Using Solar Thermal for Chemical Processing

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Savings Opportunity for Petrochemicals, Nearly half from ethylene production
Ethane Cracking

- Overall reaction: $\text{C}_2\text{H}_6 \leftrightarrow \text{C}_2\text{H}_4 + \text{H}_2$

- Typical reaction occurs at 800-900°C
- Relatively low pressure
- Typically in presence of $\sim 3:1$ steam molar ratio
- Non-catalytic

- Platform chemical
Energy Consumption in Ethylene Production

47% of energy consumed is direct thermal energy = potential solar opportunity

Miniature Reactor

Top metal plate

Sapphire window

Alumina insulation

Bottom metal body

Alumina inner tube
Miniature Reactor
Apparatus

[Diagram showing a process flow with labels such as Argon Reference, Mass Flow Controllers, 3% Ethane in Balance N₂, Liquids H₂O, Boiler, Superheater, Preheaters, 130°C, 160°C, 170°C, Truncated Ellipsoidal Reflector, 6kW Xenon Arc Lamp, Quartz Window, Solar Reactor, Flowmeter, Condenser, RGA, GC Sample Port, Temperature Controlled Heat Tape.]
Solar simulator setup
Temperatures both at the top and bottom of the reactive cavity vs. gas flowrate under different lamp power levels. The upward-pointing triangle and the downward-pointing triangle represent the temperatures measured by the top and bottom thermocouples respectively.
Performance Metrics

- **Conversion**
  \[ X_{C_2H_6} = \frac{\dot{n}_{C_2H_6,in} - \dot{n}_{C_2H_6,out}}{\dot{n}_{C_2H_6,in}} \times 100 \]

- **Selectivity**
  \[ S_{C_2H_4} = \frac{\dot{n}_{C_2H_4,out}}{\dot{n}_{C_2H_6,in} - \dot{n}_{C_2H_6,out}} \times 100 \]

- **Yield**
  \[ Y_{C_2H_4} = \frac{\dot{n}_{C_2H_4,out}}{\dot{n}_{C_2H_6,in}} \times 100 \]

- **Thermal Efficiency**
  \[ \eta = \frac{\dot{n}_{C_2H_4,out} \cdot \Delta H_r(T)}{\text{incident heat flux}} \times 100 \]
Effect of Temperature

Temperature study at a pseudo-constant residence time of 0.25 sec and a steam-to-ethane ratio of 3.3:1
Effect of Mean Residence Time

Different flow rates of gas were tested at 50% lamp power (800-880°C) with no steam in the feed.
Carbon balance for ethane cracking at different lamp powers for a constant steam to ethane ratio of 3.3:1 and mean residence time of 0.25 seconds.
Summary

• Dilute (3% or less) ethane was successfully converted to ethylene and hydrogen using simulated sunlight and a miniaturized reactor.

• Efficiency can likely be enhanced by not diluting feed gas, though coking will likely be observed.

• Yields exceeded 50%.

• Potential to replace fossil energy with solar energy
Future Work

• Higher concentration of ethane in feed
• Explore heat recuperation
• Other feed constituents and inclusion of catalysts
Nature, April 2016


*A quad is a unit of energy equal to $10^{15}$ British Thermal Units (1 BTU is about 0.0003 kilowatt-hours).
Acknowledgements

• PTT Public Company Limited (Thailand) for their generous support

• Process and Reaction Engineering research group at Oregon State University
  – Prof. Goran Jovanovic
  – Prof. Alex Yokochi
  – Prof. Líney Árnadóttir
  – Fuqiong Lei
  – Yige Wang
  – Lucas Freibergh
  – Adam Shareghi
Total Eclipse
August 21st, 2017 Corvallis, Oregon

Photo credit Logan Howell