Towards liquid hydrocarbon fuels via solar thermochemical redox cycles

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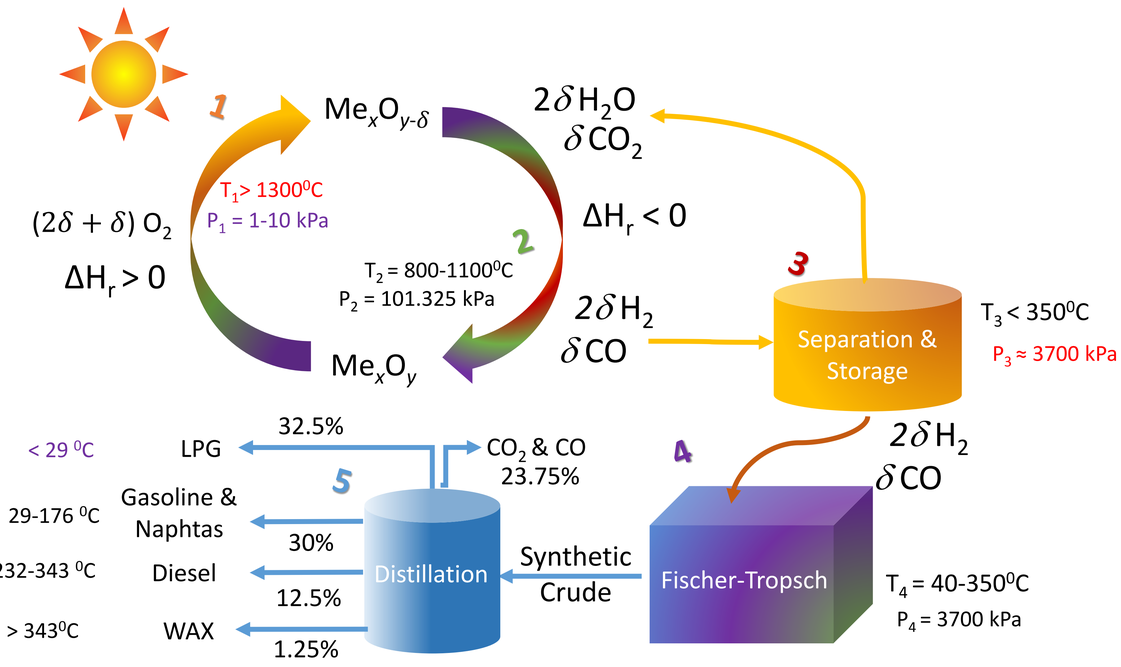
Introduction

Overall process



1 – Thermal reduction of metal oxide (driven by solar energy) → $Me_xO_{y-\delta}$ and O_2

2 – H_2O & CO_2 splitting → Me_xO_y + H_2 & CO

3 – Syngas Separation & Storage → H_2 & CO extraction & pressurization to feed FTR

4 – Fischer-Tropsch reactor → catalytic reaction to produce synthetic crude

5 – Fractional Distillation → to separate the fuels

Techno-economical challenges

Materials

Find novel materials with fast kinetics and high production to increase the solar to chemical efficiency.

Reactors/Receiver

Proven at 100kW for water splitting (HYDROSOL).

Needs of efficiency heat recovery & reduction of thermal losses (conduction & re-radiation losses).

Novel designs are required (reactors & integration):

- Monolithic & fixed bed → low thermal conductivity → low efficiency
- Rotating → higher thermal conductivity & heat recovery but low thermal-shock resistance
- Fluidized bed → low thermal conductivity & need for large inert gas flow
- Particle + vacuum → yet to be build or demonstrated

Economic assessment

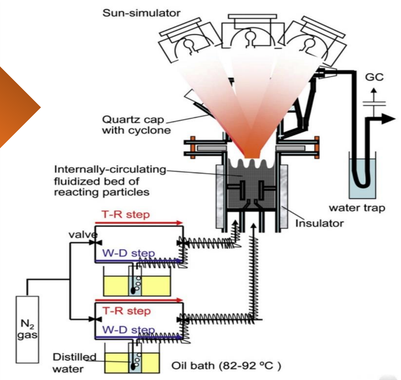
Address simulation with solar availability and integration with fuel synthesis process.

Production of DME unexplored.

First studies → 20% solar to thermal efficiency → **USD 1.21/L gasoline**

→ Methanol production → **USD 0.8/kg** ($1.12/L gasoline)

Cycles Based on MFe_2O_4



TR: MFe_2O_4 → 2FeO•MO + ½ O_2 (> 1400°C)

WS: $^2/_3$ 2FeO•MO + $^2/_3$ H_2O → $^2/_3$ MFe_2O_4 + $^2/_3$ H_2 (< 1000°C)

CDS: $^1/_3$ 2FeO•MO + $^1/_3$ CO_2 → $^1/_3$ MFe_2O_4 + $^1/_3$ CO (< 1000°C)

High H_2 production

Hercynite cycle (Co and Al) → robust

Ni and Co High sintering → deactivation

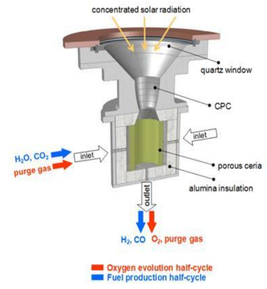
Slow kinetics

Cycle Based on Ceria

TR: CeO_2 → $CeO_{2-\delta}$ + $^\delta/_2$ O_2 (>1500°C)

WS: $^2/_3$ $CeO_{2-\delta}$ + $^{2\delta}/_3$ H_2O → $^2/_3$ CeO_2 + $^{2\delta}/_3$$H_2$ (< 1100°C)

CDS: $^1/_3$ $CeO_{2-\delta}$ + $^\delta/_3$ CO_2 → $^1/_3$ CeO_2 + $^\delta/_3$CO (< 1100°C)



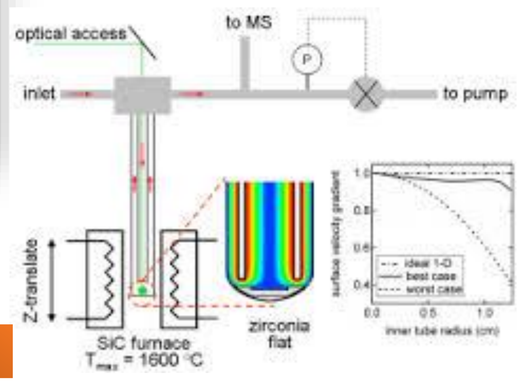
Fast kinetics

High resistance to sintering

Low H_2 and CO production

Low thermal efficiency

Much inert material → energy losses & need of HR



Cycles Based on Perovskites

TR: ABO_3 → $ABO_{3-\delta}$ + $^\delta/_2$ O_2 (≈ 1350°C)

WS: $^2/_3$ $ABO_{3-\delta}$ + $^{2\delta}/_3$ H_2O → $^2/_3$ ABO_3 + $^{2\delta}/_3$$H_2$ (< 1100°C)

CDS: $^1/_3$ $ABO_{3-\delta}$ + $^\delta/_3$ CO_2 → $^1/_3$ ABO_3 + $^\delta/_3$CO (< 1100°C)

Fastest kinetics

High resistance to sintering

Unexplored

Low H_2 and CO production

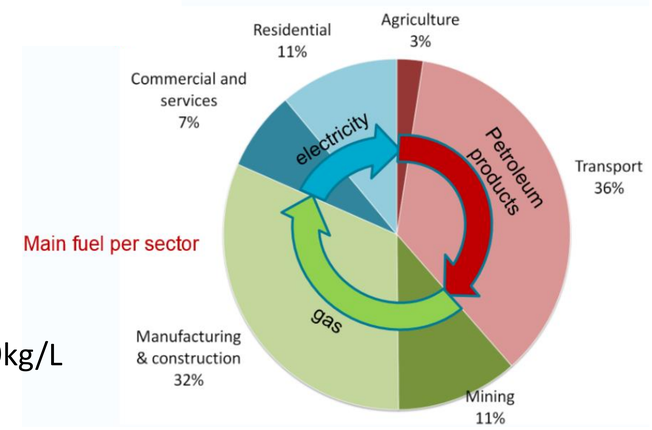
Much inert material → energy losses & need of HR

Solar fuels opportunities in Australia

LSD = AUD 1.4/L (TGP Singapore)

- 90% liquid fuels produced externally
- 36% demand in transport sector (LPG, Diesel & Gasoline)
- 12% demand NG in manufacturing and construction

CO_2 emissions must be less than 19kg/L (diesel) WTT



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References

Kim et al. *Energy Environ. Sci.*, 5, (2012) p8417-8429
Chueh et al. *Science*, 330, (2010) p1797–1801
Gokon et al. *Int J Hydrogen Energy*, 36, (2011) 4757-4767
McDaniel et al. *Energy Environ Sci.*, 6 (2013) 2424
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