V.J.1 Development and Demonstration of a New-Generation High Efficiency 10-kW Stationary Fuel Cell System

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Fiscal Year (FY) 2012 Objectives

- To identify core technology improvements, methodologies and engineered solutions to overcome challenges facing the development of fuel cells (FCs) for use in combined heat and power (CHP) applications.
- To design an integrated system based on the most promising down-selected fuel cell and fuel processor building blocks.
- To build and test a prototype unit in a laboratory setting and collect 300 hours of operating data.
- To optimize, redesign and retrofit a pressure swing adsorption (PSA) unit using lessons learned from prototype to develop a field demonstrator.
- Conduct a six-month demonstration in a International Partnership for the Hydrogen Economy country.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Durability
(B) Cost
(C) Performance

Technical Targets

Work under the project is aimed at developing novel fuel processing, polymer electrolyte membrane (PEM) fuel cell technologies and integration strategies in order to make progress toward achieving DOE targets for stationary PEM fuel cell power systems for year 2012. These targets and project progress are shown in Table 1.

TABLE 1. DOE Targets vs. Project Achievements

Metric	2011 Project Status	2012 Project Achievement	2015 DOE Target[1]
Electrical efficiency at rated power	32.6%-prototype	29% -demonstration unit testing underway	42.5%
Combined heat and power (CHP) energy efficiency	60.8%-prototype	73%-demonstration unit testing underway	87.5%
Operating lifetime	3,425 hours on hydrogen generator (Phase 1 & 2)	2,439 hours on Phase 2-only hydrogen generator[2]	40,000 hours

[1]Complete DOE table 3.4.5 found at http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/fuel_cells.pdf
[2]Accumulated on prototype, new retrofit hydrogen generator integrated into demonstration CHP unit now under test through February 2012.

Other challenges being addressed under the project are:

- Reduced startup time by improved thermal management design
- Reduced size by improved subassembly integration and packaging

Accomplishments

IE built two CHP prototypes and sent them to Loughborough, England, UK to do initial commissioning at the BSI testing Laboratories and later to IE-CHP in Bellshill, Scotland, UK for grid-tied demonstration.

- Conformité Européenne ("European Conformity") compliant design of demonstration unit resulting in:
  - Grid tie enabled using commercial solar photovoltaic inverter
  - Integrated feed gas compressor, water system and gas quality monitoring
  - Onboard safety and emissions management
  - System health monitor with remote data acquisition and analysis for predictive maintenance

  - Twin-stack fuel cell system developed for CHP application to improve system efficiency
  - Combined heat and power efficiency is expected to increase to 78%[1]
  - End-to-end electrical efficiency is expected to increase to 33%[2]
- Construction of field demonstration unit
- Prove-out of the feasibility of adsorption enhanced reforming (AER) as a potential lower cost fuel processor option (eliminates expensive alloys and PSA required by steam methane reformer [SMR] technology)

2,439 hours of total hot hours of operation of which over 150 hours of grid-tied operation has been accomplished in the two CHP prototypes in the U.S. and UK operation.

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Introduction

The development of highly efficient and cost effective clean energy solutions is not without challenge. Hydrogen fuel cell technologies are expected to become a significant player in reducing our dependence on imported fossil fuels and curb the further accumulation of green house gases and criteria pollutants.

This project is focused on the design, fabrication and field demonstration of a stationary CHP system that will provide multi-dwelling residential and light commercial end-users with on-site generated electrical and heating needs.

Approach

The approach to achieving this project's 40% electrical efficiency target is incremental and based on (1) optimization of the SMR+FC architecture and (2) the development of an 80% or greater thermally efficient AER hydrogen generator that can "plug and play" into the same SMR+FC hydrogen feed interface. The SMR+FC optimization relies on allowing slightly less than 100% hydrogen to enter the FC (99% H_2, balance methane [inert to FC]) which has a negligible impact on the FC performance, but allows for increased hydrogen recovery from the processor whereby its thermal efficiency can be boosted from 70% up to as much as 73%. Process simulations indicate that this method when combined with the benefits of a twin-stack FC configuration can increase the overall CHP system electrical efficiency from its current status of 29% to approximately 33% (demonstration unit now under test).

An AER hydrogen generator produces a feed stream similar to what the optimized SMR+FC system would receive but operates at 500ºC versus 900ºC. This means less external energy is needed for AER making it more thermally efficient than SMR. Predictive models developed for us by Sandia National Laboratories during Year 1 of the project indicate that an efficiency of up to 85% can be achieved with the AER compared to only 70%-73% which is the maximum one can obtain with SMR. The product of the AER hydrogen generator and the fuel cell efficiencies, less 12% (assumed value) for the parasitic power requirements to run the CHP system ([0.85 x 0.55] -0.12), would result in a total system electrical efficiency of approximately 41%. Furthermore, with AER, carbon dioxide removal and reforming occur simultaneously thereby eliminating the need to have an additional purification step (such as a PSA) ultimately leading to lower cost and smaller system. Our work on AER culminated in Year 2 as further development and funding is required to mature the technology the point of a "plug-and-play" swap of SMR.

At the beginning of this last year of the project, a twin-stack FC configuration was chosen for integration into the CHP demonstrator. Since each of the two stacks can run at a lower output and be combined to produce 10 kW, the efficiency of each stack will be at its maximum point thereby synergistically operating together to achieve an improvement of efficiency from 53% (single stack) to 59%. The result of using two stacks together in terms of total performance can be seen the Results section.

Results

Over the course of FY 2012, our project team focused on (1) twin-stack fuel cell system development and testing, (2) two demonstrator units were built, debugged and shipped to UK for completing Conformité Européenne certification and field demonstration, (3) the demonstrator CHP units with shorter PSAs for the purpose of optimization through relaxing the hydrogen purity requirement all while achieving a system size reduction performed well producing power at 4-, 8- and 12-kW levels, feeding the power to the grid both in Long Beach, CA and Bellshill, Scotland UK.

Two demonstration units shown in Figure 1 and Figure 2, were built after subjecting to IE's normal four-stage gated design review process which facilitated being able to reduce the number of subsystems from 23 (on prototype) down to just nine. Key component suppliers were also engaged early on to provide a purpose-built PSA that is 1.5' shorter than the previous generation, and natural gas compressor suitable for integration within the main frame by being less than one third in size compared to its equivalent standard model.

The field unit of course must meet all safety and environmental regulations as mandated by the European Union, and as such been implemented with an emissions

[1] Expected performance based on updated system model developed during retrofit redesign and new optimization approach: actual validation testing planned for the fourth quarter of FY 2011 through the second quarter of FY 2012.
[2] See above footnote: prototype achieved 29% electrical efficiency-increase to 33% predicted by new model.

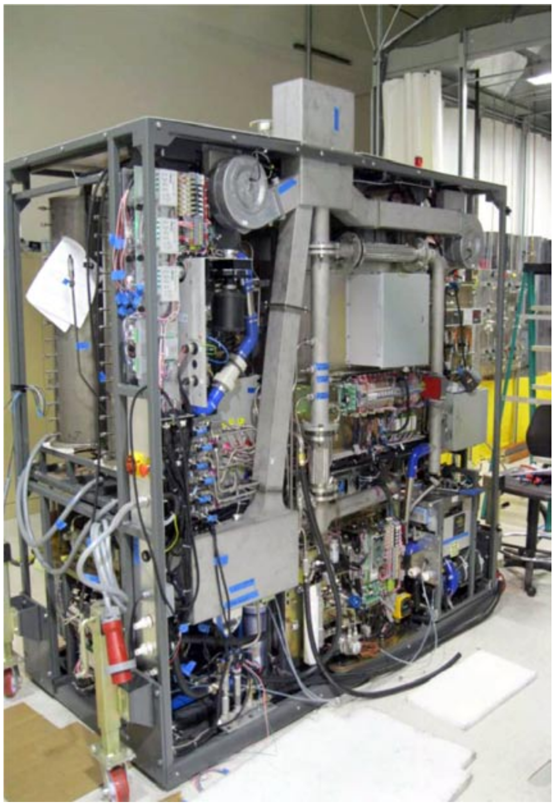

FIGURE 1. Retrofitted Demonstration Unit

FIGURE 2. Packaged Demonstration Unit Installed

monitoring and redundant, hard-wired safety shut down subsystem that constantly watches over the main system controller and software. The unit was also designed for ease of installation requiring that the site connections comprise nothing more than city water and gas, drain, heating water inlet and outlet, network connection, and flue. Components that will demand periodic maintenance while under field trial are located in areas of the machine that provide quick and easy access (e.g. water filters, sulfur adsorbent, etc.).

While on site, the system will show real-time status and performance data on a local user interface while also being stream back to IE headquarters. Startup and shutdowns will normally occur based on those commands the unit receives from the site's own energy management system.

In addition to designing and building the demonstration unit this last year, the planned site received National Environmental Protection Act determination as required by the project and federal law. A six-month field trial was planned at Chalvey, 40 miles southwest of London, England at a multi-residential housing development called Greenwatt Way. This site is owned by Scottish and Southern Energy with who IE has formed a joint venture and will serve to showcase green technologies and provide housing for up to eight families.

As the CHP unit readiness and the Chalvey site availability did not match in timing, IE and IE CHP decided to stage some of the Conformité Européenne certification related work at BSI laboratories in Loughborough, England, UK and the initial field testing at the facilities of IE CHP in Bellshill, Sctoland, UK.

Table 2 shows run-time hours of the prototype between those reported last year versus additional time logged since then (for FY 2012). The mode of particular importance is that for pure hydrogen production; the increase in hours without loss of mechanical integrity and/or notable deterioration in fuel conversion is indicative of a fundamentally sound reformer design.

TABLE 2. Accumulated Hours on Prototypes

CHP Unit	I (UK+US)	II (UK+US)
Hot Hours	1,370	1,069
Reforming Hours	531	625
Fuel cell Hours	25	62
Cold Starts	70	48
Warm Starts AC to grid	107 48 in US 0 in UK	172 48 in US 54 in UK

Preliminary performance measurements are given in Tables 3 and 4 and also in Figure 3.

TABLE 3. Efficiency Calculations

	Expected Initial Performance @ 10kW	Achieved with Prototype @ 11kW	Projected Performance of Demonstrator (Task 4)
Pure Hydrogen Produced (SLPM)		117	
Natural Gas Fed to Reformer (SLPM)		54	
Natural Gas Fed to Combustor (SLPM)		1.5	
Fraction of Natural Gas Power Converted to Pure Hydrogen	72%	66%	72% (inc. ref. temp)
Fuel cell Gross power (W)		11,109	
Hydrogen Consumed by Fuel Cell (SLPM)		117	
Gross Efficiency of Fuel Cell	53%	49%	59% (optimize)
Fuel cell parasitic power (W)	720	722	620
Hydrogen production parasitic power (W)	850	1050	610
Percentage of DC Power Available to Customer		84%	86%
End-to-End Electrical Efficiency (Electricity Out / LHV Fuels In)*	33%	29%	33% (optimize)
Thermal Power Recovered from Hydrogen Generator (W)	4200	6983	6983
Thermal Power Recovered from Fuel Cell (W)**	4200	6640	6640
End-to-End Thermal Efficiency		44%	44%
Overall Combined Heat and Power Efficiency	61%	73%	77%

TABLE 4. Preliminary Performance Measurements

Methane conversion	~82%
PSA H2 recovery	~67%
H2 generated/methane feed	~3
Lower heating value (LHV) efficiency for hydrogen generation	~66%
Fuel cell gross efficiency (FC net efficiency)	~54% ~49%
Overall electrical efficiency	~29%

Figure 4 shows the operation of the CHP with electricity feeding electricity to the grid at 8- and 12-kw levels where as the hydrogen generator (reformer plus PSA) producing 116.9 slpm hydrogen for steady-state 11-kW operation. There was a hydrogen buffer tank which was used to store the excess hydrogen during 8-kW operation and the stored hydrogen is used subsequently during 12-kW operation. This illustrates a method with which the CHP can operate to meet different electric loads.

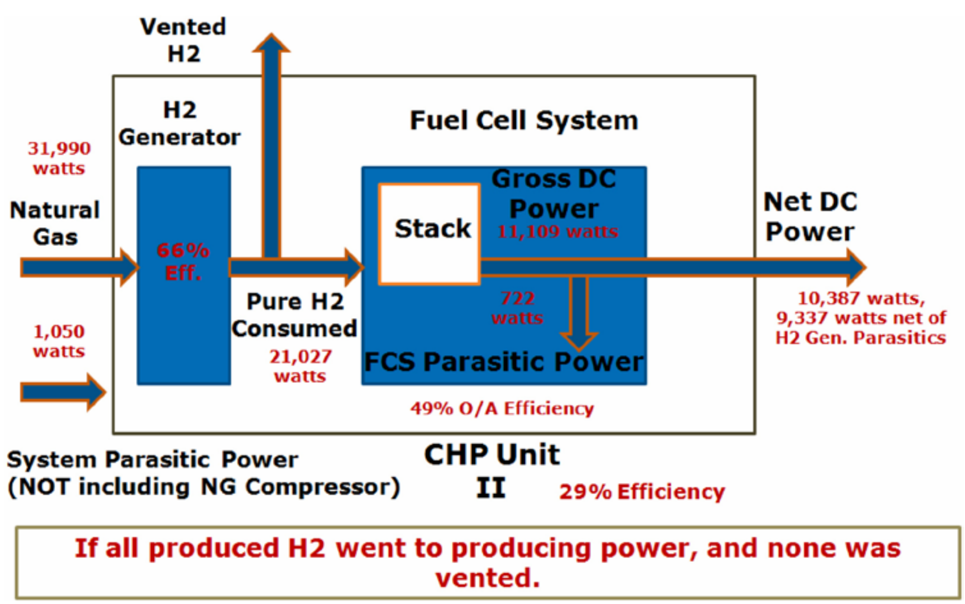

FIGURE 3. Electrical Power Diagram

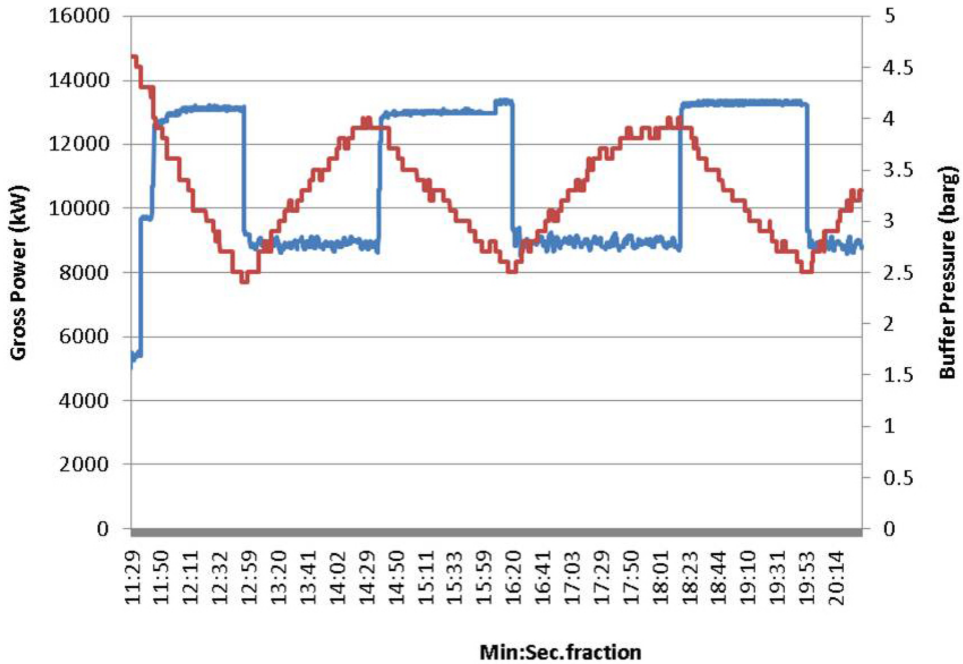

FIGURE 4. Nominal 8- and 12-kW operation of CHP feeding to alternating current to electric grid

Conclusions and Future Direction

- 2012 - Two Conformité Européenne compliant field demonstrators designed and built:
  - Approximately 30% smaller than prototype
  - Projected system electrical efficiency increased to 33%
  - Added functionality
- 2012 - Testing of fuel cell stacks with 99+% hydrogen produced by the demonstrators 1 and 2 showing no adverse impact.
- 2012-13 – Six-month field demonstration and project closure:
  - A third party company (UPS Systems PLC, Berkshire, UK) provides installation and system maintenance support.
  - SHM system relays real-time data back to the IE Knowledge Center.

Special Recognitions & Awards/Patents Issued

Patent Pending:

1. K. Duraiswamy, A. Chellappa and Mack Knobbe; Hydrogen Generation Utilizing Integrated CO_2 Removal With Steam Reforming, WO/2011/075490.