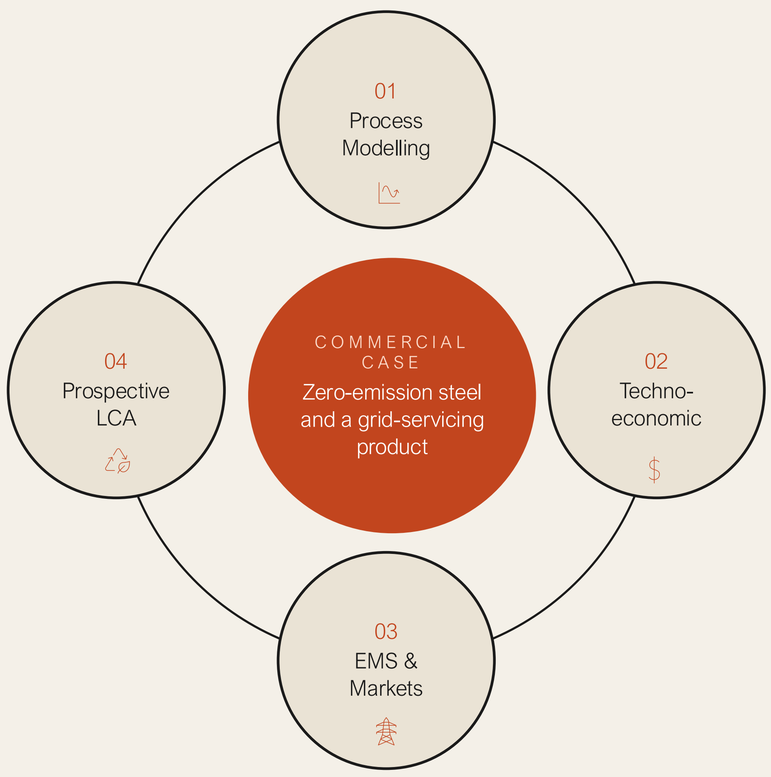
Green hydrogen direct reduction (GH-DRI) is the leading route to zero-emission iron and steel, but its high production costs make it uncompetitive against conventional pathways. GH-DRI alone is set to add 400-1,520 TWh of electricity demand by 2050, alongside competing growth from industrial electrification, EVs and AI-driven data centres, lifting electricity from 21% to 55% of global final consumption. Combined with a parallel rise in variable renewable energy, this is forecast to drive a 250% increase in EU daily grid flexibility requirements. Without sufficient flexibility, large electrified industrial loads will cannibalise renewable supply and force reliance on lower-merit sources to fill the gap

RESEARCH QUESTION

Can hybrid heating and EMS strategies make GH-DRI commercially feasible whilst supporting grid integrity?

METHODOLOGY

THE FRAMEWORK



CURRENT METHODOLOGY

01 Process Modelling

- Reactor model. 18-stage Aspen CSTR in seires (3 preheat, 15 heated),
- Reduction path. $Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow FeO \rightarrow Fe$
- Kinetics

$$K_p = \frac{PH_2O}{PH_2} \quad \textit{(Hara et al.)}$$

$$r_H = k_o e^{\frac{-Ea}{RT}} \left(PH_2 - \frac{PH_2O}{K_p}\right) C_H = exp\left(-\frac{2070}{T} + 1.3\right) \quad \textit{(Chen et al.)}$$

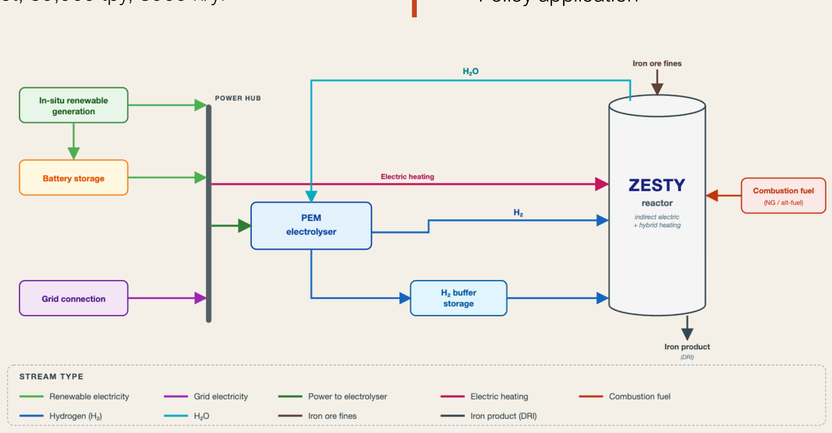
- Operating envelope. 950 / 1000 / 1050 °C at 1 atm; 90% Fe target, 30,000 tpy, 8000 h/yr

02 Techno-Economic Model

- Scenario framework. 5 dimensions: H_2 source, electricity source, heating mode, BESS, H_2 storage
- Process inputs. 203 kg H_2/h, 2.05 MW duty , 30 kt/yr Fe output

HOW THE MODEL WORKS

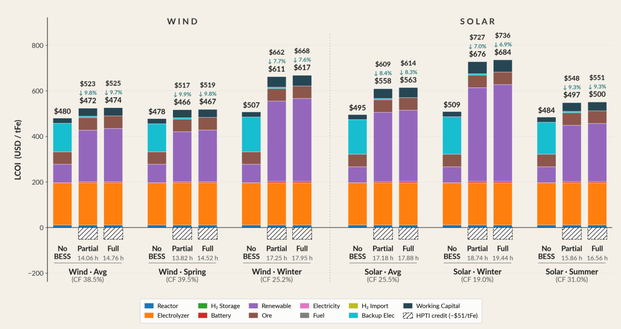
- PEM electrolyser: 10.6 MW · 52 kWh/kg H_2
- Capacity factors flat: annual mean + seasonal edges
- BESS sized Full / Partial / None vs non-gen hours
- H_2 storage sized by buffer day requirement.
- Electricity: full renewable / renewable + grid backup / full grid
- Heating: fully-electric vs hybrid (electric + NG backup)
- Policy application



CURRENT FINDINGS

IN-SITU H_2 $423 to $684 / tFe

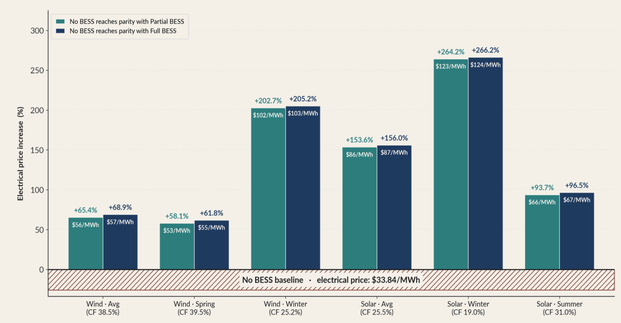
IMPORTED H_2 $701 to $725 / tFe



LCOI breakdown for solar and wind configurations across capacity factors and battery modes

NO-BESS WINS AT THE FEED BASELINE

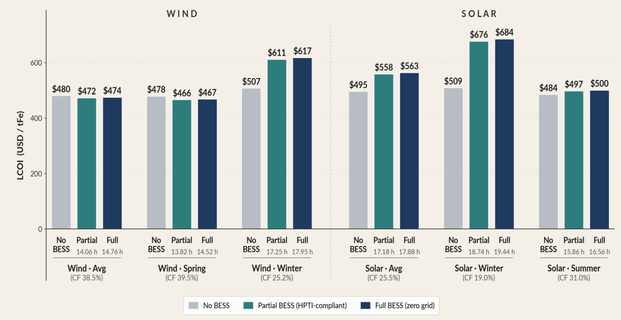
- Range. $423 to $684 per tFe across six renewable scenarios
- No-BESS wins. At $33.84/MWh FEED price, no-battery grid-backed is cheapest in every case
- Why. Renewables + grid backup contribute $150 to $167/tFe; oversized renewables + battery reach $181 to $379/tFe
- HPTI credit. $51.07/tFe applied; reduces LCOI by 7 to 10%



Grid price parameter sweep showing breakeven for No-BESS vs battery cases

NO-BESS HOLDS UNTIL PRICES RISE 58%

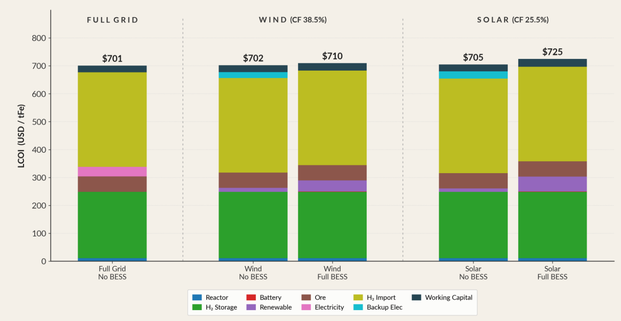
- Robust margin. Minimum 58.1% price rise needed for No-BESS to lose its advantage
- Worst case. Up to 266% rise required (winter solar, full BESS)
- Current Market Price. 2024 to 2025 Average at $59.91/MWh, 77% above ZESTY FEED baseline



LCOI re-evaluated at the average AEMO STEM clearing price of $59.91/MWh

AT MARKET PRICE WIND SHIFTS TO PARTIAL BESS

- Wind shifts. Wind average and Wind spring move to Partial BESS, beating No-BESS by $8 to $12/tFe
- Solar holds. Four scenarios still favour No-BESS; Solar summer gap narrows from $71 to $13/tFe
- Driver. HPTI credit, and high grid backup costs make high-CF wind cost-competitive
- Sensitivity. Outcome highly sensitive to wholesale price secured



Imported H2 LCOI breakdown across five plant configurations at $59.91/MWh and seven days storage

IMPORTED H_2 DOMINATED BY DELIVERY & STORAGE

- Tight band. LCOI spans only $24/tFe across five cases; max $725/tFe
- Cost driver. H_2 import + storage = 79.5 to 82.1% of LCOI in every case
- Parity. Delivered H_2 must fall below $2.34/kg to match in-situ benchmark of $489/tFe
- Verdict. Imports not competitive at 7-day buffer storage

WHAT'S NEXT

Process model — Alternative fuels, impurities, heat recovery

→ **Hourly TEA** — Sizing + dispatch, flexibility levers

→ **EMS & markets** — Day-ahead, ancillary, capacity products

→ **Prospective LCA** — Premise, various future pathways

EXPECTED OUTCOMES

- Validated TEA + LCA framework for hybrid heating across Calix processes
- EMS revenue models spanning Australian, UK, and European grid markets
- Commercial business case benchmarking ZESTY against grid-balancing peers

CONNECT WITH ME

Hara, Y., M. Tsuchiya, and S.-i. Kondo, Intraparticle Temperature of Iron-Oxide Pellet during the Reduction. Tetsu-to-Hagané, 1974. 60.

Chen, F., et al., Hydrogen Reduction Kinetics of Hematite Concentrate Particles Relevant to a Novel Flash Ironmaking Process. Metallurgical and Materials Transactions B, 2015. 46(3): p. 1133-1145.

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