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SOLAR-INDUCED MINERAL CARBONATION OF MINE WASTE: A TECHNO-ECONOMIC AND EMISSION ANALYSIS

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Mineral Carbonation: Background

What is Mineral Carbonation?

- It is a naturally occurring process whereby certain silicates convert to carbonates absorbing CO_2

$$\mathbf{MgSiO_4\ (s) + CO_2\ (g) \rightarrow MgCO_3\ (s) + SiO_2\ (s)}$$

- **CO_2 stored in a solid form** over 1000-years scale, plus formation of **valuable co-products** (e.g., silica, carbonates)
- Ideal candidates are mafic/ultra-mafic rocks and **tailings rich in Mg and Ca**

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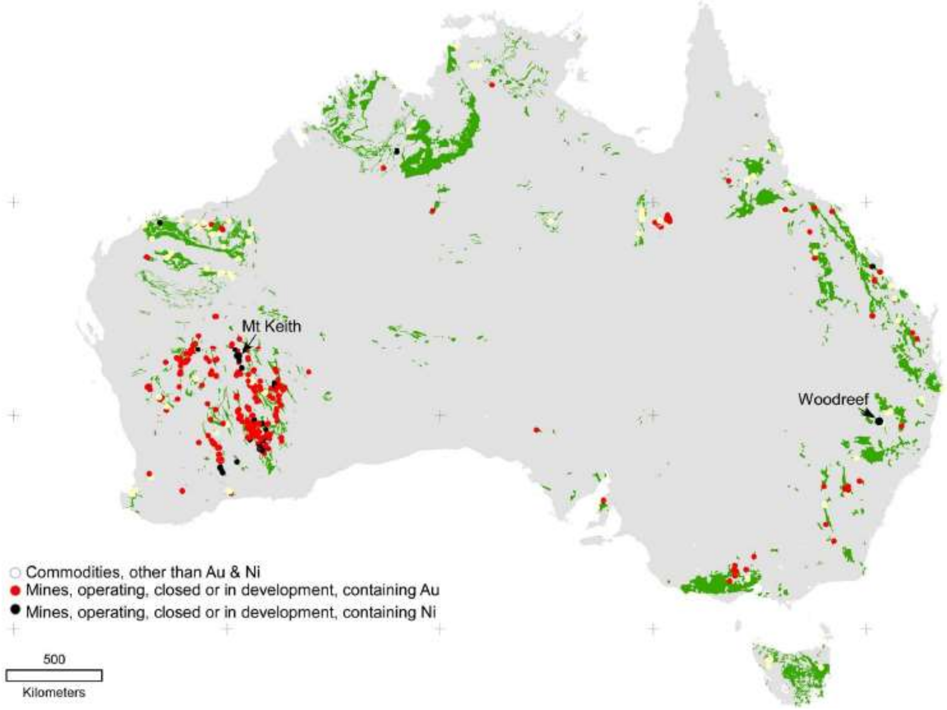
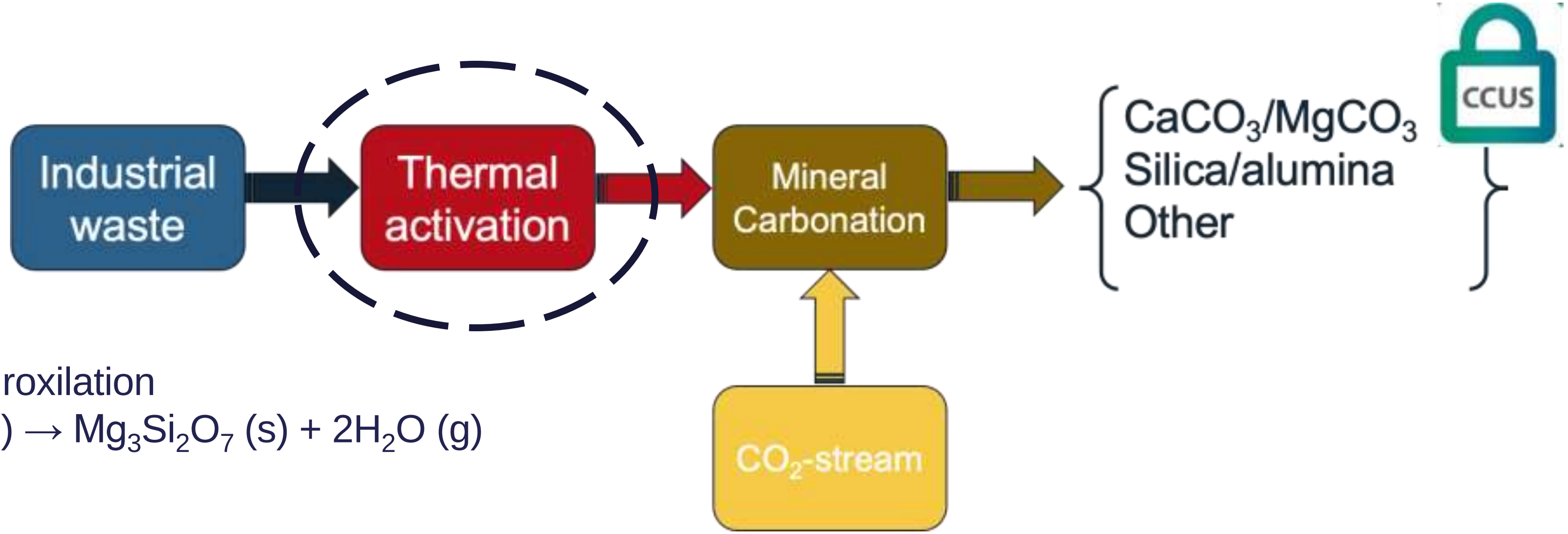
- **In Australia:**
  - Nickel and gold tailings well suited
  - BHP Mt Keith Nickel Mine most studied site
  - Potential = 36Mt $CO_{2\text{-eq}}$ pa by 2050 (CSIRO, 2022)



Mineral Carbonation: Thermal Activation

Thermal Activation

- Naturally, the process occurs very slowly (years) and with a low capture rate
- Majority of the work in the field focused on accelerating kinetics, improving overall efficiency and technology scale-up
- MCi (Australian-based company) reached TRL 7-8
- **Thermal Activation of serpentine-based minerals** paramount to produce a highly activated materials (via dehydroxilation)



Serpentine dehydroxilation

$Mg_3Si_2O_5(OH)_4$ (s) → $Mg_3Si_2O_7$ (s) + $2H_2O$ (g)

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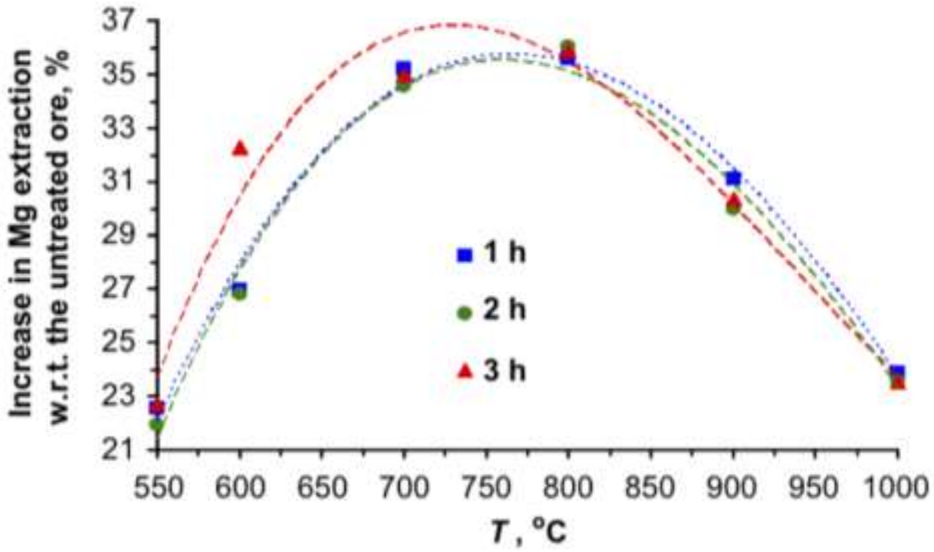
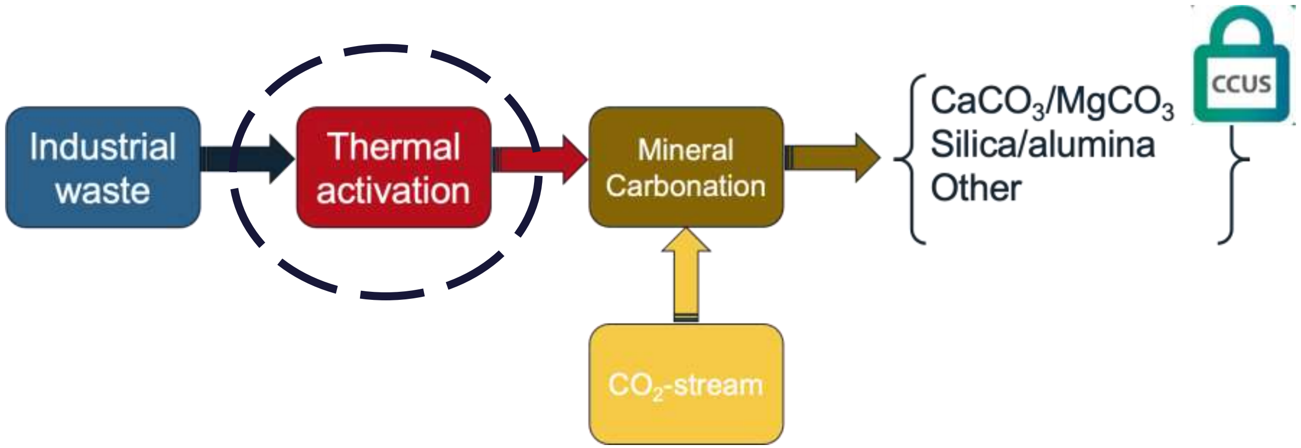
- Thermal Activation of serpentine-based minerals paramount to produce a highly activated materials (via dehydroxilation)
- **Activation window is quite narrow and temperature control is critical → 650-700 C**

(Kennedy et al, 2013)





Gaps & Aims

Gaps

- Limited work on techno-economics and supply chain emission analysis of the thermal activation process
- No data on CST-based thermal activation and in Australian context (main works for Canadian waste tailings)

Objectives

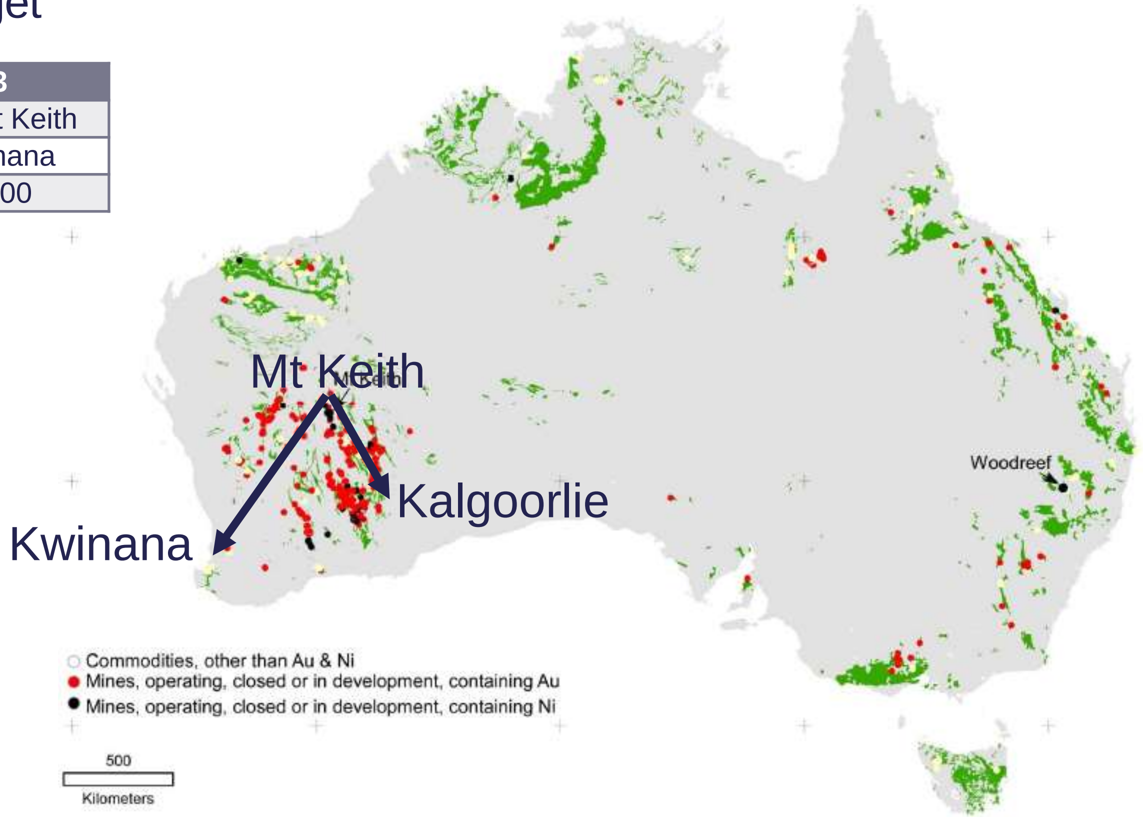
- **To provide a first-order TEA and emissions analysis of CST-based and non-CST thermal activation plant using Australian nickel mine tailings, including CST plant layout**

Scenarios

Scenarios and basic assumptions

- Use of BHP Mt Keith nickel mine tailings (Western Australia) for thermal activation
- Thermal activation and carbonation plants co-located near a CO_2 point source from an industrial hub
- Kalgoorlie (nickel hub) and Kwinana (alumina hub) as target

Scenarios	1	2	3
Location serpentine tailings	Mount Keith	Mount Keith	Mount Keith
Location activation plant and CO_2 source	Mount Keith	Kalgoorlie	Kwinana
Distance (km)	0	500	1000



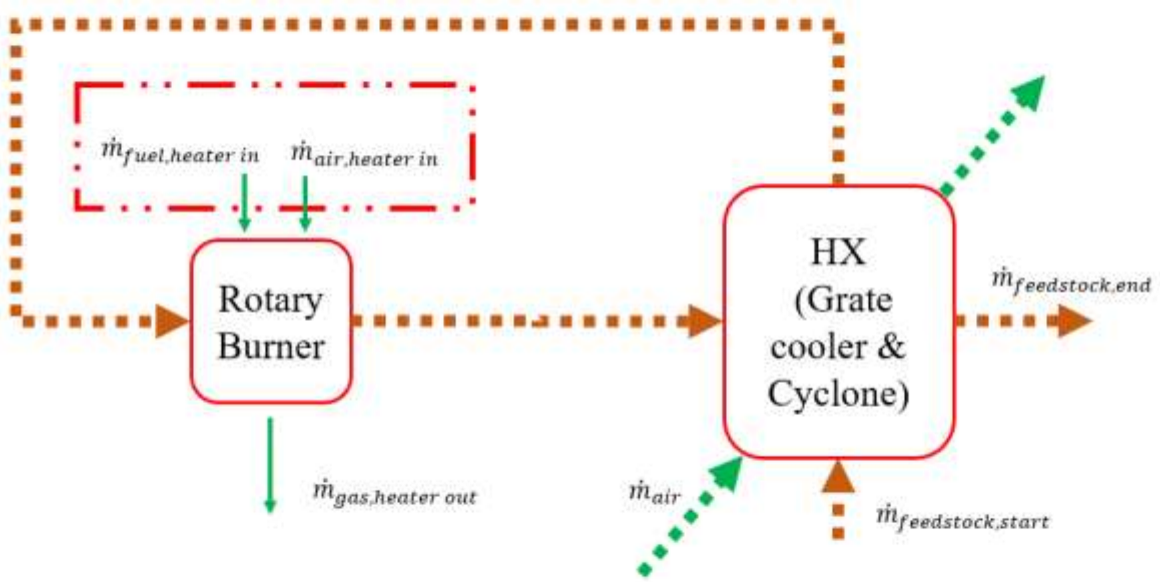
Energy requirements

- Target activation temperature being 700 C
- Aspen process model to estimate energy requirements
  - Energy needed per ton, is 572 MJ/ton
  - 200 ton/hr → 35 MW_{th}
  - 600 ton/hr → 106 MW_{th}

Fuel-based options

Assumptions

- Natural gas, low-carbon H_2 (electrolytic and from steam reforming +CCUS) considered
- Sensitivity on fuel price. Baseline NG being 12 AUD/GJ while low-carbon H_2 is 2.5 AUD/kgH_2
- Specific $CO_{2\text{-eq}}$ emissions for fuels taken from IEA report 2022

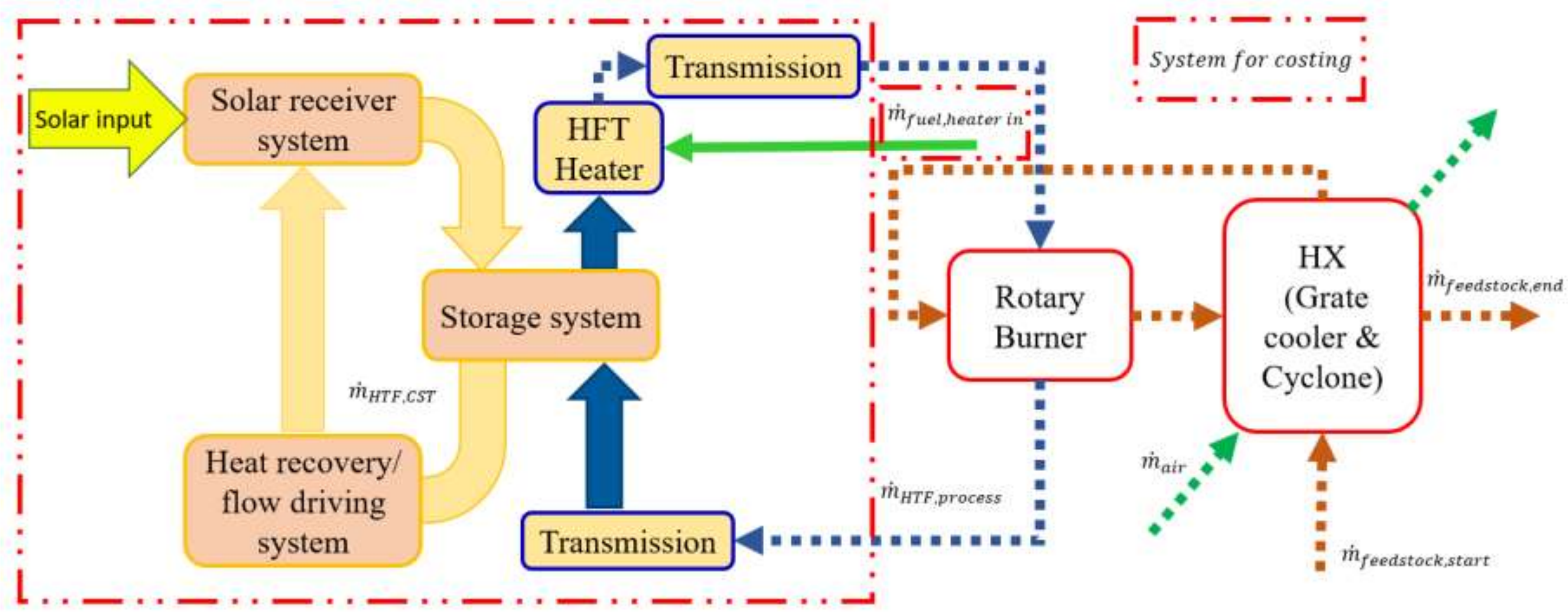


Specific cost of fuel (USD/GJ)	3 to 30
Baseline specific cost of Natural gas (USD/GJ)	8.5
Baseline specific cost of Low-carbon Hydrogen (USD/GJ)	15 (2.5 AUD/kgH2)
Specific CO_2 emission Natural gas (kg CO_2/ GJ)	65.9
Specific CO_2 emission H_2 (B) (kg CO_2/ GJ)	38.7
Specific CO_2 emission H_2 (G) (kg CO_2/ GJ)	7.0[c]

CST-based options

Assumptions

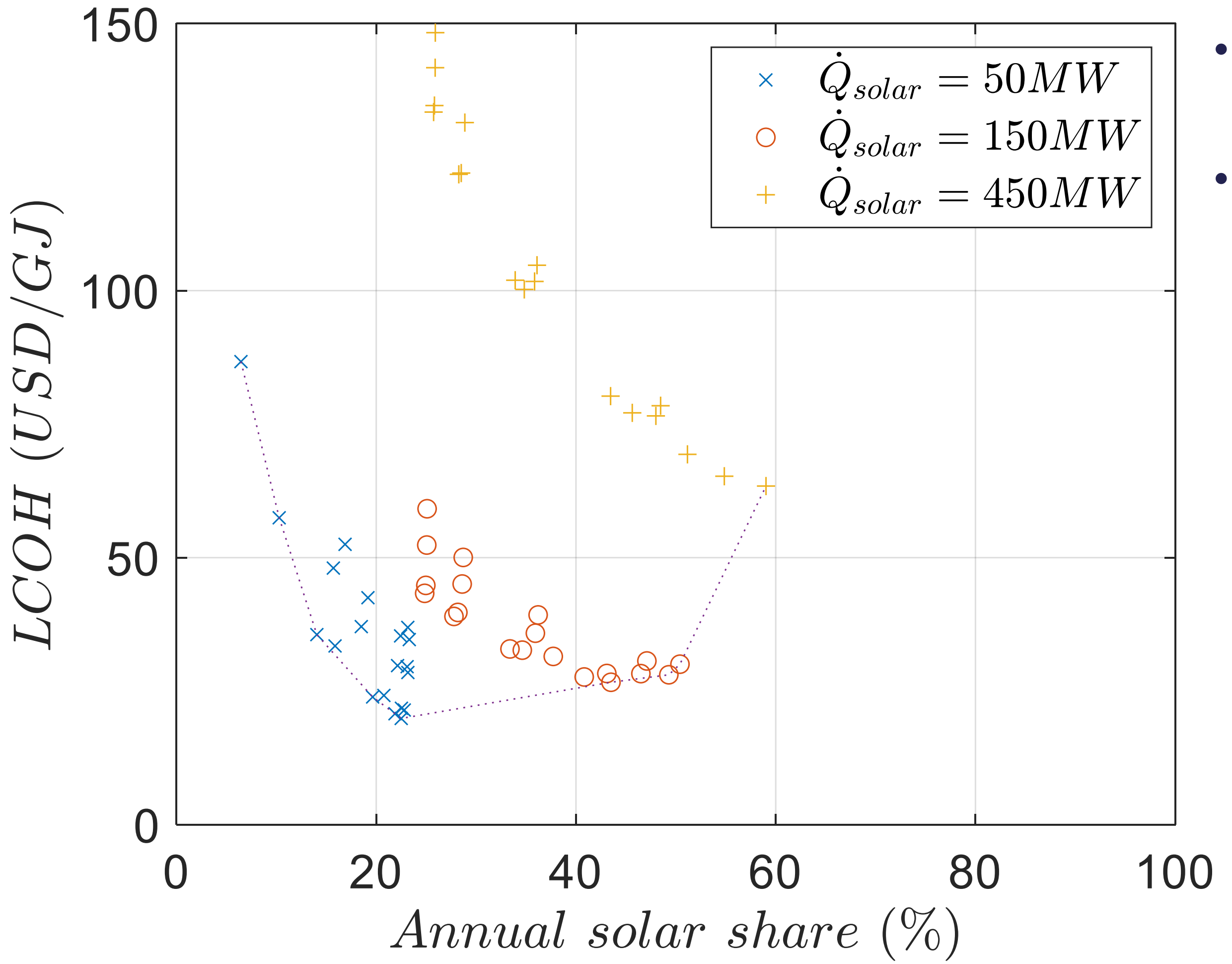
- CST plant layout featuring an air solar receiver, thermal storage, and back-up burner.
- Model adapted from previous works from UoA group to provide 24/7, firm supply of high-T heat to alumina calcination
- Time-series of 10 min interval for a full year simulation, 3 locations – Phoenix UoA supercomputer



- 3 solar scales of 50, 150 and 450 MW into the receiver were assessed
- 3 solar multiples assessed with a range of storage capacity (2-32 hours), and the most suitable storage capacity was selected for each case

LCOH for CST-based options

- 200 ton/hr plant → 35 MW_{th} thermal demand, 700C target temperature, Mt Keith

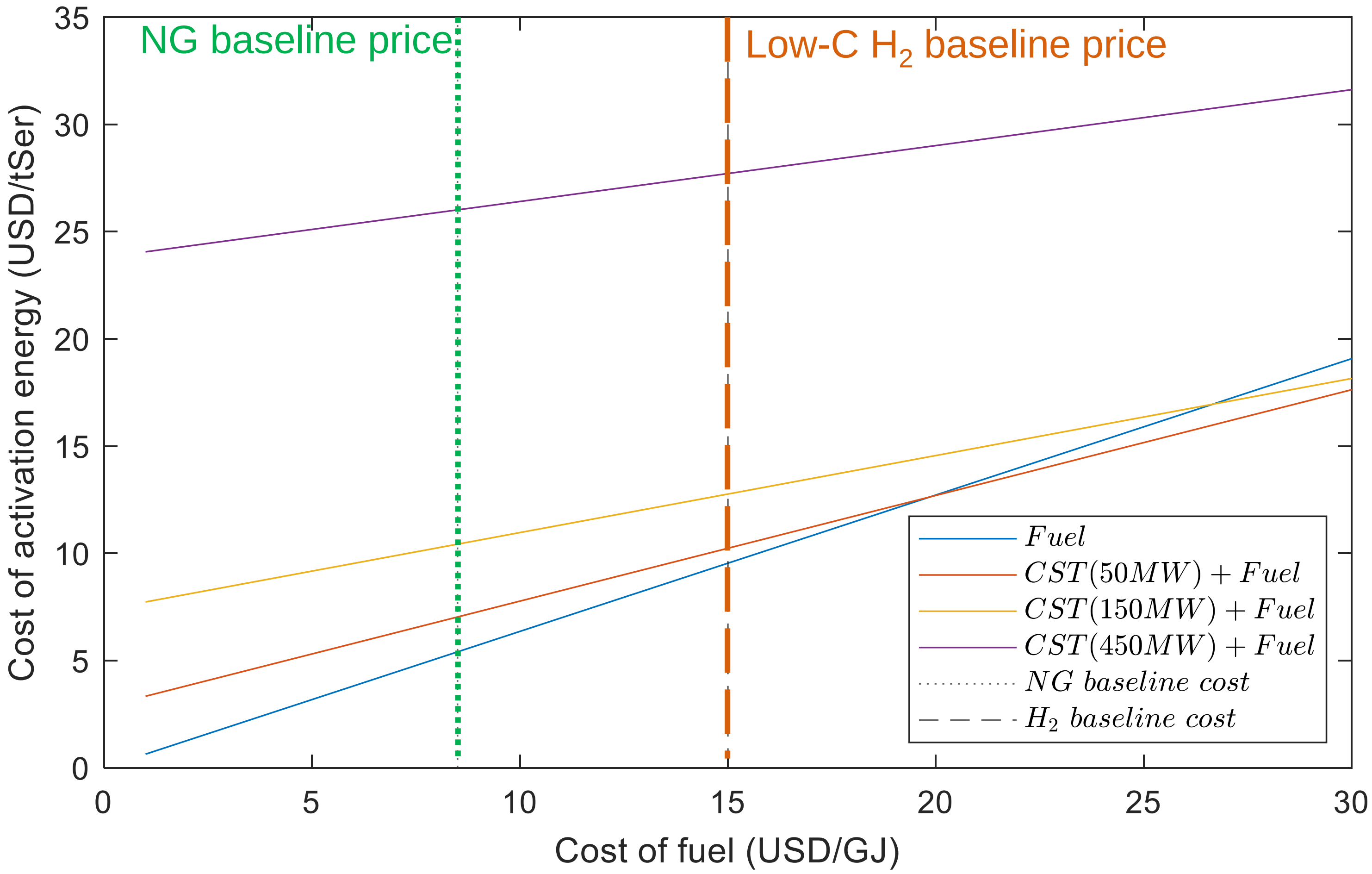


- Optimal CST plant layout to minimise LCOH identified for a given thermal requirement and operating temperature
- LCOH < 20 USD/GJ potentially achievable, by selecting an appropriate ratio between scales of CST plant and thermal activation plant

CST Scale (MW)	Solar share (%)	Storage capacity (hrs)	LCOH of CST (USD/GJ)
50	22.5	2	19.8
150	43.5	16	26.7
450	59.0	32	63.4

LCOH for CST-based vs fuel-only options

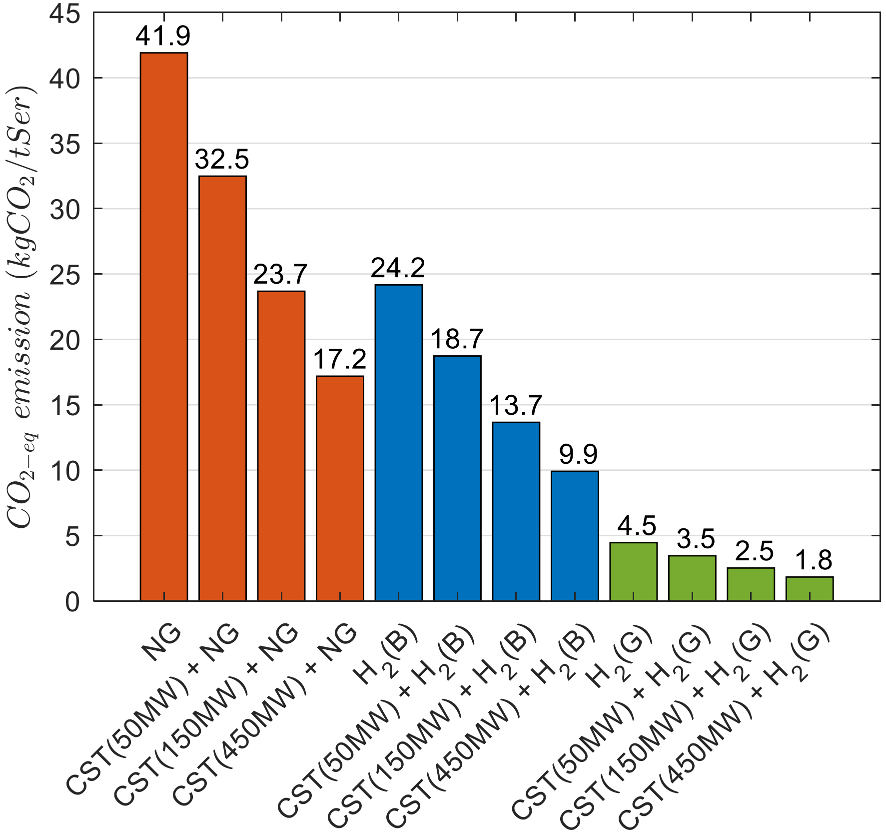
- 200 ton/hr plant → 35 MW_{th} thermal demand, 700C target temperature, Mt Keith

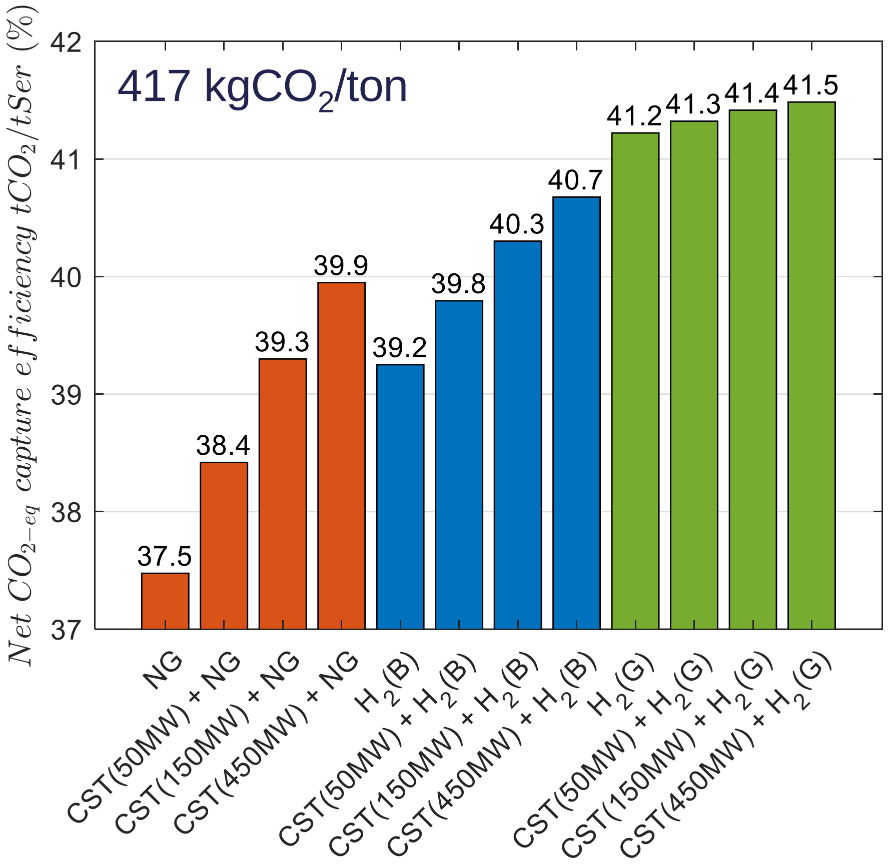


CST-based cases:

- Higher costs than 100% NG-based case for current NG prices
- On pair with 100% H_2-based case for baseline H_2 price
- Lower LCOH than 100% H_2-based case achievable for H_2 prices > 3.5 AUD/kgH_2

Supply chain emissions and net CO_2 capture efficiency



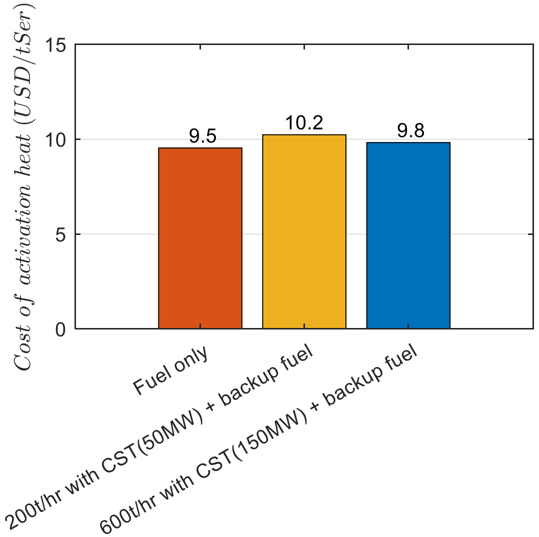


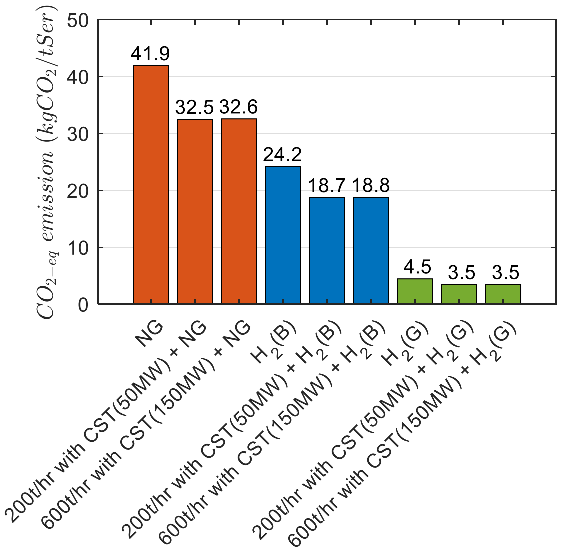
$CO_{2\text{-eq}}$ emissions (including fuel supply chain emissions): 2-42 $kgCO_{2\text{-eq}}$/ton

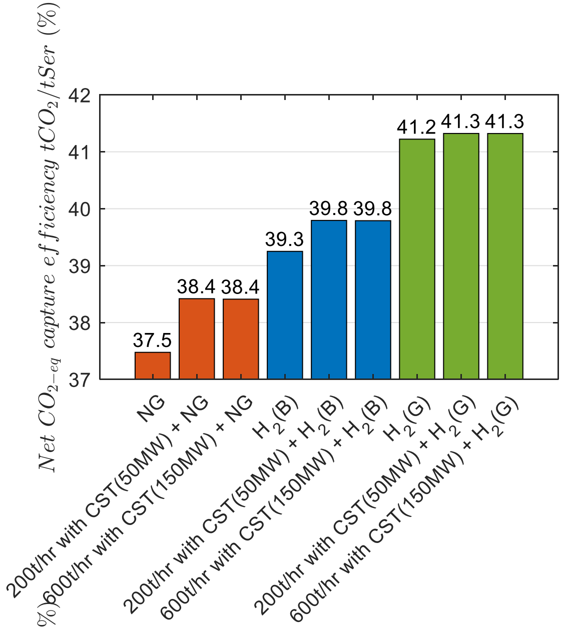
- **Hydrogen-based options from green routes (H_2 and CST-H_2) →** lowest emissions
- **Emissions from CST-hybrid with NG** similar to that of 100% H_2 produced from SMR+CCUS

Scale effects (fuel @ 15 USD/GJ, 200 and 600 ton/hr)

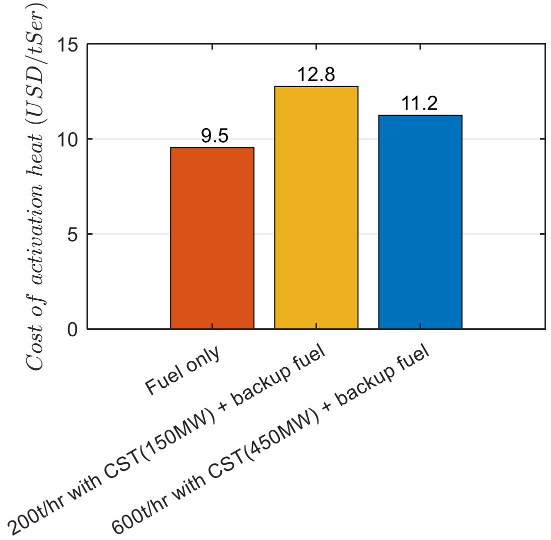
Solar multiple = 1.42

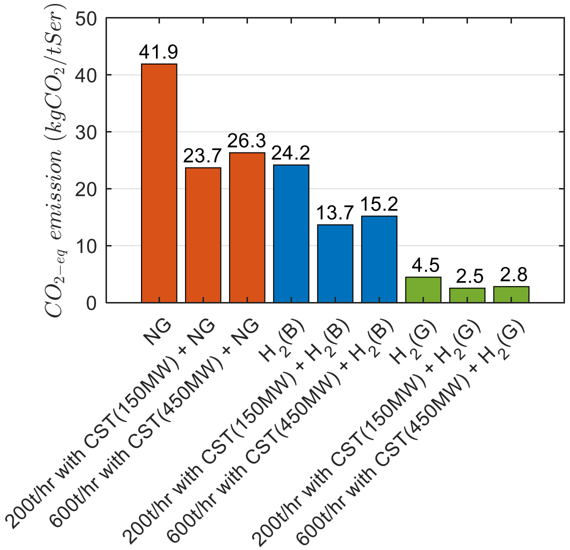


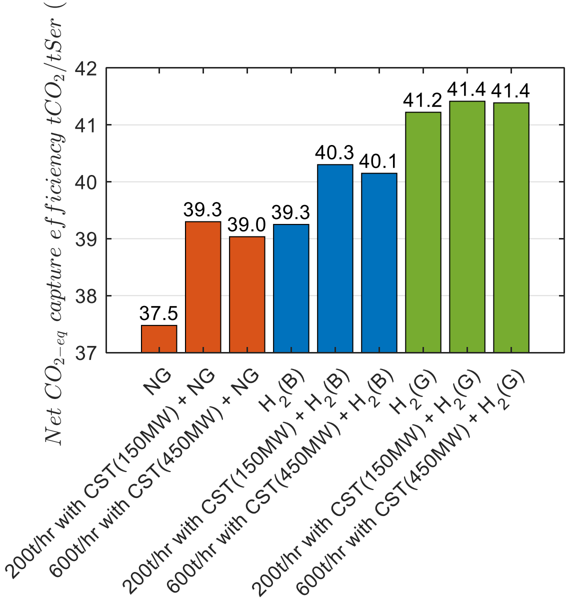




Solar multiple = 4.25



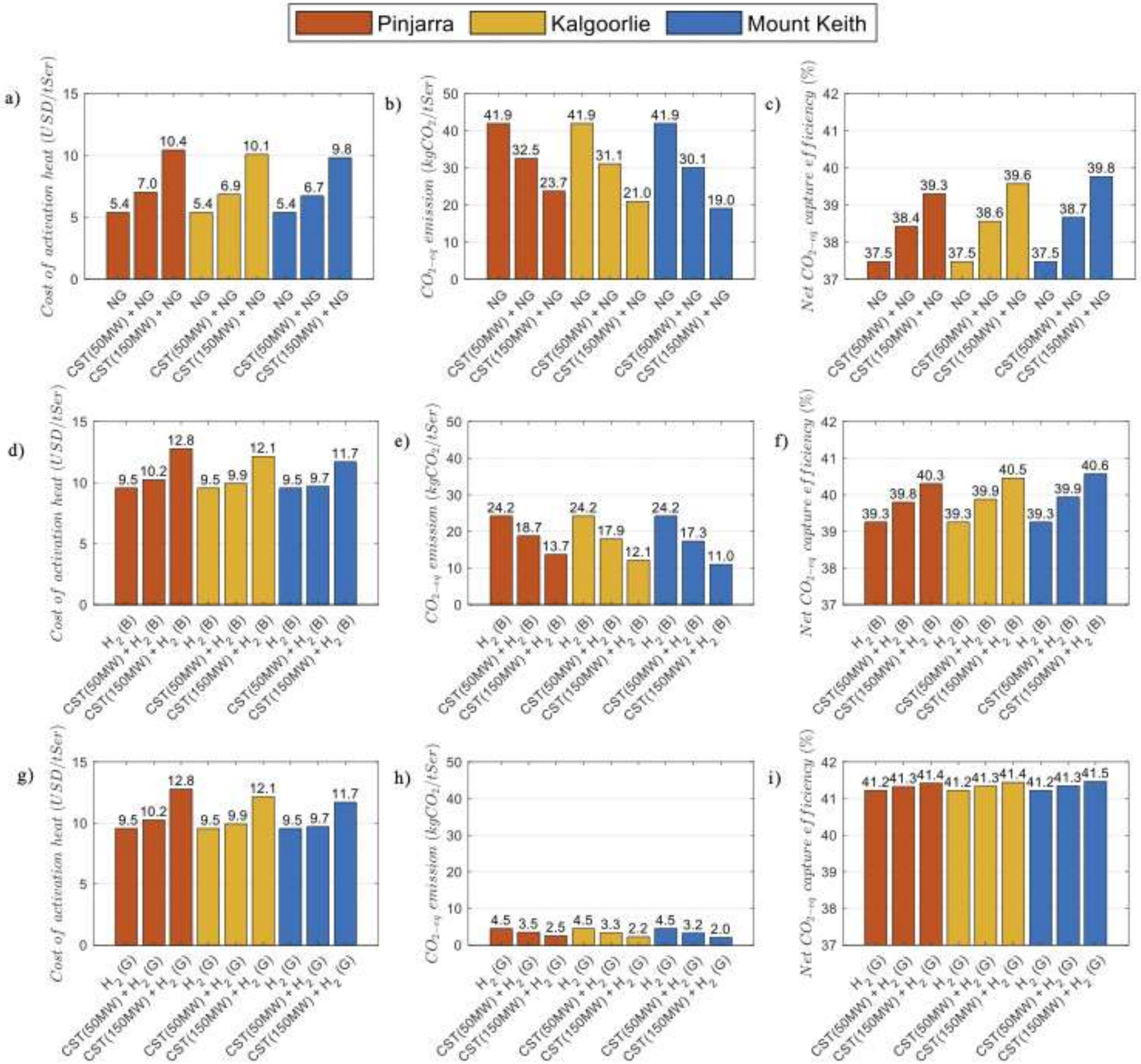




Larger scale:

- Slightly lower LCOH
- On pair with fuel-only case but with higher solar share

Location effects

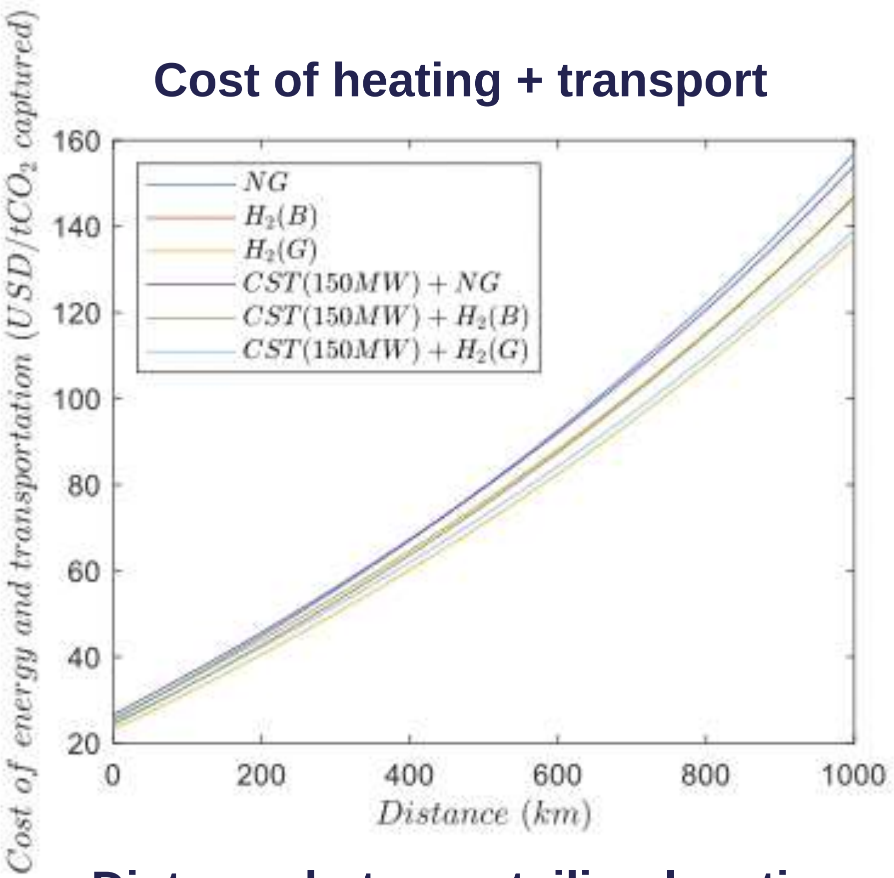


DNI Mt Keith > DNI Kalgoorlie > DNI Kwinana

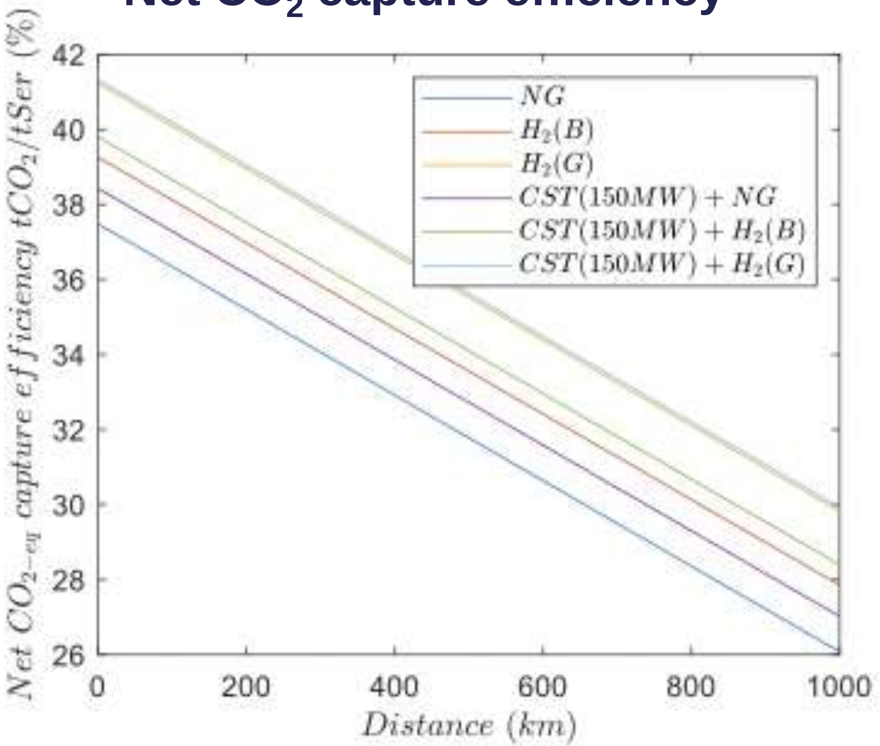
CST Scale (MW)	Location	Pinjarra/ Kwinana	Kalgoorlie	Mount Keith
	DNI (kWh/m2 year)	**2275**	**2615**	**2856**
50	LCOH (USD/GJ)	19.9	17.3	15.8
	Solar share (%)	22.5	25.9	28.3
150	LCOH (USD/GJ)	26.7	23.2	21.2
	Solar share (%)	43.5	50.0	54.6
450	LCOH (USD/GJ)	63.4	55.2	50.5
	Solar share (%)	59	67.9	74.1

Impact of transport on cost and net capture efficiency

Cost of heating + transport



Net CO_2 capture efficiency



- Transport by truck (diesel)

Distance between tailing location and thermal activation plant:

- By far the main variable influencing both cost and net CO_2 capture efficiency
- Net CO_2 capture efficiency reduces by about half for a 1000 km distance

Conclusions

The key outcomes from this study are as follows:

- **A potential, attractive business case for CST:** use of CST as major source of heat avoids reduction in the net CO_2 sequestration efficiency of some 10% in comparison with fuel-only cases (due to avoidance of CO_2 emissions associated with fuel supply chain). By selecting an appropriate ratio between scales of the CST system and the thermal activation plant, the overall cost of heating for a CST-hybrid plant is similar to that of fuel-only cases, but with lower CO_2-equivalent emissions
- **Role of CST in a thermally assisted CCUS process**: the solar route can provide the heat required to sustain activation of serpentine tailings for CO_2 mineral carbonation processes. An indirect (with the solar heat collector system being different from the thermal activation device), hybrid (CST with back-up burner and thermal storage) approach was identified as a potential, preferred route to achieve 24/7 continuos heat supply while retaining fine tuning of activation temperature process
- **Distance between tailings and thermal activation plant**: by far the main variable impacting on the feasibility and viability of the process, both from a technical and economic perspective

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