STERG

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

S Moodley[1], Dr. JE Hoffmann[1]

[1]Solar Thermal Energy Research Group (STERG), University of Stellenbosch

STERG SOLAR THERMAL ENERGY RESEARCH GROUP

UNIVERSITEIT iYUNIVESITHI STELLENBOSCH UNIVERSITY 100 1918·2018

6th Annual STERG Symposium
STELLENBOSCH, SOUTH AFRICA
18 - 19 JULY 2019

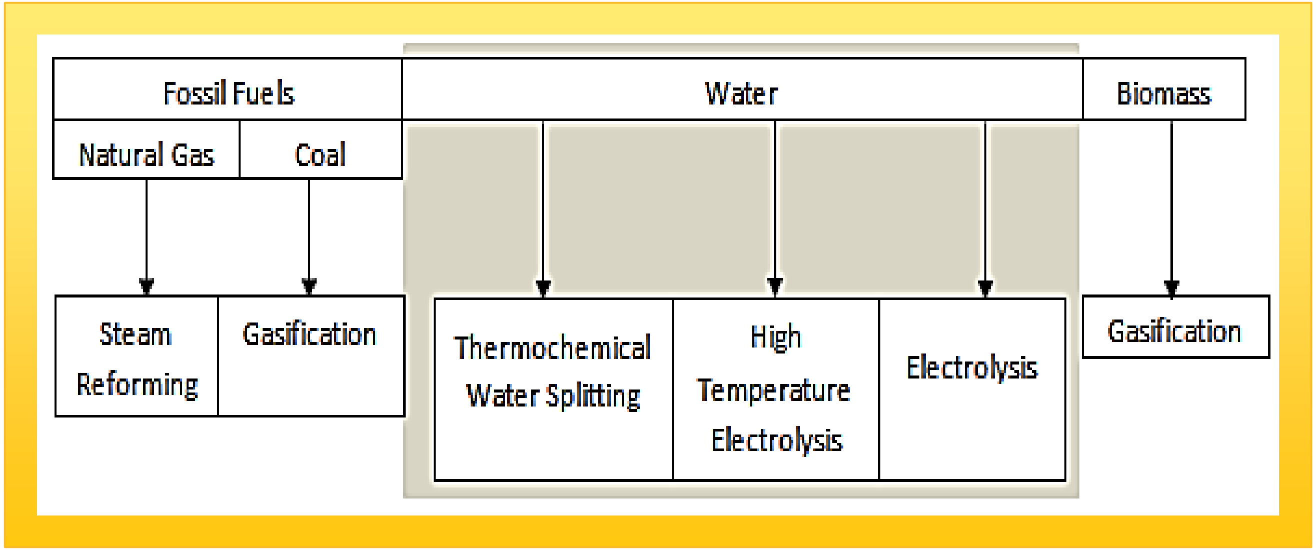
STERG SOLAR THERMAL ENERGY RESEARCH GROUP

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.

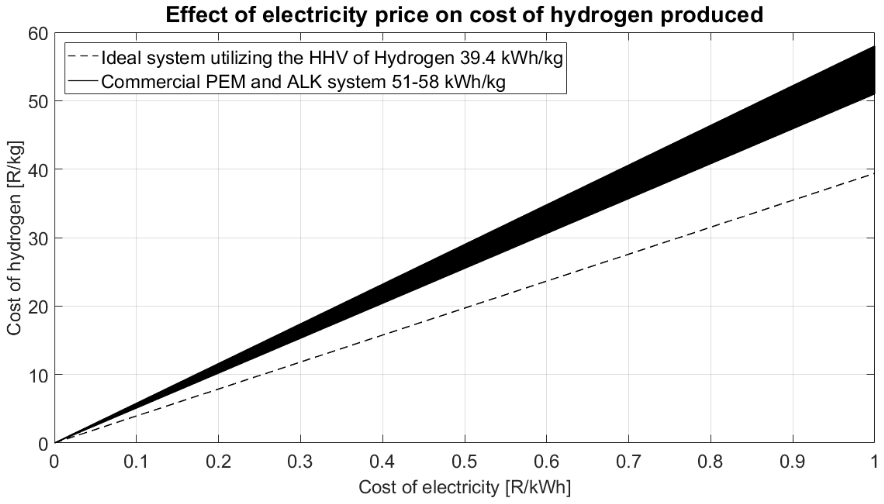


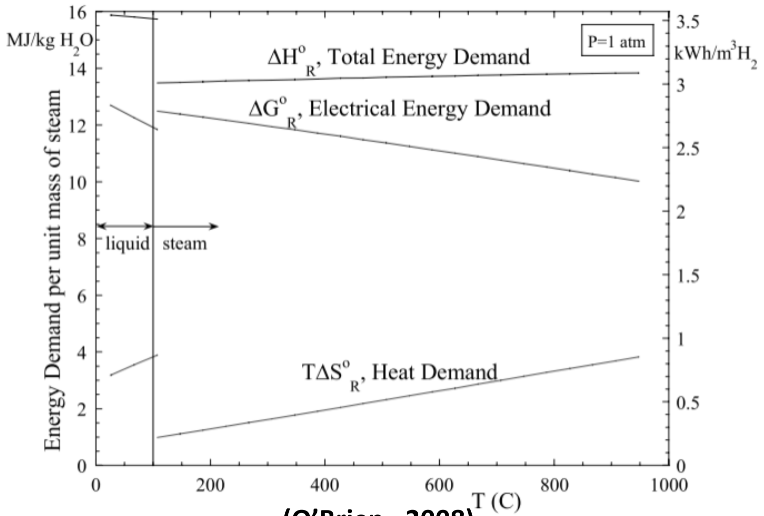
[adapted from Holladay et al., (2009)]

Background and motivation

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

$$H_2O_{(liquid)} + 237.2\frac{kJ}{mole}\text{ electricity} + 48.6\frac{kJ}{mole}\text{ heat} \rightarrow H_2 + ½\,O_2\ \text{[STP]}$$





(O'Brien., 2008)

Agenda

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

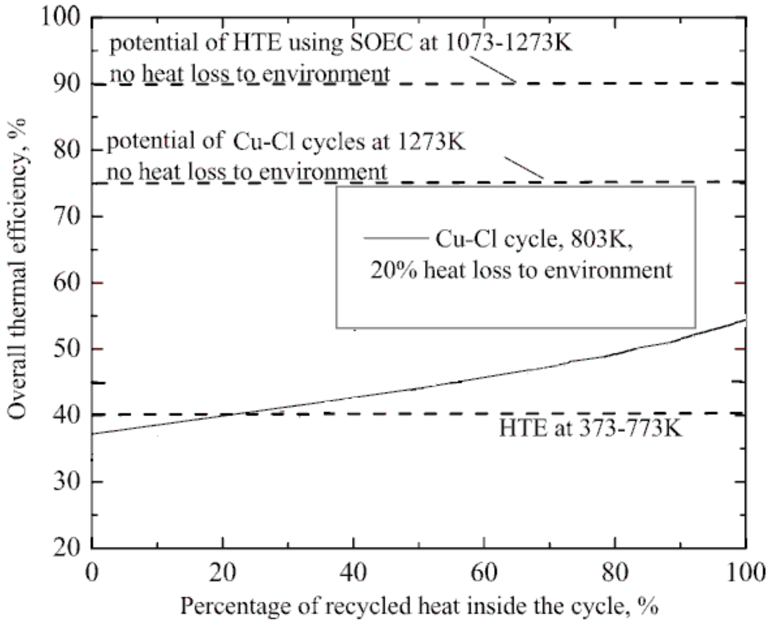
CSP integration with Cu-Cl hydrogen production process

Processes which consider the addition of heat

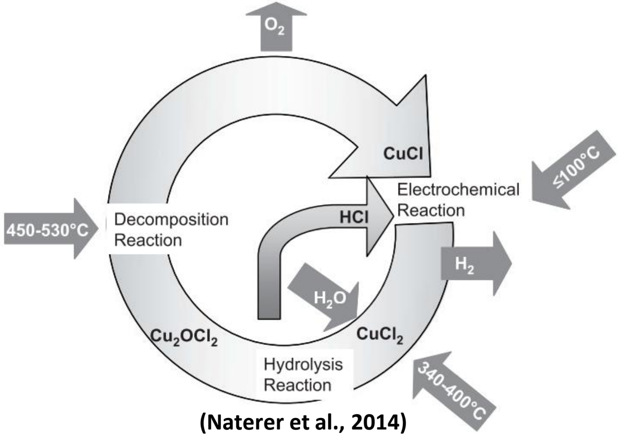
High temperature steam electrolysis SOEC 800 – 1 000°C	*Intermediate Temperature Steam Electrolysis (ITSE) 600-650°C*	*Thermochemical water splitting 450-530°C*
- Research phase - Material instability - Electrode degradation at elevated temperature - Acidic environment for plant material at elevated temperature - at 1000°C, the electric energy consumption required unfavourably represents 61% of the total energy demand	- 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	- 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



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



(Naterer et al., 2014)

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

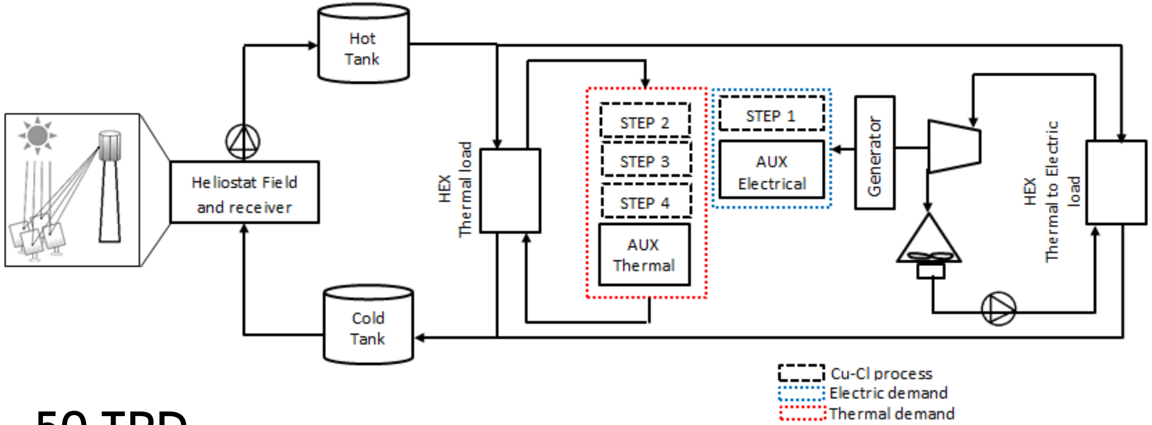
Agenda

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

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



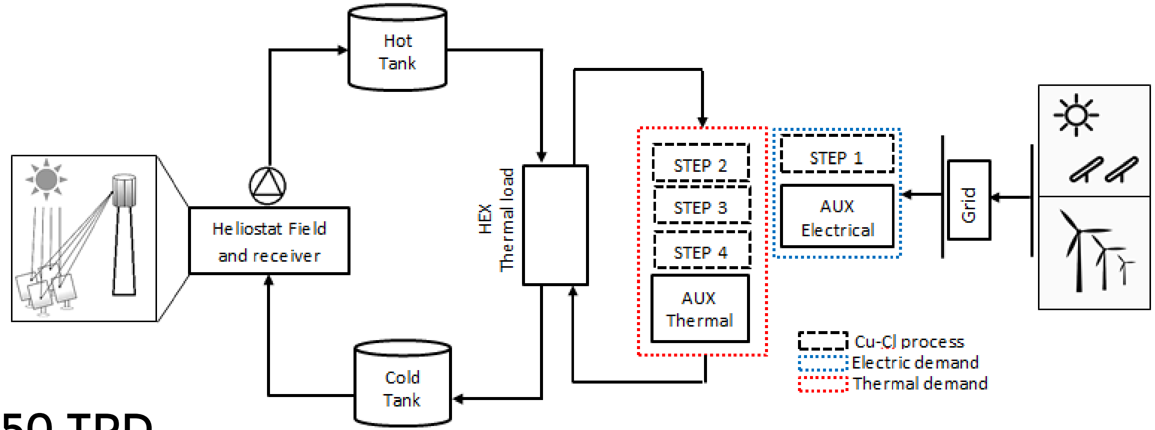
50 TPD
Steady-state conditions
Reaction completion

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

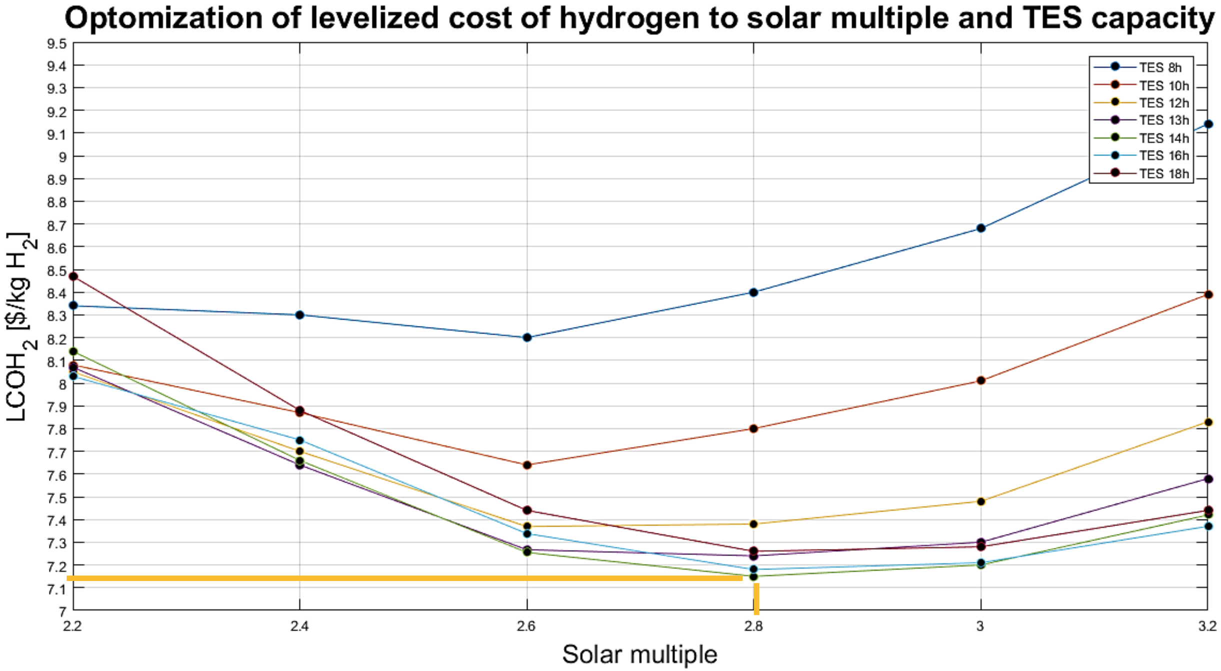


50 TPD
Steady-state conditions
Reaction completion

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



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

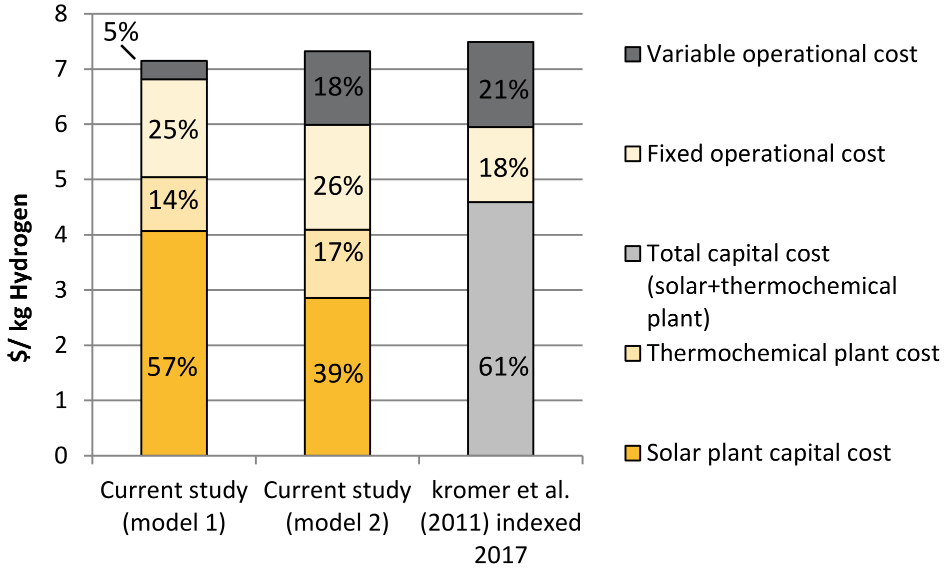
LHV_{H2} is 242 kJ/mol

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

Agenda

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

Conclusions

Feasibility and future work

- In comparison to SMR (9 kg CO_2 per 1 kg of H_2) plant omits 131 850 metric tons of CO_2 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/kg[1]

- 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

ACKNOWLEDGEMENTS:

The CRSES for the generous funding of my masters degree

The solar thermal energy research group

& my supervisor Dr. Hoffmann

CONTACT DETAILS:

Seranya Moodley
Solar Thermal Energy Research Group (STERG)
Stellenbosch University
South Africa

22106235@sun.ac.za

visit us: concentrating.sun.ac.za