Cost-effective High-efficiency Advanced Reformer Module (CHARM)

Michael Leshchiner, Darryl Pollica, Christian Stanley, Changsik Kim, Atul Sharma, Kara Gilhooly, Lawrence Clawson
Nuvera Fuel Cells, 129 Concord Road, Billerica, MA 01821 (http://www.nuvera.com)

Nuvera's Shareholders

Overview

Project ID: FCP 10

Project Task	Project Milestones	Task Completion Dates: Original Planned	Actual	Revised Planned	Percent Complete	Progress Notes
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Program Budget Award: DE-FC36-02AL67618	Project Period: 01/01/2002 thru 09/30/2008		
	Summary	Through FY 2007	FY 2008 Expected
Recipient Share	$ 5,020,600	$ 4,727,790	$ 292,810
DOE Share	$ 12,000,000	$ 10,961,395	$ 1,038,605
Total Approved Budget	$ 17,020,600	$ 15,689,184	$ 1,331,416

Hydrogen FC Infrastructure Technologies Program
Barrier Addressed: 40,000-hour Fuel Processor Durability

Publications: A.Sharma, D.Pollica, B.Rogers, L.Clawson, T.Holmes, Low Life Cycle Cost Natural Gas Reforming for Fuel Cell Forklift Market Application, **American Chemical Society National Meeting, August 2007, Boston MA**

This presentation does not contain any proprietary, confidential or otherwise restricted information

Objectives

Develop a durable steam reforming module for stationary applications:

- Design & Test a 1,000 scfh H2 (2.4kg/hr) SR module
- Minimize product life-cycle cost (capital, O&M over 5 year lifetime)
- Validate durability through accelerated aging & profiling
- Acquire 3rd party validation (ANL) of 1,000 scfh FP subsystem
- Develop a scaleable technology: 500 to 2,000 scfh (1.2 to 4.7 kg/hr)

Nuvera H2 Generator Fuel Processor Roadmap: Key Targets		
Fuels	NG, LPG	To afford fuel flexibility
Efficiency	>75% (LHV)	H2 produced (LHV)*PSA U% / Total feedstock fuel (LHV)
Lifetime	40000 hours 1000 cold cycles	Ultimate goal = 80000 hours & 4000 cold cycles represents daily cycling

Nuvera's intent is to commercialize natural gas steam reforming for the H2FC forklift Materials Handling Market

Technical Approach

Task-1: System Definition
- ✓ Use system modeling to determine proper balance of fuel processor integration
- ✓ Define specifications and operating conditions

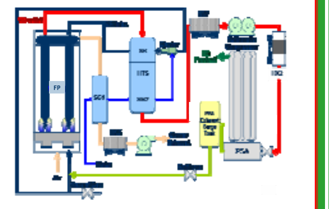
Task-2: Design & Analysis
- ✓ Conduct subscale testing and select fuel processor concept to achieve the performance, cost and durability specifications

Task-3: Prototyping & Testing
- ✓ Demonstrate full-scale performance of the fuel processor subsystem
- ✓ Assess temperature profiles, heat flux, reaction equilibrium and burner emissions

Task-4: System Demonstration
- ✓ Validate performance with system level testing
- Demonstrate durability via accelerated aging
- Conduct a fuel processor validation by Argonne National Laboratory

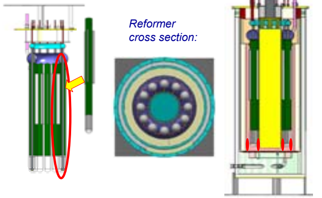
System Configuration

- Low to medium pressure NG steam reformer coupled with reformate compressor and PSA for Hydrogen separation
- HTS and Superheater for additional Hydrogen yield



Fuel Processor Design Features

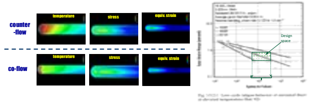
- Integrated tubular Reformer and Burner – concept similar to large scale industrial reformers
- Combustion occurs around SR tubes



Modeling of Stress and Durability

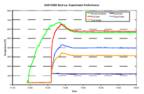
FP durability and reliability are key components of system life cycle cost
CFD – FEA coupling activity was undertaken to predict stress, strain and ultimately FP life

- Durability prediction involves thermal stress/strain analysis
- FEA models require boundary conditions/loads
  - surface temperature, heat flux, pressure, etc.
- CFD provides this information
- CFD-FEA coupling allows more accurate thermal stress calculation

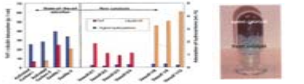


Technical Accomplishments

Found new supplier and implemented new Superheater
- Improved durability: tested for over 1600 hrs and 43 cold cycles
- Increased effectiveness
- Shortened start-up time
- Simplified control strategy



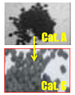
Implemented new desulfurization material
- Chemisorption-based materials with higher sulfur removing capacity
- Better retention and reduced elevated temperature desorption
- Visual indication of when replacement is needed

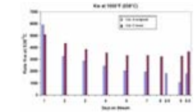


Technical Accomplishments

Improved caps manufacturing
- Performed extensively modeling
- Identified locations of hot spots
- Adopted extended forged Inconel 625 cap

Selected and validated new steam reforming catalyst
- Enhanced support with high pore volume for improved rection activity
- Catalyst testing confirmed significantly improved hydrothermal stability, anti-coking, crush strength



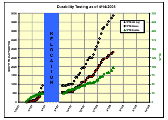


FP and System Testing Infrastructure

- FPTS is used for system performance testing and durability assessment:
  - 2812 hrs (as of 4/14/08)
  - 97 cycles
- Durability / Cycling TS is used for FP cycling test:
  - 1040 cycles on SR / Burner
  - 2778 cycles on steam generators

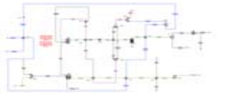
Durability Test Stand (DTS)

Fuel Processor Test Stand (FPTS)



Fuel Processor Validation

- Fuel Processor performance is to be validated at Nuvera by Argonne National Laboratory
  - FPTS will be used for this purpose
  - Fuel processor process diagram and actual test data is shared with ANL for process model development and further analysis
  - Final validation is tentatively scheduled for July – August 2008
- Extensive mapping of system performance in co-flow and counter-flow configurations is being executed
  - Performance is compared to Aspen and CFD models



PowerTap Hydrogen System Deployments

- CHARM FP serving H2 to East Penn Manufacturing facility since August 2006 (PEMFC Forklifts) – 3720 kg H_2 produced as of 4/14/08
- Alpha Generator commissioned in Dec. 2006 with updated fuel processing subsystem design
- >50kg/day H2 @ measured >99.995% purity, <1ppmCO; >4500 hrs of integrated system experience
- Provided on-site H2 to Cambridge FC labs in Q1-Q2 2006 and now Billerica labs with Alpha Generator – 4414 kg H_2 produced as of 4/14/08
- Monitored w/remote telemetry for improved O&M
- 3rd and 4th systems soon to be deployed

Future Work

- Conclude accelerated FP testing for investigation of creep – fatigue interaction and investigate impact of cycling on expected FP life
- Complete validation of Co-flow and Counter-flow reformer configurations and assess trade-offs between durability and efficiency for minimization of the hydrogen generator life cycle cost
- Complete a toolbox for design of next generation system
- Assist ANL in validation of performance of the 1000 SCFH system
- Demonstrate fuel processor durability with 5000 hrs and 250 cycles
- Evaluate system concepts for design of scaleable, high efficiency fuel processor
- Complete conceptual design of scaleable and cycleable larger scale fuel processor

Challenges Faced and Opportunities for Further Developments:

- The stigma in industry is fuel processor durability – life cycle cost is to high;
- There is a unique challenge in small scale H2 generation – frequent cycling;
- Creep – fatigue interaction while cycling present the biggest durability threat;
- Metal temperature and stress reduction and metallurgy selection are of utmost importance;
- Compromise between efficiency and durability in conventional system configuration.

Conclusions:

- CHARM is in final phase of development. Plan to complete by September 2008
- CHARM Fuel Processor and System development is central to Nuvera Product Development / Total Power Solution initiative
- Major effort is on improvement of FP durability for minimization of life cycle cost of Hydrogen generation system
- Models and DTS data confirm FP should survive at least 1,000 thermal cycles. Accelerated testing will further improve prediction accuracy
- Exploring concepts to improve system efficiency and LCC with potential of H_2 cost reduction to under $3.00 / gge H_2 (based on DOE assumptions)

Acknowledgements:

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