Low-Cost Hydrogen Distributed Production System Development

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H2Gen Innovations, Inc.

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Project ID #
pd_01_lomax

Overview

Timeline

- Start: July 1st, 2005
- End: June 30th, 2009
- Percent complete: 96%

Barriers

A. Fuel Processor Capital Costs
B. Fuel Processing Manufacturing
C. Operation and Maintenance Costs

Budget

- Total project funding*
  - DOE share: $3.58 million
  - Contractor share:$2.41 million
- Funding received in FY08 $627,093
- Funding for FY09*: $106,439

*Through Feb 28, 2009

Partners

- Süd Chemie, Inc.

Objectives-Relevance

Overall objectives	Objectives in 2008
design, build and test a steam methane reformer and pressure swing adsorption system that will meet the DOE 2015 cost and efficiency targets for on-site distributed hydrogen generation	Operate HGM-10,000 for over 2,500 hours
demonstrate the efficacy of a low-cost renewable hydrogen generation system based on reforming ethanol to hydrogen at the fueling station	Evaluate the efficiency of reforming standard E-85 fuel grade ethanol with 15% gasoline additive

Milestone

Month/Year	Milestone
May-08	Complete 3,963 field operating hours on the first prototype HGM-10,000, exceeding our goal of 2,500 filed-test hours. The unit was returned to our Alexandria plant for inspection and refurbishment at H2Gen expense. The second HGM-10,000 prototype, incorporating all the “lessons learned” from the first system was shipped to the field on April 15th, 2008 to begin initial field testing, also at H2Gen expense without DOE cost share.
Dec-08	The experimental evaluation of fuel grade ethanol, E-85 with 15% gasoline additive, reaches over 2,700 hours in a catalyst aging test before an apparent carbon coating covered the catalyst.
Dec-08	After substantial study and research, it was found no burner manufacturer would qualify a burner to run on ethanol. Thus, original plan “ complete design of ethanol feed for HGM3000” has to be redirected.

HGM-10,000 operational testing (mainly completed without USDOE funding)

HGM Unit #1 – 4,606 hours

HGM Unit #2 – 3,314 hours

H2Gen has completed three rounds of technical and manufacturing improvements between the original USDOE deliverable and the production design now being supplied to customers

Projected Cost of Hydrogen from the HGM-10,000 & HGM-25,950 (1,500 kg/day)

HGM Cost Projections

	HGM-10,000			HGM-25,950		
Capacity (scf/hr)	10,000			25,950		
Capacity (kg/day)	578.0			1,500		
Production Quantity	1.0	100	500	1.0	100	500
HGM lifetime (years)	15	15	15	15	15	20
CSM lifetime (years)	20	20	20	20	20	20
Reactor Replacement (yrs)	5	5	6	7	7	8
Final Price FOB Alexandria	**$ 1,211,765**	**$ 858,466**	**$ 762,044**	**$ 1,818,426**	**$ 1,290,090**	**$ 1,145,686**
Total Installed HGM Costs	**$ 1,331,544**	**$ 963,562**	**$ 862,643**	**$ 1,993,189**	**$ 1,442,675**	**$ 1,291,485**
Average Annual O&M Cost	$ 60,654	$ 42,530	$ 35,750	$ 77,411	$ 55,508	$ 48,049
Hydrogen Production Costs ($/kg)						
Capital Recovery (70% capacity factor)	1.42	1.03	0.92	0.82	0.59	0.48
O&M	0.42	0.29	0.25	0.21	0.15	0.13
Taxes & Ins	0.18	0.13	0.12	0.11	0.08	0.07
NG fuel @ $11.28/MBTU	1.95	1.95	1.95	1.95	1.95	1.95
HGM Electricity @ 8cents/kWh	0.08	0.08	0.08	0.08	0.08	0.08
H2 Production Cost	4.05	3.48	3.32	3.16	2.85	2.70
Estimated Compression & Storage Costs ($/kg)						
Capital Recovery	1.50	1.08	0.97	0.86	0.63	0.500
O&M	0.432	0.313	0.280	0.249	0.181	0.162
Taxes & Ins	0.216	0.156	0.140	0.125	0.090	0.081
Compression Electricity	0.19	0.19	0.19	0.19	0.19	0.19
Total Compression & Storage cost	2.34	1.75	1.58	1.43	1.09	0.94
Total Compressed H2 Cost ($/kg)	**6.39**	**5.23**	**4.90**	**4.59**	**3.94**	**3.64**

H2Gen: HGM Cost Scaling size and quantity.XLS; Tab 'HGM$';Q73 - 4 / 13 / 2009

Ethanol Reforming System Design task

- Commercial nozzle mix burner vendors will not provide alcohol burners due to detonation/safety concerns
- Possible option – burner start and balance/trim using natural gas or LPG
  - This option would have similar environmental benefits to ethanol-only system
  - Uses safe, proven burners (same as our commercial offerings)
  - Incurs greater installation cost for natural gas connection

Conclusion – solution exists, but USDOE guidance needed on acceptability

Ethanol reforming:

❖ Liquid ethanol is attractive as renewable energy carrier.

❖ Typical ethanol reforming includes: Pre-reforming of Ethanol followed by Reforming of Methane.

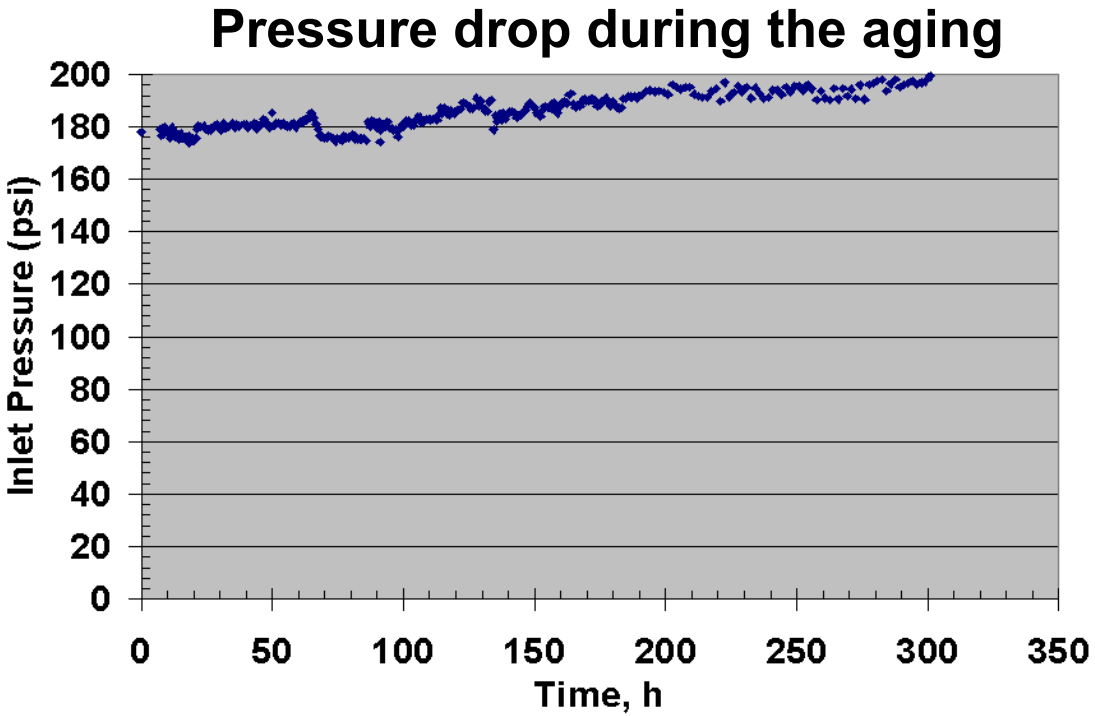
$$C_2H_5OH + H_2O + H2 = CO_2 + CH_4$$

$$CH_4 + 2H_2O = CO + 3H_4$$

❖ Previous reflux ethanol (7.76% H_2O content) reforming test: stable performance for 1,800 hours, full conversion of ethanol to syngas, no coke formation.

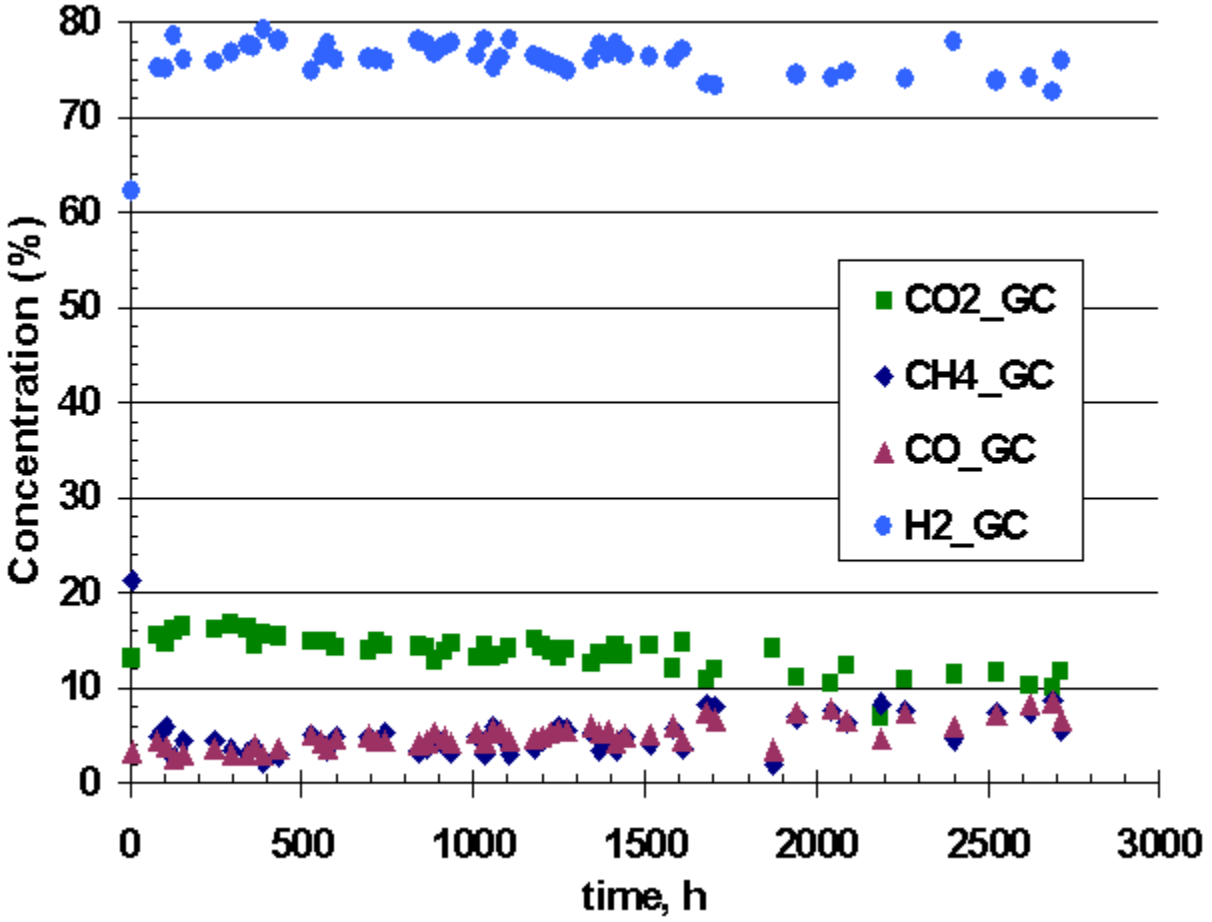
❖ The efficiency of reforming commercial denatured ethanol (E-85) needs to be examined.

Reforming test using E85 – 300 hours



- A sequence of reforming catalysts:
  pre-reforming/ steam reforming/ ultra-high T WGS/ WGS.
- Full conversion of ethanol into syngas.
- Gradual increase in pressure drop.
- Coke was found on reforming catalyst, NOT on pre-reforming catalyst. May be due to different support formulation

Reforming test using E85 – 2,700 hours



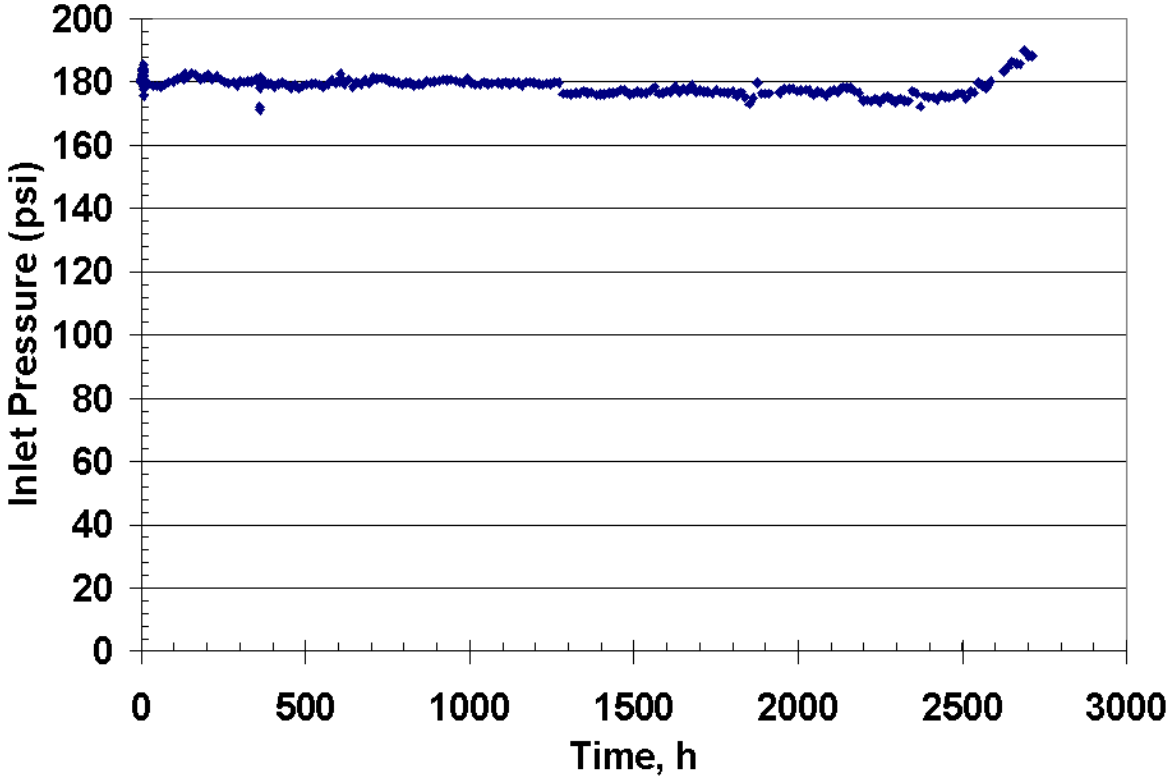
Conditions:

- Pre-reforming catalyst in place of reforming catalyst.
- S:C = 3.75
- H_2:C = 1.0
- Pressure = 180 psig
- Boiler T = 250 ^oC
- Mixing T before reactor inlet = 340 ^oC
- HDS T = 350 ^oC

Full conversion of ethanol to syngas.
Stable product composition.

Reforming test using E85 – 2,700 hours

Pressure drop during the aging



- **Increase of pressure drop after 2,500 hours operation due to coke formation and agglomeration on catalysts.**
- **No S, P, or Pb was detected on used catalysts with SEM/EDX analysis.**
- **Possible reason for coke formation onset: lower steam to carbon ratio caused by upset of H_2O flow meter.**

Projected Cost of Hydrogen from E-85

HGM Cost Projections

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Compression Electricity	0.19	0.19	0.19	0.19	0.19	0.19
Total Compression & Storage cost	2.34	1.75	1.58	1.43	1.09	0.94
Total Compressed H2 Cost ($/kg)	**9.2**	**8.1**	**7.7**	**7.4**	**6.7**	**6.4**

- Similar cost and efficiency as for NG HGM
- E-85 cost is higher fraction of the H2 cost

Collaborations

Working Partner: Sud Chemie, Inc.

Cost Sharing Partner: Sud Chemie, Inc.

Plan for continuing the program :

- Lack of a commercial burner running on ethanol – ethanol-only reforming system roadblock
  - Need to ascertain USDOE interest in possible natural gas start, ethanol run system – no further USDOE resources expended towards full system design

- Diverting remaining resources toward testing ethanol steam reforming on coated wall tube reactor.

Why coated wall tube?

- **Reduce the risk of coking**
  No contact of gas with hot bare Ni-alloy tube wall

- **Decrease required tube size**
  less alloy material needed

- **Minimize the pressure drop at high throughput requirement**
  less flow resistance

Future test plan (March – June 2009)

Short Term Test

Goal: *Compare susceptibility to coking in steam reforming reaction (the traditional packed bed vs. coated wall reactor*)

Test condition: *Favoring coke formation – low S:C, high wall T.*

Test results: *Coke characterization by temperature programmed oxidation (TPO) technique.*

Long Term Test

Goal: *Assessing the performance stability of coated wall tube in ethanol steam reforming.*

Test condition: *Ensuring no coke is formed. At least 1,000 hours on stream time.*

Test results: *Product composition, pressure drop over the reactor tube and temperature profile along the reactor tube.*

Summary

- The first HGM10,000 prototype was successfully tested in field for 3,963 hours, exceeding the goal of 2,500 hours.
- A long term aging testing of ethanol reforming catalyst using commercial available fuel ethanol (E85) reaches over 2,700 hours when coke formation was observed.
- The preliminary design of an ethanol version of the H2Gen HGM natural gas reformer was hampered by the lack of a commercial burner could run on ethanol.
- Diverting remaining resources toward testing ethanol steam reforming on coated wall tube reactor.