Development of a 50kW Fuel Processor for Stationary Fuel Cell Applications Using Revolutionary Materials for Absorption-Enhanced Natural Gas Reforming

Program Manager: Jim Stevens

Contractor: ChevronTexaco Technology Ventures, LLC

Subcontractor: Cabot Superior MicroPowders

Project Duration: October 2003 - September 2006

DOE 2004 Yearly Review Meeting

May 26, 2004

This presentation does not contain any proprietary or confidential information.

Project Overview/Objectives

ChevronTexaco

Assist DOE in Developing Distributed Hydrogen Production Technology with Significant Cost Advantages in:

- Reduced reformer + PEMFC system operating costs through improved fuel efficiency
- Reduced capital costs through reduced system complexity
- Reduced reformer + fuel cell system costs

First Six Months Objectives

•Samples of low temperature reforming and high temp shift catalysts, CO_2 fixing materials, integrated function materials

•Process Simulation

•Efficiency Analysis

•Capital Cost Estimates

•Reactor Tests

CTTV

Budget

	Total	DOE	Contractor
Project Total	$8,954,793	$5,551,972	$3,402,821
Year 1	$2,258,066	$1,400,001	$858,065
Year 2	$3,214,568	$1,993,032	$1,221,536
Year 3	$3,482,160	$2,158,939	$1,323,221

DOE Technical Barriers

- Hydrogen Production
  - A. Fuel Processor CAPEX
  - B. Operation and Maintenance
- Crosscutting Barriers
  - Catalysts
  - Hydrogen Separation and Purification
- Fuel Flexible Processors
  - I. Start-up time
  - J. Durability
  - K. Emissions
  - L. Hydrogen Purification
  - M. Efficiency
  - N. Cost

DOE Technical Targets

Characteristics		Units	Calendar Year 2005	2010
	Cost	$/Kg H2	1.98	0.82
Reforming	Efficiency	%(LHV)	72	75
	Cost	$/Kg H2	0.11	0.03
Purification	Efficiency	% (LHV)	82	90

Approach – Absorption Enhanced Reforming

Conversion of natural gas to hydrogen using a reformer that combines steam reforming, water gas shift, and purification processes into one reactor.

- Developing calcium based materials that are capable of fixing and releasing carbon oxides over thousands of cycles
- Building reactors and control systems that take advantage of process simplification
- Conducting process modeling and testing to demonstrate significant savings in OPEX and CAPEX of these systems

Project Safety

Qualitative Hazard Analysis (HAZOP) conducted for all new test systems according to AIChE guidelines.

- P&ID analysis
- Material Safety Data Sheets
- Equipment Specifications and Operating Procedures

Formal Management of Change Process

- Codes and Standards, EH&S, Process Engineering, Electrical, etc. reviews
- Management authorization/sign-off

Pre-Startup Reviews

Extensive Safety Training tied to annual bonus

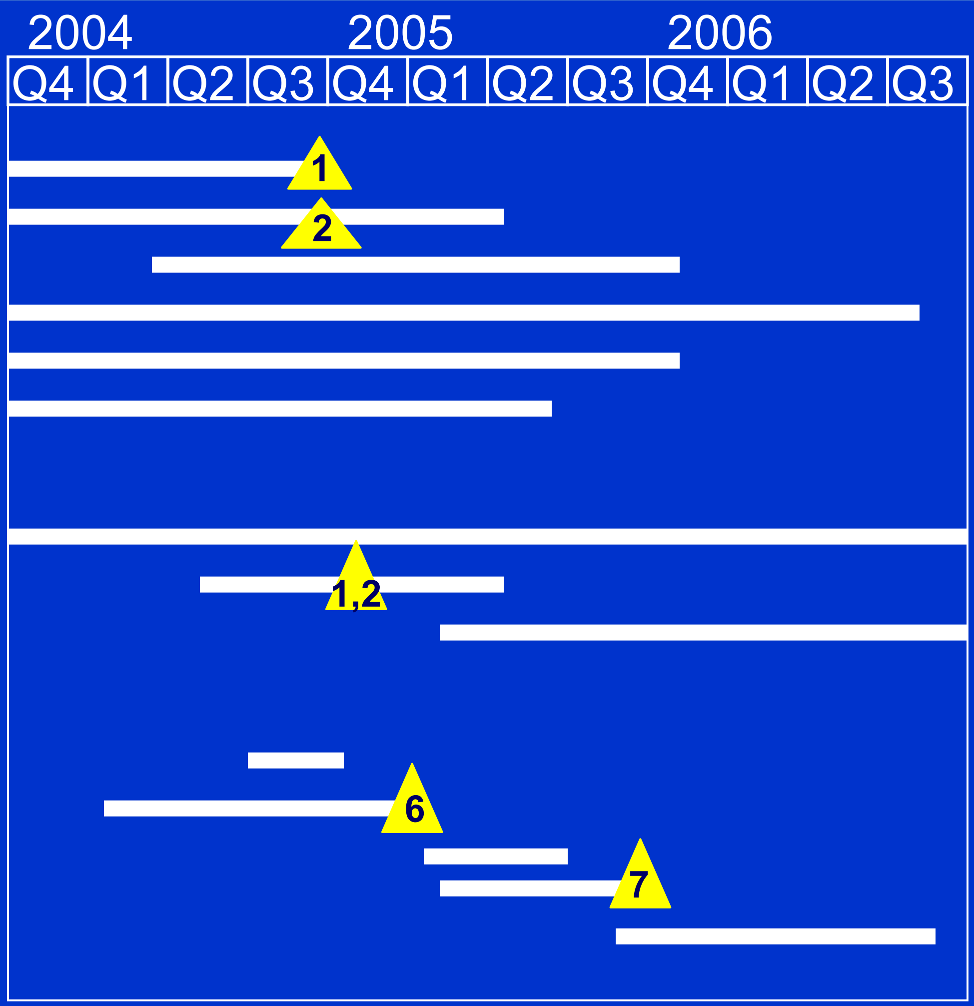
Inspection by peers, EH&S, and management

Program Timeline

1. Materials Synthesis
- 1.1 Reforming Catalysts
- 1.2 Sorption Materials
- 1.3 Pelletization
- 1.4 Integrated Materials
- 1.5 Improved Kinetics
- 1.6 WGS Integration

2. Catalyst Performance Testing
- 2.1 Screening of Materials
- 2.2 Short Term Cycle Test
- 2.3 Long Term Cycle Test

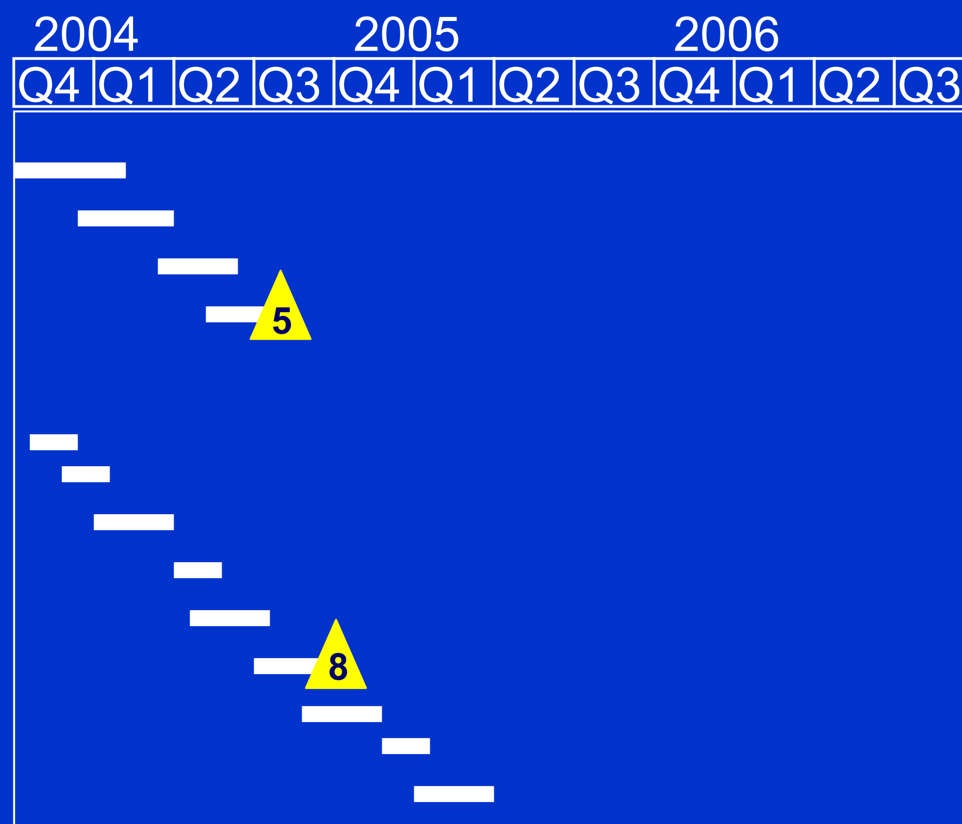
3. Powder Production Scale Up
- 3.1 Equipment Installation
- 3.2. Reactor Catalyst
- 3.3 Scale up Phase 1
- 3.4 Reformer Catalyst
- 3.5 Scale up Phase 2



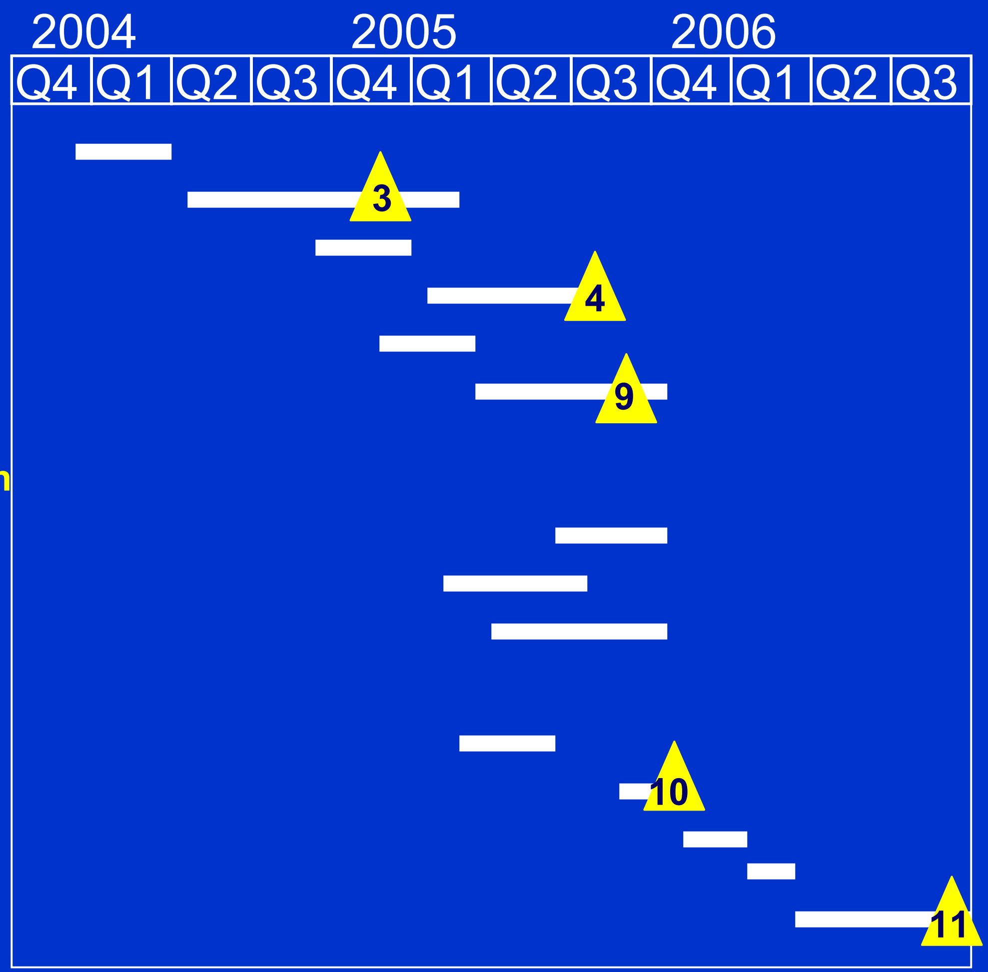
Program Timeline

4. Reformer Concept Testing
- 4.1 Process Simulation
- 4.2 Efficiency Analysis
- 4.3 Reformer Design Guide
- 4.4 Design and Cost Estimates

5. Reactor Design and Construction
- 5.1 First 1 kW Reactor Design
- 5.2 First 1 kW Reactor Fabrication
- 5.3 First 1 kW Installation
- 5.4 Second 1 kW Reactor Design
- 5.5 Second 1 kW Reactor Fab
- 5.6 Second 1 kW Reactor Inst
- 5.7 5 kW Reactor Design
- 5.8 5 kW Reactor Fabrication
- 5.9 5 kW Reactor Installation



Program Timeline



6. Reactor Testing
- 6.1 First Test Stand
- 6.2 First Reactor Tests
- 6.3 Second Test Stand
- 6.4 Second Reactor Tests
- 6.5 Third Test Stand
- 6.6 5 kW Reactor Tests

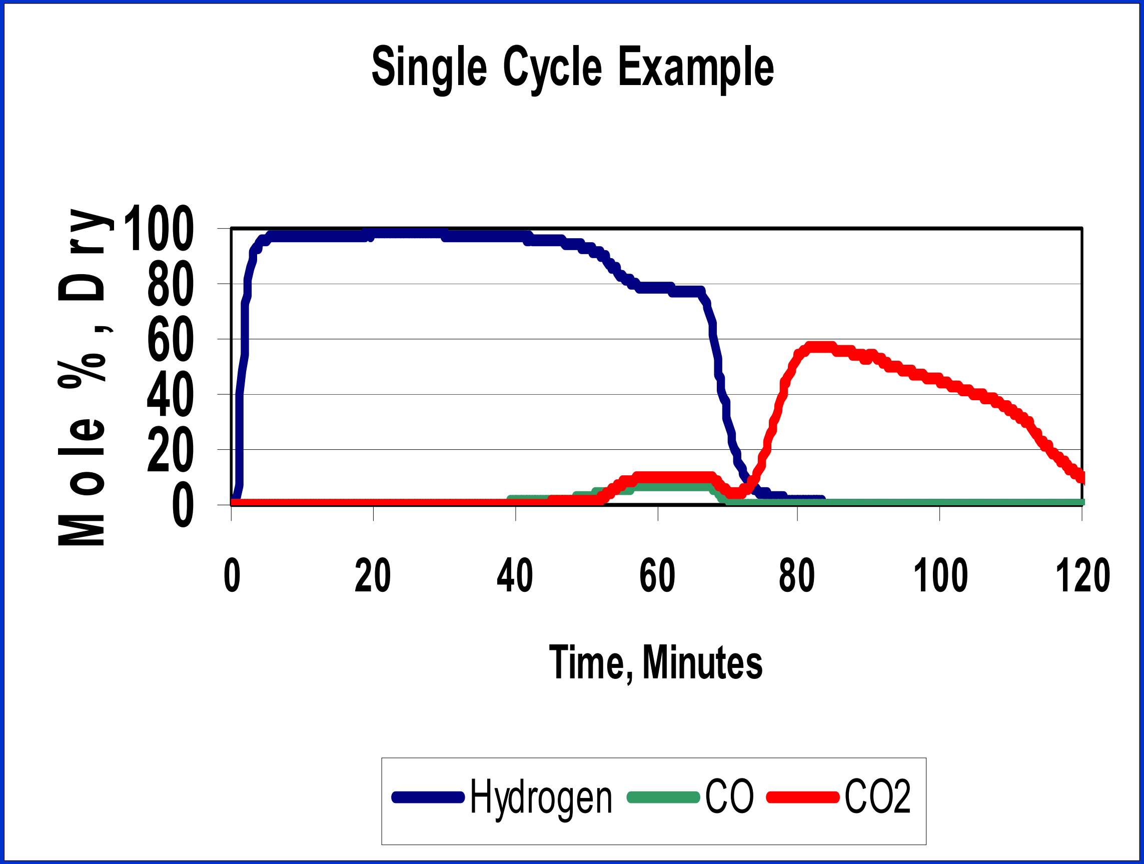
7. 50 kW Reformer Construction
- 7.1 Control Design/Coding
- 7.2 Hardware Purchase
- 7.3 Fabrication

8. 50kw Reformer Test
- 8.1 Site Safety Review
- 8.2 Reformer Installation
- 8.3 Start-up/Shut Down
- 8.4 Transient Testing
- 8.5 Durability Tests

Milestone Schedule

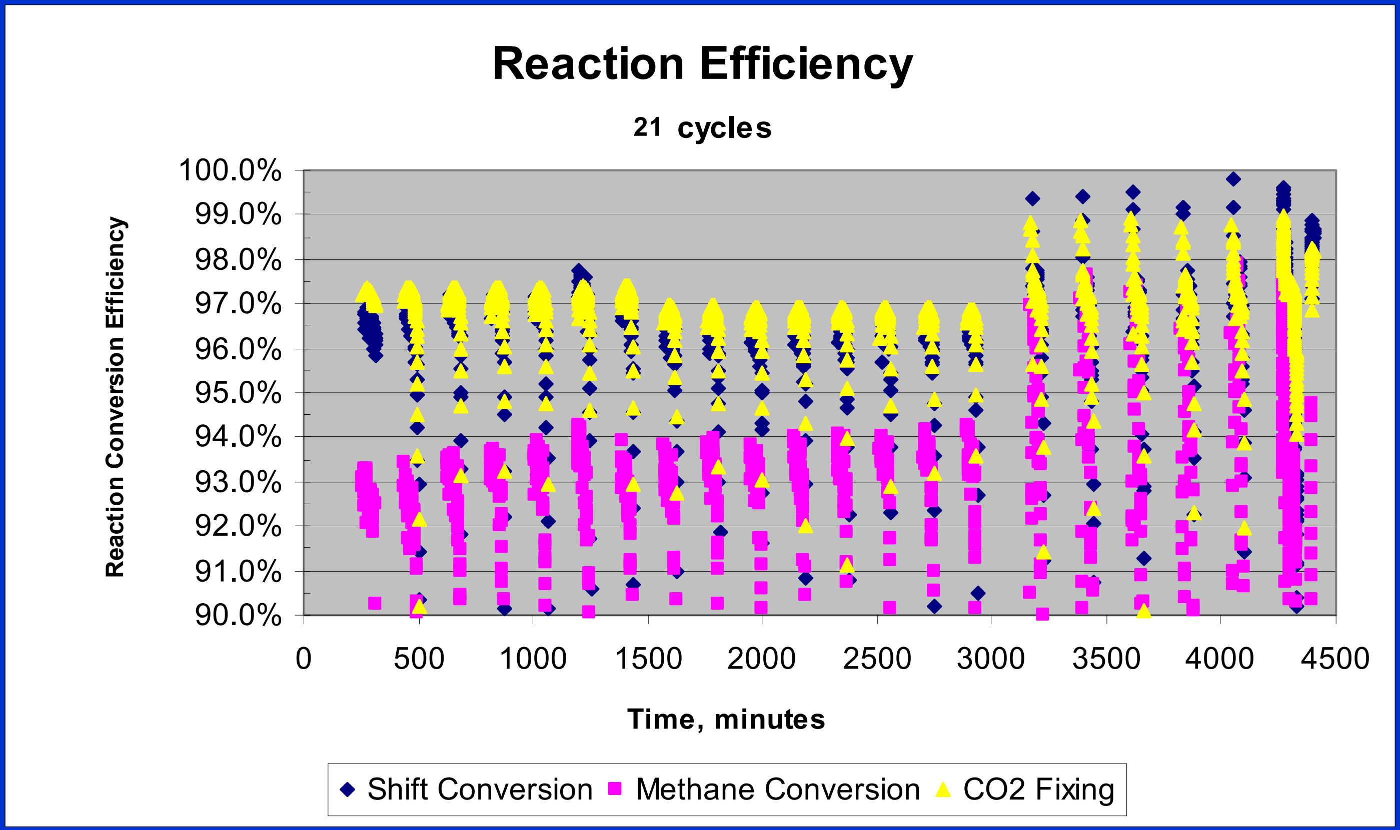
Number	Milestone/Decision point	Date
1	90% of the thermodynamic equilibrium conversion of methane	09/30/04
2	>50 % CO_2 theoretical. adsorption capacity after 50 cycles, >90 % equilibrium conversion of CO at 800 h^{-1}	09/30/04
3	>98 % H_2, CO/CO_2< 1% on dry basis after 50 cycles	11/15/04
4	>98 % H_2, CO/CO_2< 1% on dry basis after 500 cycles	08/15/05
5	Predicted efficiency of system must be greater than 78% and low capital cost	07/06/04
6	Deliver enough integrated material for one full scale reactor,	11/15/04
7	Deliver enough integrated material for one full scale fuel processor, estimated 350 kg	08/15/05
8	Reactor ready for testing	11/12/04
9	Reactor meets design criteria	08/03/05
10	Stand alone reformer installed in Houston Test area	09/15/05
11	Reformer start-up/shut-down cycle testing, transient testing, durability testing.	9/30/06

Reactor Systems



- 3 (2 CTTV & 1 CSMP) tube reactors and 2 kg H_2/day operational
- Additional 2kg/day in construction
- 10 kg/day reactor design started

Simultaneous Reforming, WGS & CO_2 Fixing



97% methane conversion, >99% CO removed, >98% CO_2 removed

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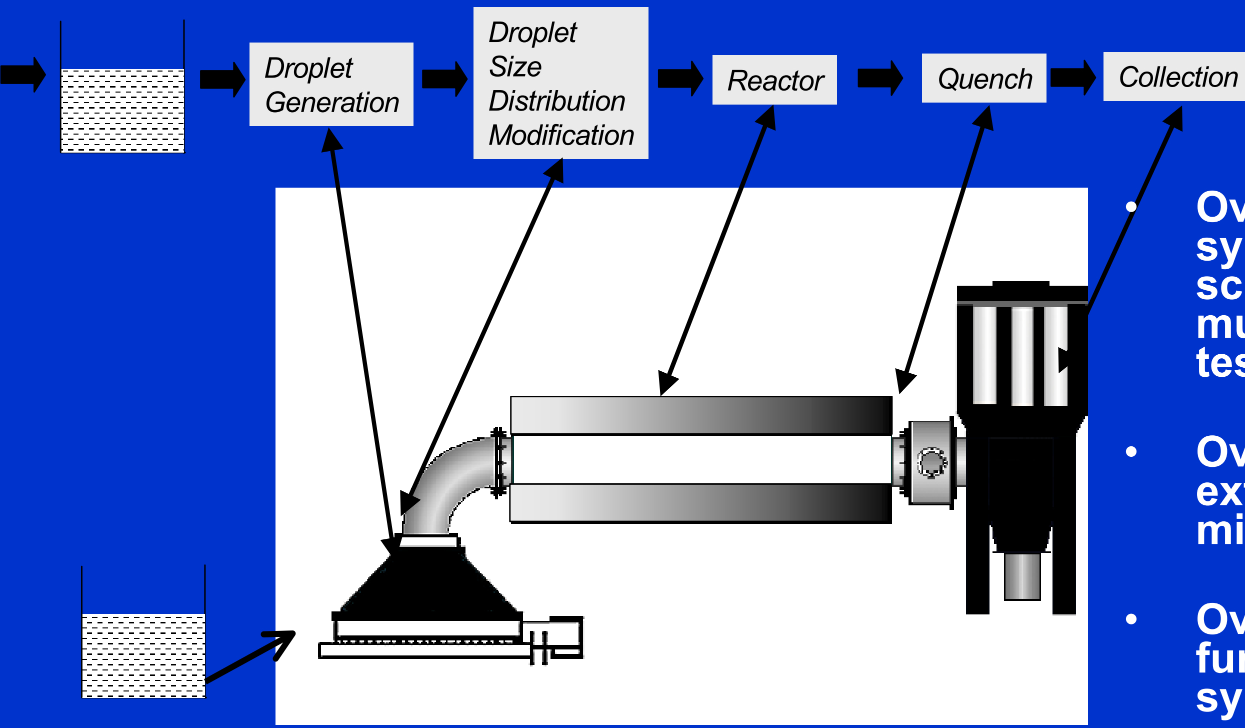
CSMP Materials Synthesis Approach---Synthetic Sorbents by Spray Conversion



- Over 100 sorbents synthesized and screened with multiple cycle TGA testing
- Over 30 sorbents extruded and tested in microreactor
- Over 20 integrated function materials synthesized
- Over 20 steam reforming catalysts synthesized
- 3 sorbent powders manufactured in >10 kg scale

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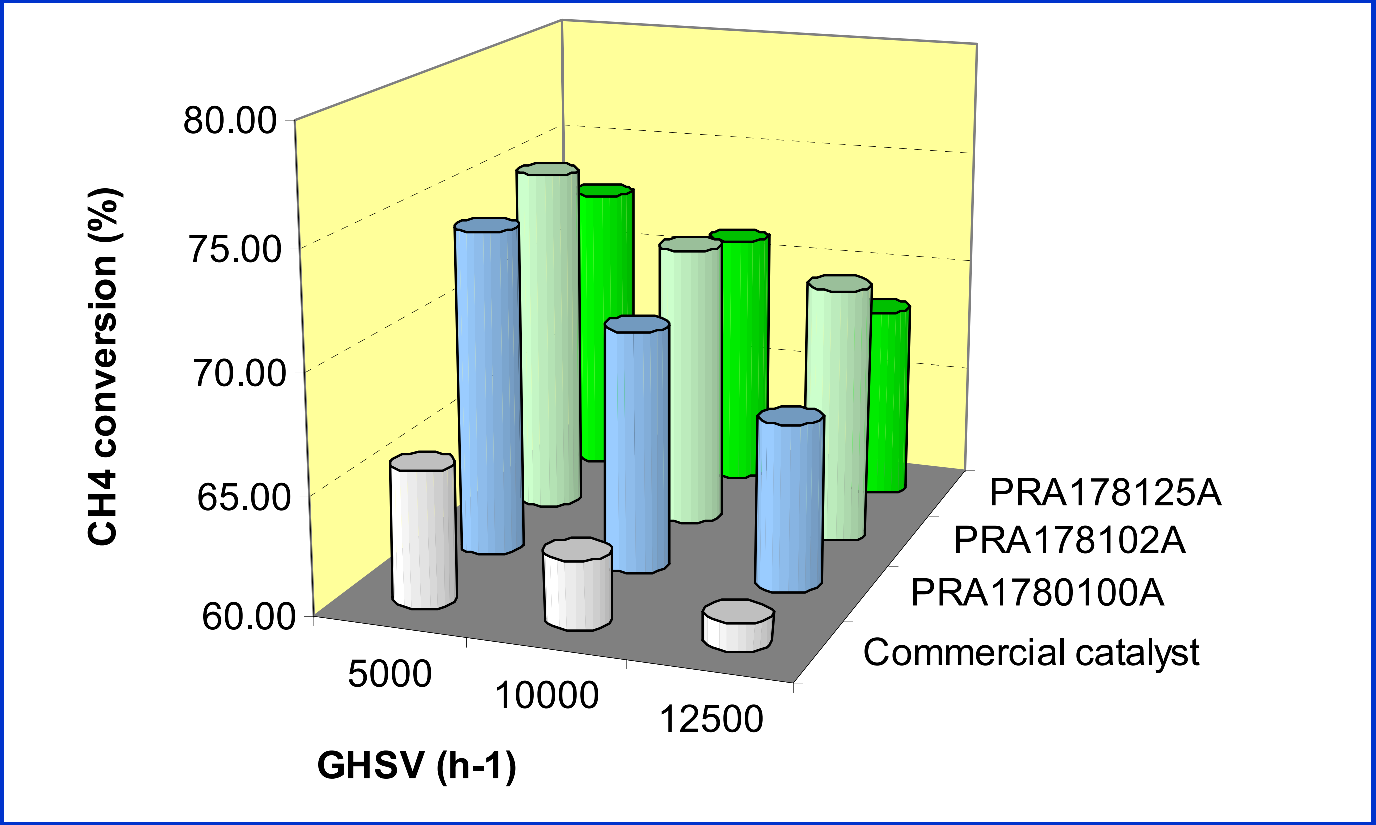
High Activity Steam Reforming Catalyst from CSMP ---- Exceeds Milestone #1



Reaction conditions: S/C=3:1 and 600°C

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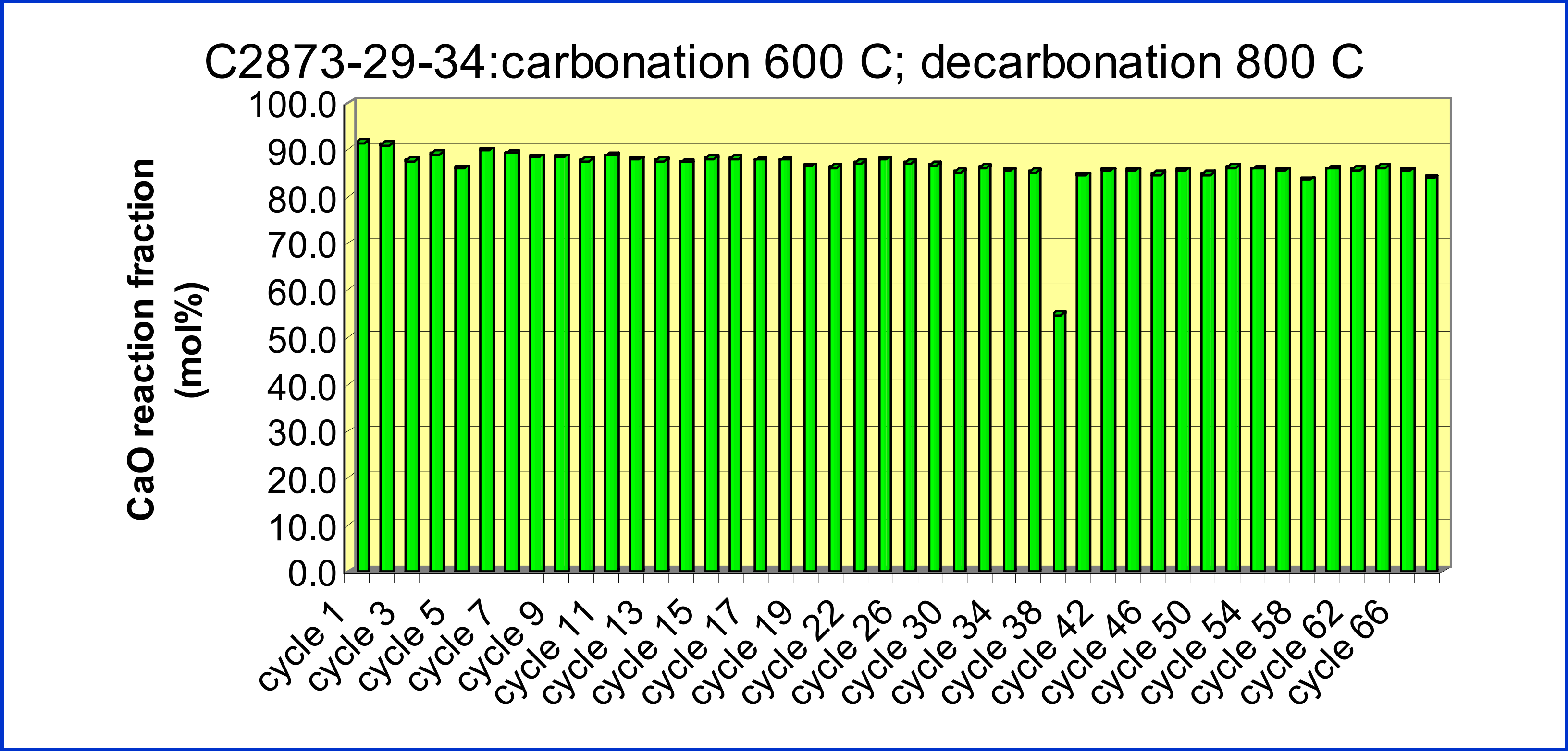
Highly Durable CO_2 Fixing Materials from CSMP ---- Exceeds Milestone #2



>1500 hours and still meeting specs

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Cost and Efficiency Studies---- Exceeds Milestone #5

Efficiency Comparison

	SMR/PSA	AER
Feed	1.23	0.88
Fuel	0.25	0.34
Total	1.48	1.22
Efficiency	67.6%	82.0 %

Notes: (kcal/kcal-H2 – LHV Basis)

- SMR Case adjusted for no steam export, includes NG Compression to 440 psia, PSA H_2 recovery = 88%

- AER Case includes parasitic power for BFW & CW pumps, ID fans

CAPEX Comparison

	SMR/PSA	AER
Major Equipment	15.6	6.0
Other direct Field Costs(*)	5.1	4.9
Indirect Field Costs	4.6	3.5
Engineering & HO	4.1	2.6
Total MM$ (**)	29.4	17.0

*** = Piping, Civil, Steel, Instruments, Insulation, Paint**

**** Exclusive of catalyst, contingency, taxes, permits, escalation, other Administrative Overheads**

Interactions and Collaborations

- Cabot Superior Micropowders - Joint Development Agreement in place
- Reactor design discussions with two potential manufacturers
- Confidential discussions with two automakers
- Confidential discussions with three hydrogen technology companies
- Confidential discussions with commercial catalyst company
- Confidential discussions with university and commercial forming technology leaders
- Presentation “Development of a Fuel Processor Using Revolutionary Materials for Single Step Absorption-Enhanced Natural Gas Reforming” at 2004 National Hydrogen Association Conference

Future Work

Remainder of 2004 FY

- Continue material synthesis and testing
- Dynamic modeling using experimental kinetic data
- Complete cost study
- Operate four installed reactors
- Design and fabricate 5 kW reactor

Remaining Two Years of Project

- Install & operate 5 kW reactor
- Design and fabricate stand alone 50 kW fuel processor
- Operate processor for 10 months continuous operation