PCI

Precision Combustion

Topic 18F – Clean Coal and Carbon Management

Solar Energy Powered Materials-Based Conversion of CO_2 to Fuels

DE-SC0015855

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INTRODUCTION

Solar Energy Powered Materials-Based Conversion of CO2 to Fuels

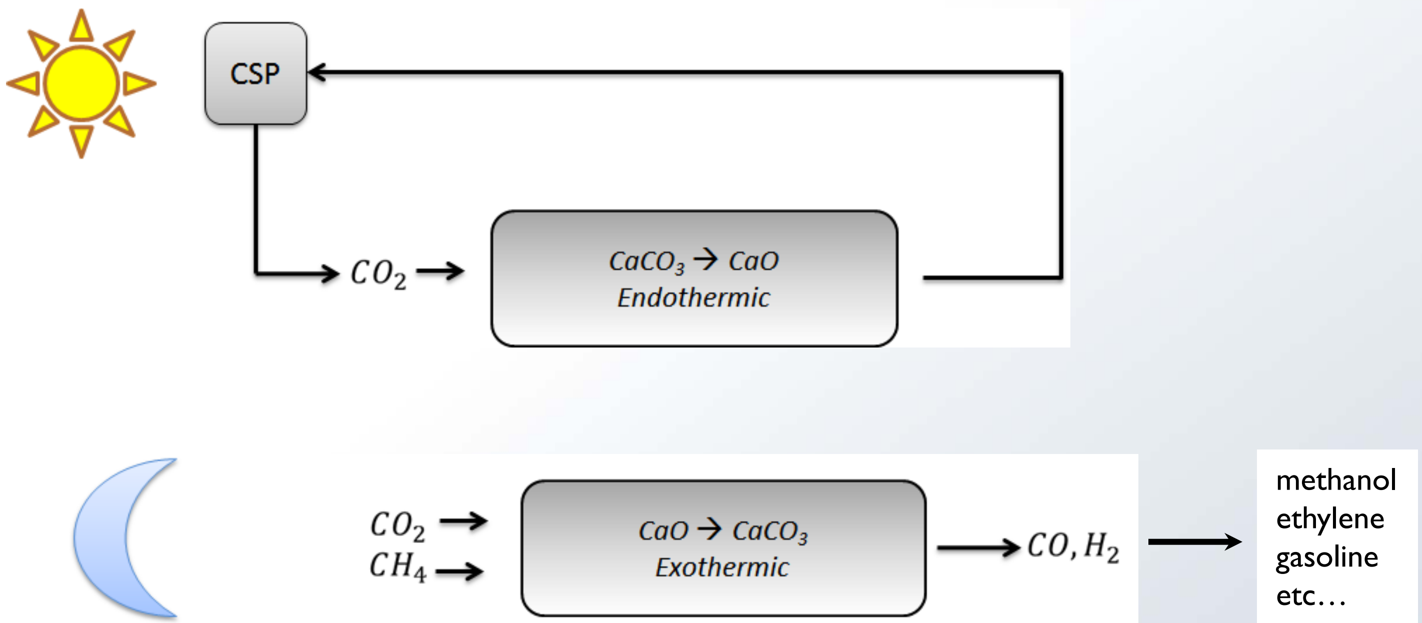
- Convert thermal energy to chemical energy
  - High grade thermal energy (750 – 900 °C)
    - from Concentrated Solar Power
  - Reactants
    - CO_2
    - CH_4

- Requirements
  - Ready sources of CO_2, natural gas, sunshine
    - CA, NM, TX – yes   CT, PA, WV – not as likely

- Potential advantages of PCI approach
  - Compact, scalable, process intensification → improved efficiencies

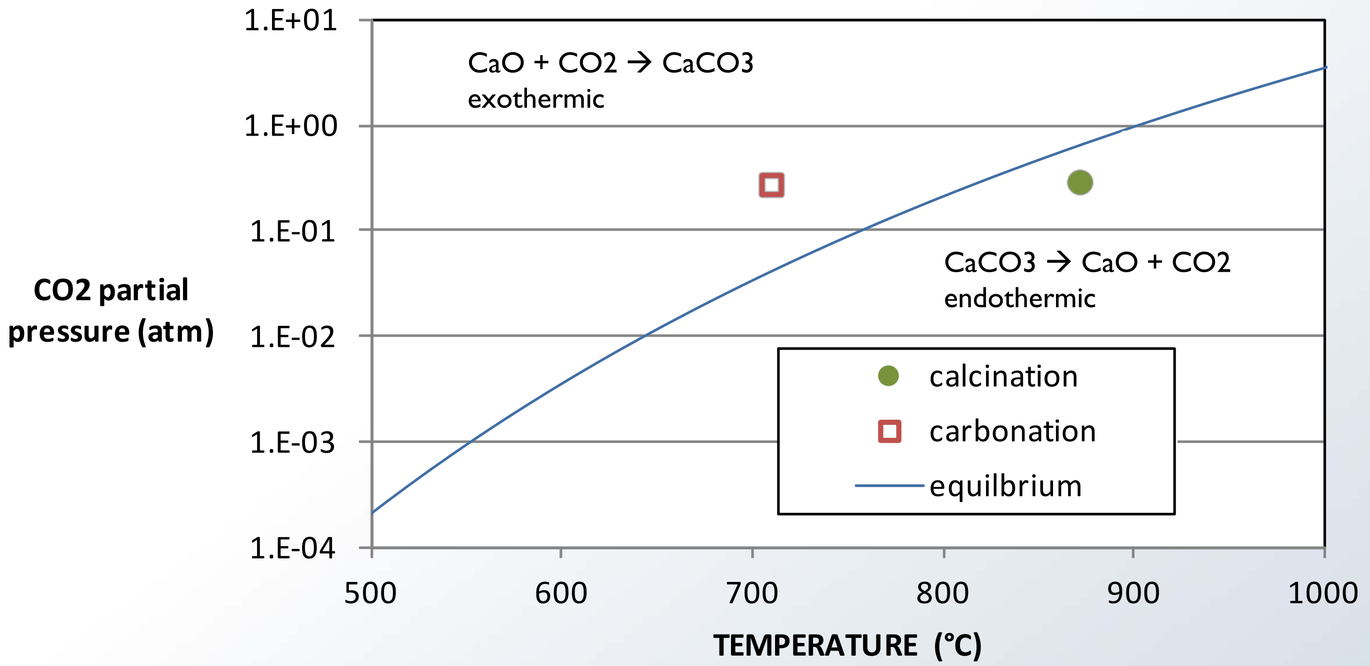
Process Overview - System

- Solar power driven conversion of CO_2 and CH_4 to fuels/chemicals via syngas intermediate
- Key aspects – energy storage/release and CO_2 conversion
- Concentrated solar power (CSP) – NREL technology
- $CaCO_3$ based energy storage – well known process
- CO_2 / CH_4 'dry reforming' well known
- CO/H_2 upgrading – various processes available



Process Overview – Energy Storage and Release

- $CaCO_3$ ⇔ $CaO + CO_2$ equilibrium based energy storage
- CO_2 is used as:
  - Heat transfer fluid
  - Drives thermal energy storage reaction cycle
  - Reactant with CH_4

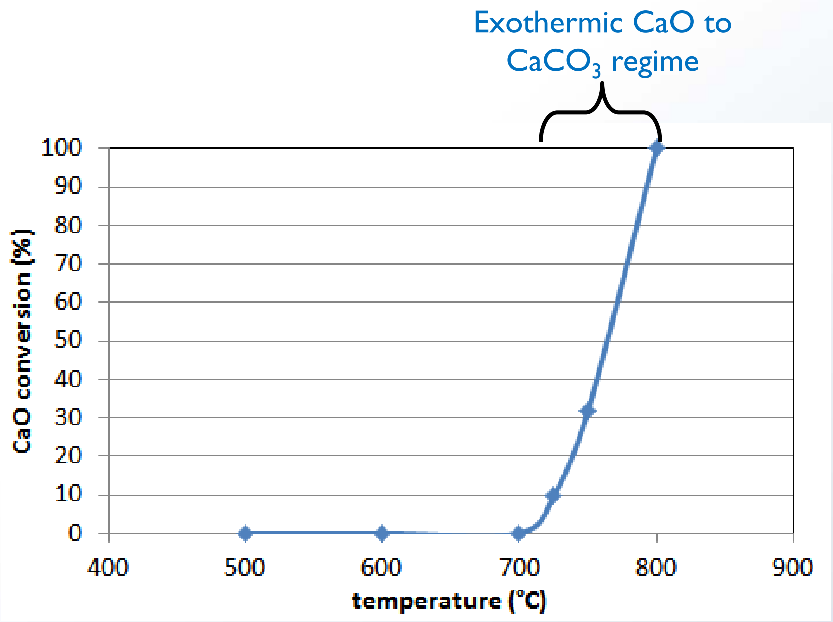


Process Overview - Chemistry

- Optimum performance of synthesis step 725-750 °C
  - Based on Gibb-free energy minimization to calculate equilibrium

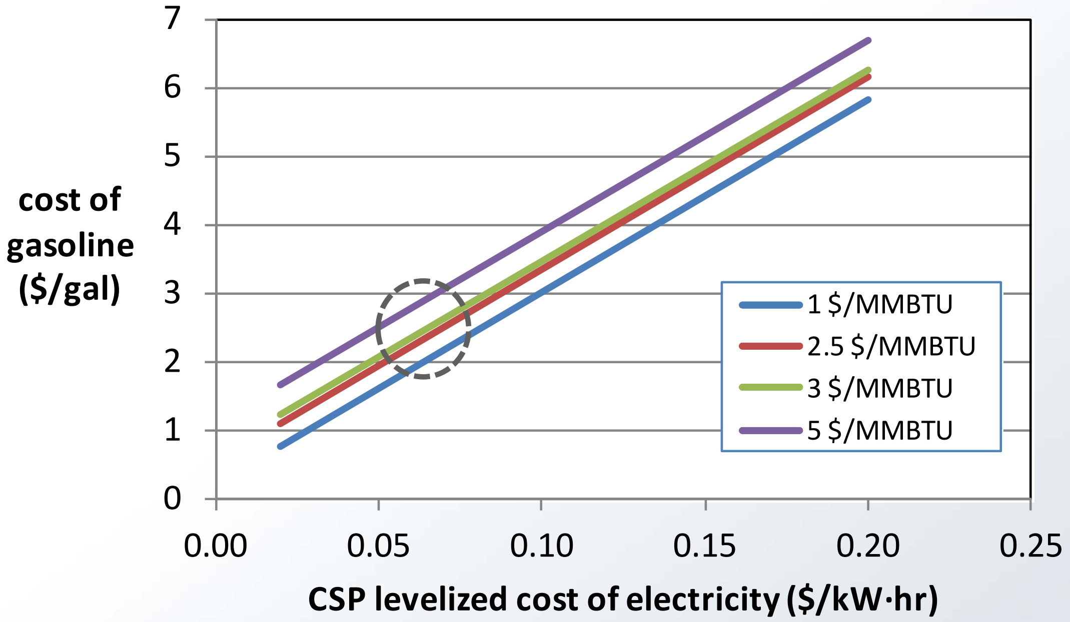
energy charging – endothermic calcination of $CaCO_3$ to CaO
CO_2 acts as heat transfer fluid to carry CSP energy to reactor

energy release – exothermic heat release of reaction with CaO and CO_2
used to drive the endothermic reaction of CO_2 and CH_4 to CO and H_2



Process Overview - Economics

- Assuming overall process efficiency of 75 % (guestimate)
- 90% conversion of syngas to gasoline (based on MOG/MTG information)
- CSP levelized cost accounts for all cost factors
    - currently at 0.13 $/kW-hr, DOE target is 0.06
- Need to factor in off-setting costs of CO_2 sequestration



Task Plan

- Task 1 – Qualify reactor with baseline materials
- Task 2 – Develop materials formulation and characterize
- Task 3 – Place materials onto support for testing
- Task 4 – Test materials for CO_2 cycling and CO_2/CH_4 reforming reactions
- Task 5 – Reactor test data analysis
- Task 6 – Process model and economic analysis
- Task 7 – Reporting

Task 1 – Qualify reactor with baseline materials

- Existing tubular reactor(s), ~1” OD
  - Three zone or one zone
  - Wide range of MFC’s
  - Automated LabVIEW control
  - Micro GC on-line gas analysis

- Test Plan
  - Currently running baseline materials
  - Determine best space velocity, T, CO_2/CH_4 ratio for syngas conversion

- Outcome
  - Verify test stand performance, mass balance, and analytical capabilities
  - Pick set of standard operating conditions for performance and kinetics measurements

Task 2 – Develop materials formulation and characterize

- Prepare base materials as a powder
- Make use of existing small scale prep equipment
- Materials characterization
  - Particle size, surface area, pore volume, metal surface area
  - EDS/SEM
  - In-situ high temperature controlled atm. XRD
  - TEM if needed

- Outcome
  - Preliminary understanding of relationship between materials composition, materials properties and structure, and performance
  - Limited by number of samples in Phase I

Task 3 – Place materials onto support

- Apply base materials onto support
- Product tested for
  - Quality
  - EDS/SEM for chemical uniformity

- Outcome – quality sufficient for use in Task 4

Task 4 – Test materials for CO_2 cycling and CO_2/CH_4 reforming reactions

- Employ Separate Test Rigs

- CO_2/CH_4 reforming – use rig of Task 1
  - Initial operating conditions determined in Task 1
  - Measure kinetics as functions of SV, T, composition, CO_2/CH_4 ratio

- CO_2 cycling
  - Use existing test rig employed for materials development
  - ~20 g, calcine high temperature, carbonation at lower temperature
    - Measure mass change after each ½ cycle initially
    - Target – 50 cycles with less than 1% degradation
    - parallel to XRD measurements

- Outcome
  - Determine usefulness of materials for CO_2 reforming
  - Determine use of materials does not impact $CaCO_3$-CaO cycling performance

Task 5 – Reactor test data analysis

- Analysis of reaction products – mass balance
- Determine kinetics

- Outcome
  - Collect sufficient data to permit sizing of reactors for Task 6
    - Consider both energy storage and CO_2 conversion reactions

- Additional work if time allows
  - Sensitivity to potential CO_2 contaminants
    - We routinely test with H_2S, others?
  - Sensitivity to or need for air, water, etc…
  - Measure CO_2 sorption/desorption kinetics

Task 6 – Process model and economic analysis

- Data from Task 5 for preliminary reactor sizing and cycle time estimation
  - Relationship between flow rate, reactor sizes, conversion and product composition and cycle time, etc…
- Integration with CSP system
- Process modeling for unit operation mass and energy balances – ASPEN or similar
- Compare/contrast w/CO_2 sequestration and conversion schemes

- Outcome
  - Preliminary economic analysis on costs associated with a combined system
  - Demonstrate advantages of CSP to fuels/chemicals approach

Phase 1 Tasks and Schedule, as proposed

	Month								
Task	1	2	3	4	5	6	7	8	9
1 - Modify test stand, baseline testing									
2 - Synthesis and characterization									
3 – Add to support			M1						
4 - Testing – CO_2 cycling and syngas gen						M2		M3	
5 - Data analysis									
6 - Preliminary economic analysis									
7 - Reporting									

Milestones:

1. Demonstrate applying materials on support
2. Demonstrate suitable CO_2-CH_4 conversion activity
3. Demonstrate stability of materials