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SOLAR THERMAL ENERGY
RESEARCH GROUP



Concentrating solar technology for the generation of high temperature process heat for industrial applications in South Africa: A pre-feasibility study in sustainable hydrogen production

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Agenda

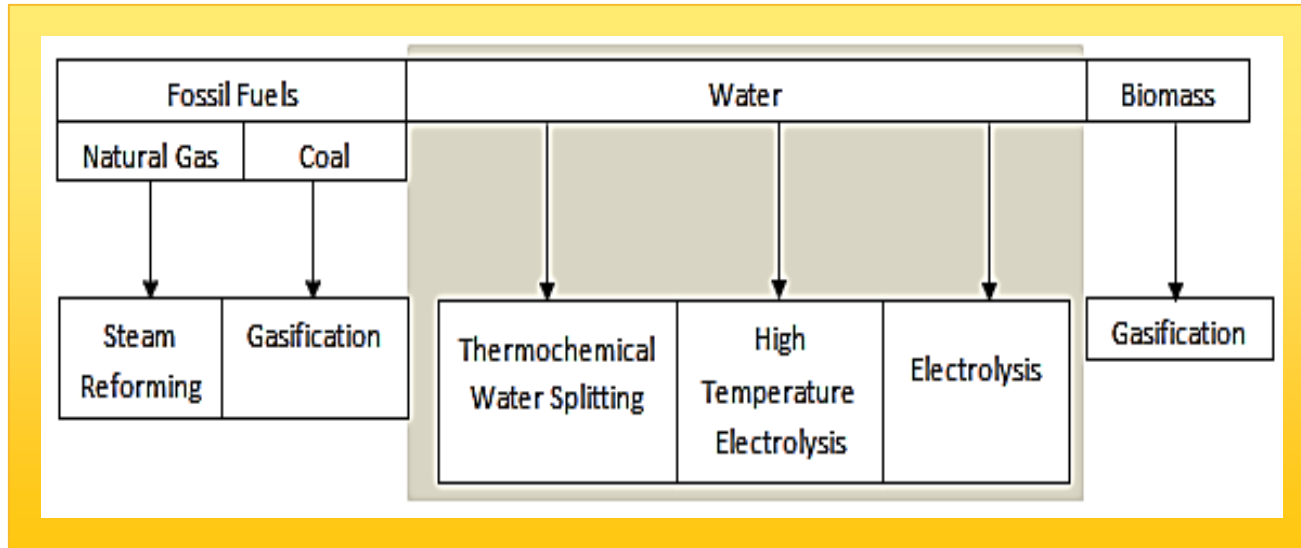


- **Background and motivation**
 - Sustainable hydrogen production methods
- **CST integration with Cu-Cl hydrogen production process**
 - Heat process requirement
 - Electric process requirement
- **Simulation methods and results**
 - literature
 - current study
- **Conclusion**
 - Feasibility
 - Future work

Background and motivation



Highlighted methods for sustainable production of hydrogen.

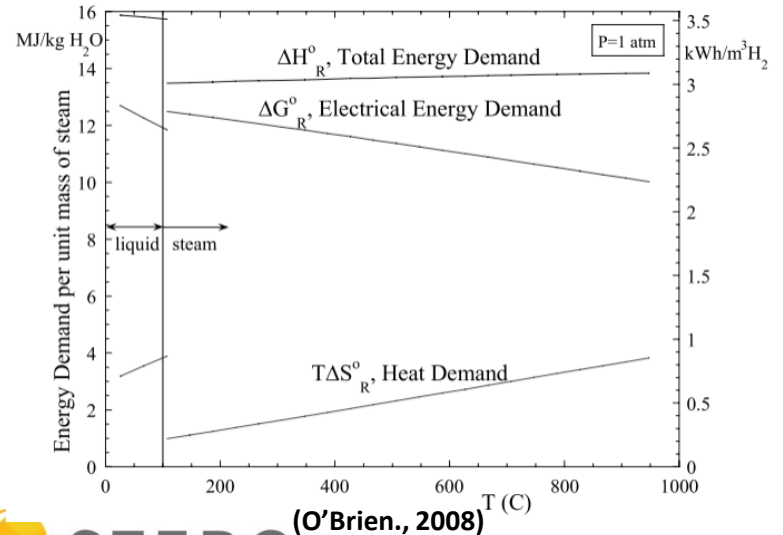
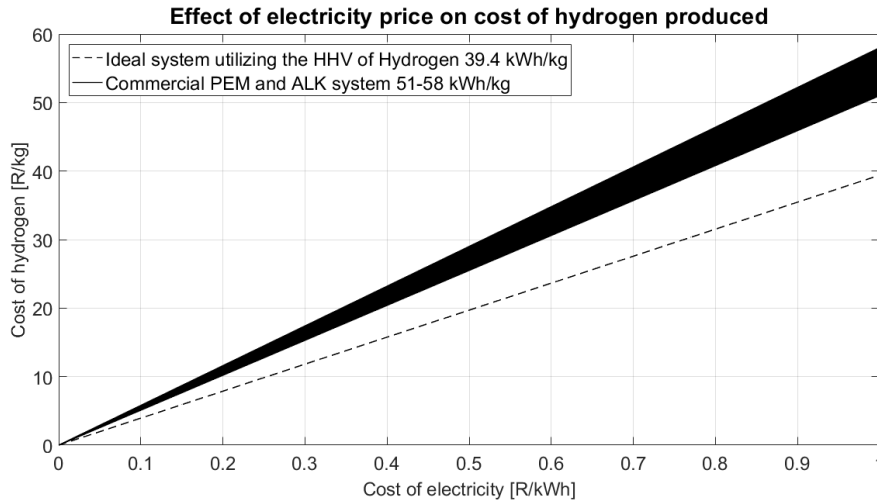
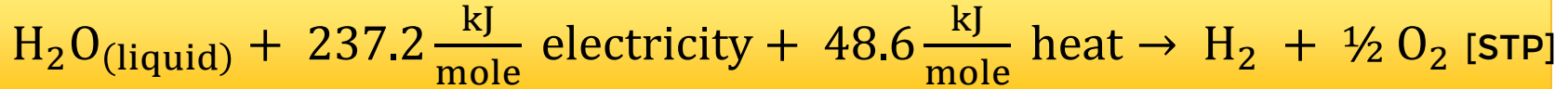


[adapted from Holladay et al., (2009)]

Background and motivation



Limit to cost reduction achievable by electricity price influence
 - leads to need for the introduction of heat



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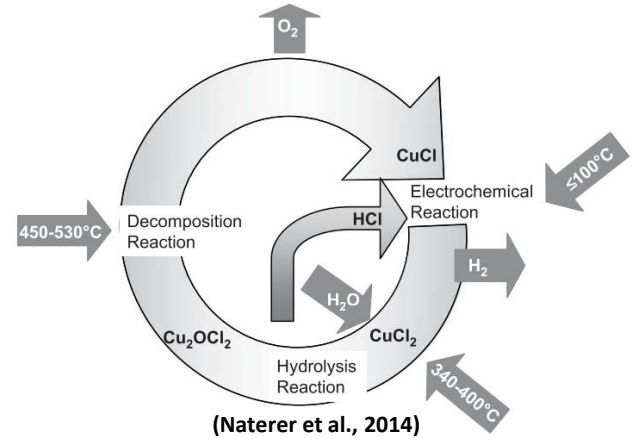
CSP integration with Cu-Cl hydrogen production process

Processes which consider the addition of heat

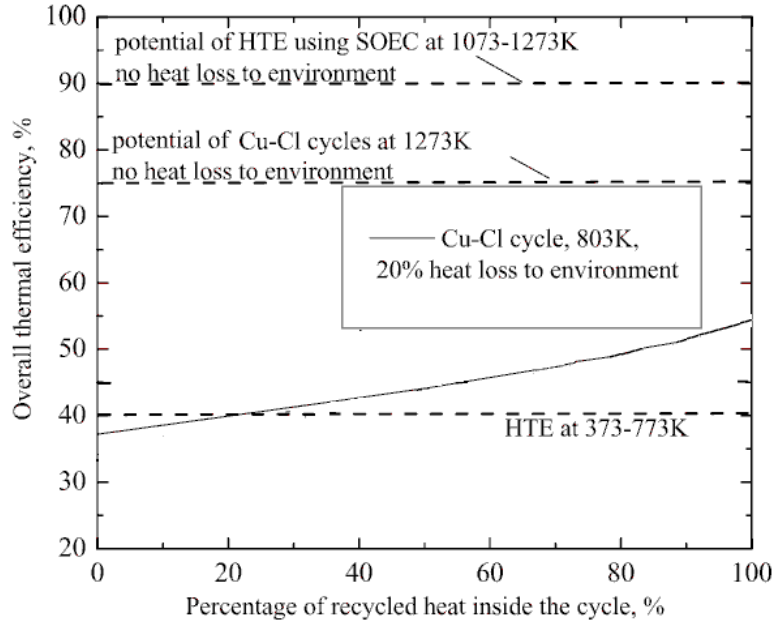
<i>High temperature steam electrolysis</i> SOEC 800 – 1 000°C	<i>Intermediate Temperature Steam Electrolysis (ITSE)</i> 600-650°C	<i>Thermochemical water splitting</i> 450-530°C
<ul style="list-style-type: none"> - Research phase - Material instability - Electrode degradation at elevated temperature - Acidic environment for plant material at elevated temperature - at 1000°C, the electric energy consumption required unfavourably represents 61% of the total energy demand 	<ul style="list-style-type: none"> - Aims to eliminate the degradation associated high temperature electrolysis - Corrosive environment for electrodes and cell material - stack lifetime, performance under thermal loads and suitability to centralized large-scale generation require further investigation - Under varying loads, risk the production of impure hydrogen 	<ul style="list-style-type: none"> - within the heat quality range of current concentrating solar thermal technology - each step and reaction completion demonstrated on laboratory scale - electrolysis occurs at low temperature and pressure, favourable for material stability - Reduced electric requirement

CSP integration with Cu-Cl hyd production process

Heat and electric requirements



20% of the energy flow is electric (step 1)



Step	Temperature Range [°C]	Energy input [kJ/mol H ₂]
1. Electrolysis	~100	52.3
2. Separation/drying	<100	122.2
3. Hydrolysis	350-400	227.9
4. Thermal decomposition	450-530	149.4

Comparison of thermal efficiency of HTE, Cu-Cl cycle adapted from (Wang et al., 2010)

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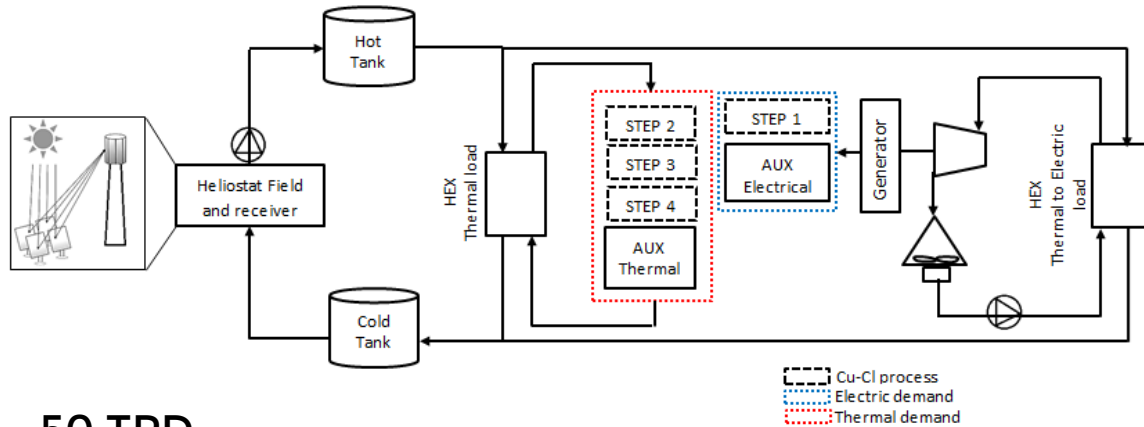
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Simulation methods and results



NREL's SolarPILOT 1.2.1 and MATLAB were used to simulate each hour of a TMY year in Upington, South Africa [8760 points]

MODEL 1: CST plant - thermal and electric load



50 TPD
Steady-state conditions
Reaction completion

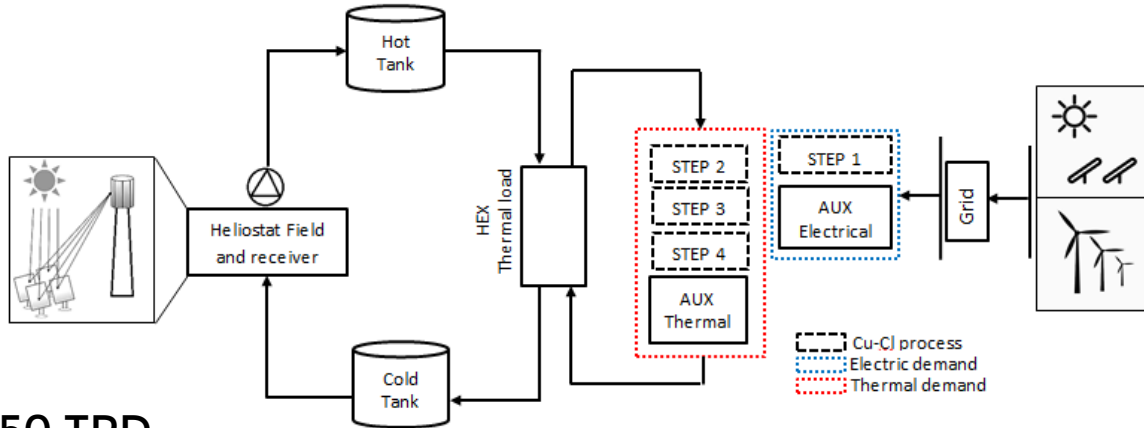
Parameter	unit	value
Plant size	MW_t	293
Capacity factor solar thermal plant (TES = 0h)	%	40.03
Capacity factor solar thermal plant (TES = 14h)	%	83.33
Plant production load factor (TES = 0h)	%	34.46
Plant production load factor (TES = 14h)	%	80.27
Hydrogen Production	tons	14 650
Feedwater consumed	tons	131 850
Total plant thermal energy	GWh	2 154.43

Simulation methods and results



NREL's SolarPILOT 1.2.1 and MATLAB were used to simulate each hour of a TMY year in Upington, South Africa [8760 points]

MODEL 2: CST plant - thermal load & Grid - electric load



Parameter	unit	value
Plant size	MWt	183
	MWe	29
Capacity factor solar thermal plant (TES = 0h)	%	33.97
Capacity factor solar thermal plant (TES = 14h)	%	74.93
Plant production load factor (TES = 0h)	%	38.94
Plant production load factor (TES = 14h)	%	74.93
Hydrogen Production	tons	13 675
Feedwater consumed	tons	123 075
Total plant thermal energy	GWh	1 254 .78

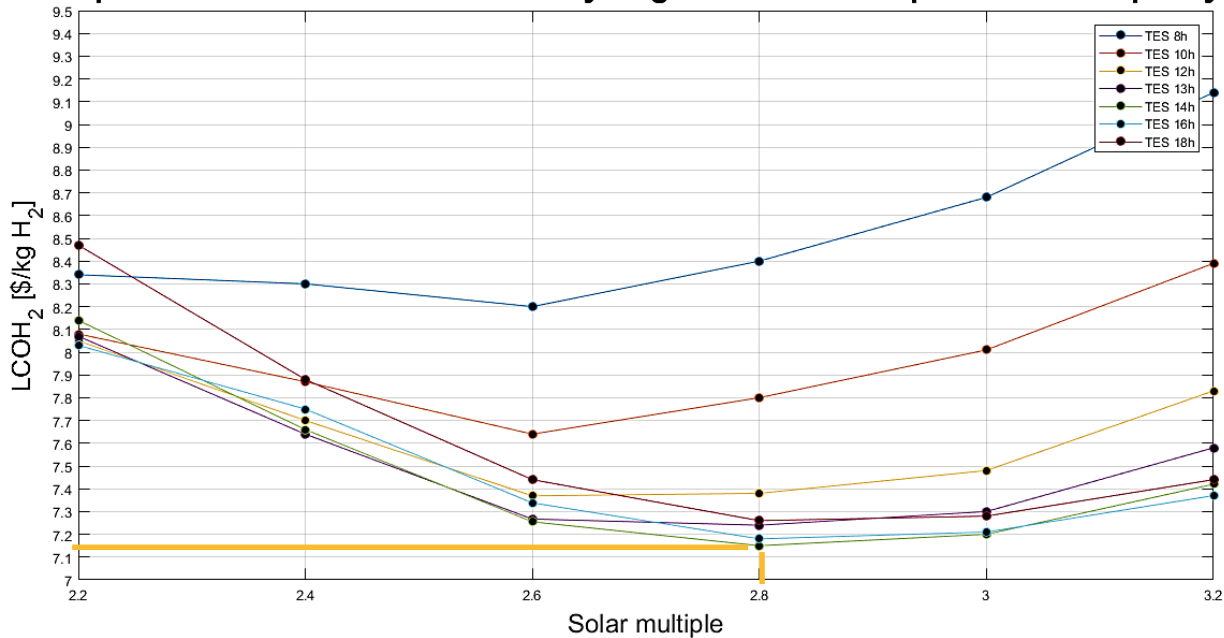


Simulation methods and results



Levelized cost of hydrogen

Optimization of levelized cost of hydrogen to solar multiple and TES capacity



Model 1: \$7.15/kg

Model 2: \$7.32/kg

Cycle efficiency: 22.7%

$$\eta = \frac{LHV_{H_2}}{Q + \frac{1}{n}E}$$

Where

LHV_{H₂} is 242 kJ/mol

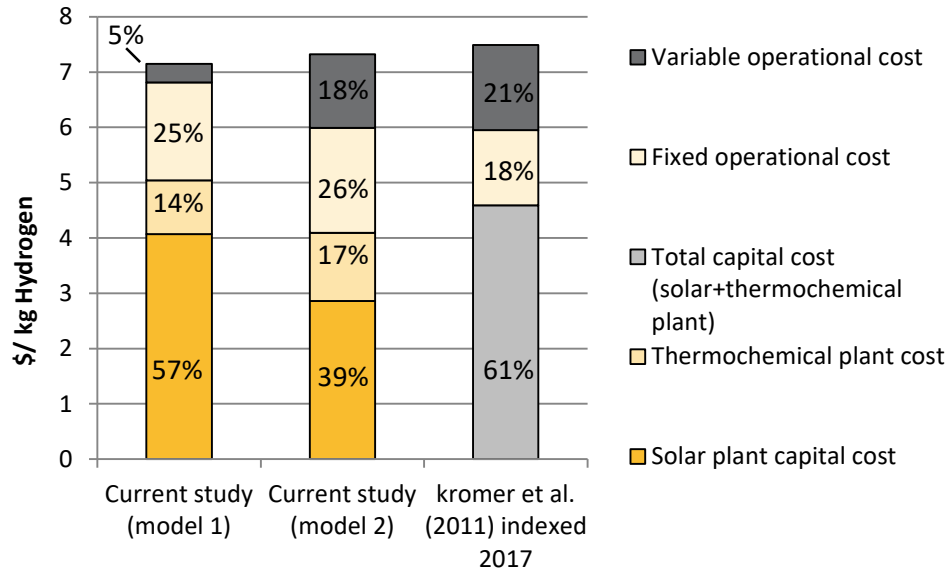
Q is the **thermal energy supplied** to the process by external sources per mol of hydrogen produced

E is the **electrical energy supplied** to the process by external sources per mol of hydrogen produced

Simulation methods and results



Levelized cost of hydrogen



Model 1: \$7.15/kg

Model 2: \$7.32/kg

\$ Indexed to 2017

10% discount rate (H2A assumption)

Similar to that found in literature study utilizing H2A assumptions

Above target price of \$2/kg

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Conclusions



Feasibility and future work

- In comparison to SMR (9 kg CO₂ per 1 kg of H₂) plant omits 131 850 metric tons of CO₂ for 14 650 metric tons of Hydrogen annually (50 TPD)
- An Oxygen resale price of \$1.91/kg is required to reach the target hydrogen price. Market price found currently \$0.1/kg¹
- Levelized cost of hydrogen most sensitive to *discount rate*, *capital cost* and *solar resource*.
- Future work should consider a detail CST model linked to a hydrogen production process model to broaden understanding of effects of electric and thermal supply variability and heat recovery within the process to improve cycle efficiency
- ¹ www.intratec.us/chemical-markets/oxygen-price

Thank you for your time and attention

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