IV.F Fuel Processing

IV.F.1 Advanced High-Efficiency Quick-Start Fuel Processor for Transportation Applications

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Objectives

Through the STAR (Substrate-based Transportation Autothermal Reformer) project, Nuvera is addressing the goal of developing a multi-fuel automotive fuel processing system that meets the size, power, durability, and start-up time needed for integration onboard a vehicle. The objectives include the following:

- Improve fuel processor (FP) power density, specific power, and start-up time via advanced catalysts and substrates
- Design and build a STAR FP
- Test STAR FP to prove high power density and operation with a high-power fuel cell
- Demonstrate STAR FP operation on gasoline, ethanol, and natural gas
- Increase FP system durability
- Verify operation by testing the STAR FP system at Argonne National Laboratory (ANL)

Technical Barriers

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

- D. Fuel Cell Power System Benchmarking
- I. Fuel Processor Startup/Transient Operation
- J. Durability
- K. Hydrogen Purification/Carbon Monoxide Cleanup
- M. Fuel Processor System Integration and Efficiency

Approach

General Approach

- Perform a system analysis to identify strategies to meet FreedomCAR targets
- Develop key FP technologies and sub-components
- Design and build a compact integrated STAR FP system and test on multiple fuels

- Integrate the STAR FP and a fuel cell to measure power system performance and identify system-level integration issues
- Deliver the FP system for testing at ANL
- Continue to improve FP start-up time and durability through design iterations

<u>2003-2004 Technical Approach</u>

- Multi-fuel testing
  - Measure performance at Nuvera on gasoline, ethanol, and natural gas
- Performance verification at ANL
  - Test from 50 to 200 kWth of gasoline input
- Durability improvement
  - Test autothermal reformer (ATR), water gas shift (WGS), and preferential oxidation (PROX) catalysts in micro reactors for 1000 hours
  - Design and build a new PROX reactor and obtain most recent catalysts
  - Test the entire STAR FP system for 500 hours
- Start-up time improvement
  - Develop new burner concepts and integrate into a fuel processor
  - Optimize controls

Accomplishments

<u>2003-2004 STAR Fuel Processor Accomplishments</u>

- Gasoline testing
  - 200 kWth, 81 ± 3.5% hydrogen efficiency, 10 ppm CO
- CNG testing
  - 75 kWth, 77% hydrogen efficiency, 40 ppm CO
- Ethanol testing
  - 80 kWth, 75% hydrogen efficiency, 50 ppm CO
- Delivery and testing of STAR FP system at ANL
  - 50 - 200 kWth on gasoline, 76 ± 2% hydrogen efficiency, 30 ppm CO
- Durability improvement
  - Completed 1000-hour micro reactor testing of catalysts (ATR, WGS, PROX)
  - 500-hour FP system test showed significant advances in system durability and controls. The test also identified areas to study further.
- Start-up time advances
  - New hardware/controls gave a start-up under 10 min (improved from ~25 min)
- Controls hardware and packaging
  - Work with an automotive partner shows that combining current FP technology with automotive controls components and new controls algorithms improves response time and allows the FP system to be packaged in a vehicle

Future Directions

- Finish analysis of recent durability tests of the STAR fuel processor
- Submit the final report

Introduction

Nuvera Fuel Cells, Inc. (Nuvera) is a leading developer and supplier of fuel cells, fuel processors, and integrated power systems for the stationary and transportation markets. Nuvera is working with the DOE to develop efficient, low-emission, multi-fuel processors for transportation applications. These fuel processors offer the possibility to introduce fuel cell vehicles without building an expensive hydrogen fueling infrastructure. The onboard fuel processor converts conventional fuels such as gasoline into hydrogen that powers the fuel cell and can give better fuel economy than traditional vehicles. Fuels tested in Nuvera fuel processors include gasoline, ethanol, natural gas, and methanol.

Approach

With the STAR project, Nuvera is addressing the goal of developing an automotive fuel processor. To achieve the small volume necessary for vehicle installation, the STAR project is focused on development of high-power-density reforming technologies using substrate-based catalysts. Nuvera worked with other companies to develop the required catalysts, and then Nuvera designed and built multiple iterations of the STAR fuel processor. An entire STAR fuel processor system with controls was sent in 2003 to Argonne National Laboratory and was tested while research continued to improve efficiency, durability, and start-up time. The 4-year STAR project ends in 2004, but directions for future projects have been identified that could continue to advance fuel processor technology.

Results

Based on the catalyst, burner, and heat exchanger technologies previously produced in the STAR project, Nuvera built and tested several iterations of the compact STAR fuel processing system. The STAR design contains all the catalyst reaction zones and heat exchangers to process 200 kWth of fuel and has a volume of ~75 L (Figure 1). This FP also has the shape factor necessary for installation in the fuel cell vehicle, as the height is less than 9 inches. This compact size is one of the major achievements of this project, as it demonstrates power density more than ten times greater than in the previous generation

Figure 1. STAR Fuel Processor On Test Stand

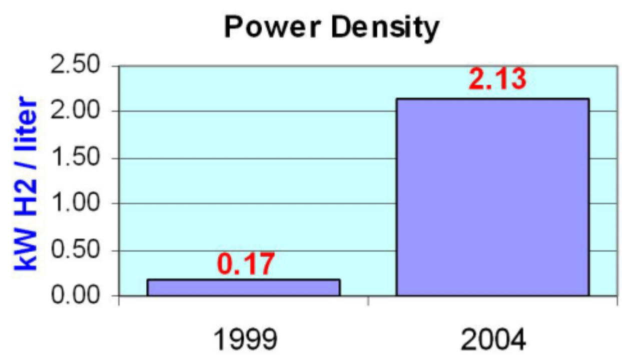

Figure 2. Progress in Power Density

systems and it allows for the possibility of vehicle installation (Figure 2).

During this reporting period, Nuvera focused on five main areas:

1) Multi-fuel testing on gasoline, ethanol, and natural gas
2) Performance verification testing of the STAR system at ANL
3) Research, development, and demonstration of faster start-up STAR systems
4) Durability testing of the STAR technology
5) Automotive controls technologies

STAR fuel processor testing proved high-power operation on gasoline, ethanol, and natural gas. The gasoline results exceeded targets, with a hydrogen efficiency of 80% and CO of less than 50 ppmv at up to 200 kWth (Figure 3). The STAR fuel processor also showed successful operation on ethanol and natural gas, processing both fuels with less than 50 ppmv CO, with hydrogen efficiencies of 74% on natural gas and

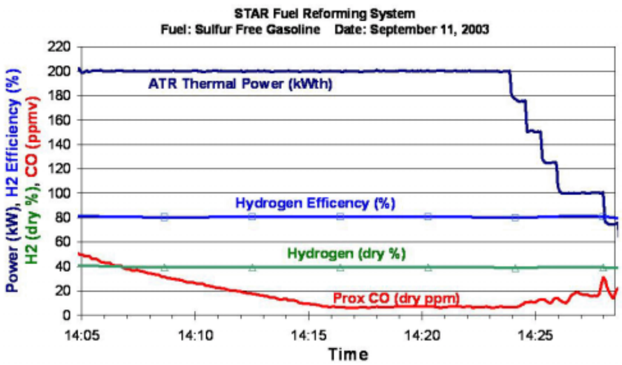

Figure 3. STAR Testing on Gasoline (200 kWth)

Figure 4. STAR Fuel Processor System Installed at Argonne National Laboratory

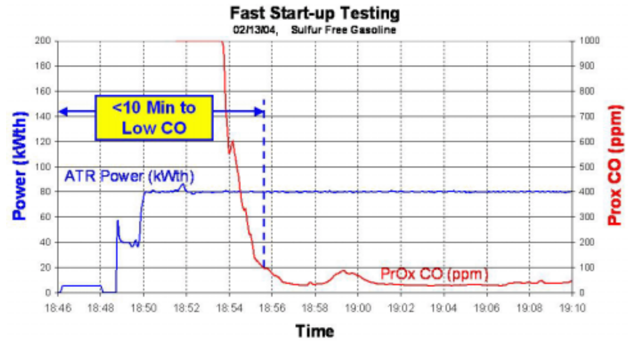

Figure 5. Fuel Processor Start-up in Less Than 10 Min

75% on ethanol. Natural gas and ethanol testing focused on proving the reforming capability and had lower efficiencies than gasoline only because time constraints prevented full optimization.

Testing at ANL verified operation of the STAR system between 50 and 200 kWth of gasoline input (Figure 4). The test report written by ANL shows the system met the CO specification with between 21 and 41 ppm of CO over this range of power. In addition, ANL reported an average hydrogen efficiency percentage with measurement uncertainty as 76 ± 2. Tests at Nuvera just before shipment to ANL showed hydrogen efficiency percentages of 81 ± 4. The difference between these two results is likely due to differences in gas measurement calibrations and slightly different batches of fuel.

In parallel to the testing at ANL, Nuvera worked on another iteration of the STAR fuel processor design to improve the start-up time. Improved burners, mixers, and heat exchangers were developed on a test bench and then incorporated into an actual fuel processor. These new features dramatically decreased the time it takes to warm the ATR to the required operation temperature. In addition, a faster start-up steam generation system was being developed and was temporarily simulated using a laboratory steam supply. The FP system with the improved design showed a start-up time of under 10 min to achieve output of less than 100 ppm CO (Figure 5). This 10-min start-up is the fastest to date for a STAR fuel processor system and shows tremendous progress from the previous full-scale Model B systems. Future improvements on thermal mass and burners could take the system start-up time to just a few minutes or less if this work is included in future research projects.

After the start-up testing, Nuvera conducted durability tests to evaluate the progress during the STAR project. The 2002 STAR design was tested for about 200 hours at 100 kWth and showed sound mechanical design but weak catalyst performance, as all catalysts were worn out at the end of the test and CO could not be kept below 100 ppm. After two years of research, the 2004 STAR system incorporated improved substrates and catalysts as well as improved controls components and algorithms. The 2004 STAR fuel processor completed 500 hours of durability testing (200 hours

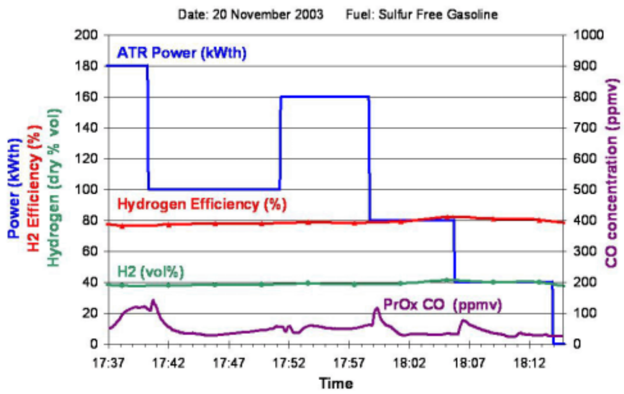

Figure 6. Transient Fuel Processor Performance

Figure 7. Fuel Processor Packaging Study with Automotive Controls Components

at 100 kWth, 300 hours at 50 kWth). The system showed dramatically improved durability performance over the 2002 system. While new catalyst issues were identified, the 2004 system still achieved 80% hydrogen efficiency and less than 100 ppm CO after 200 hours. At about 350 hours, catalyst degradation started to decrease the overall efficiency, but it was still possible to compensate and obtain less than 50 ppm CO at 500 hours. These tests provide very useful design feedback and suggest directions for future catalyst work that could improve system durability if included in future research projects.

Nuvera also worked on automotive controls systems and balance of plant components in conjunction with an automotive company. These components and controls systems were integrated with current fuel processor technology and showed significant improvements in transient performance, with power changes in only a few seconds, the ability to maintain CO of approximately 100 ppm or less, and hydrogen efficiency of 78% (Figure 6). In addition, these automotive controls allow packaging of the fuel processor system in a volume that can fit in a vehicle (Figure 7).

Conclusions

The STAR fuel processor project represents a culmination of four years of intensive R&D and design efforts. Nuvera started with basic component testing of the catalysts and developed custom heat exchanger and burner designs. Today Nuvera has combined these components to produce an advanced automotive fuel processor system that finally achieves the volume, power, efficiency, hydrogen production, and CO targets for an onboard fuel processor. The STAR project represents a significant advance in onboard fuel processors. In addition, this work offers many valuable lessons and directions that could allow future projects to continue to advance automotive fuel processor technology.

During this reporting period, the major achievements of the STAR project include the following:

- The STAR fuel processor meets the volume (75 liters), power (200 kWth), hydrogen efficiency (80%), and CO (<50 ppm) targets for onboard fuel processors.
- The STAR fuel processor was successfully tested on gasoline, ethanol, and natural gas.
- STAR system performance was successfully verified at Argonne National Laboratory with 50 - 200 kWth of gasoline, CO of 21 - 41 ppm, and hydrogen efficiencies of 76%.
- Improved burners, mixers, and heat exchangers led to a new STAR fuel processor that showed a start-up in less than 10 minutes to 100 ppm CO.
- Durability testing of STAR technology showed much better performance than in 2002 with targets met after 200 hours and new issues for catalyst research identified.
- When matched with automotive controls components and new control algorithms, the fuel processor system can make rapid power changes and can be packaged in a vehicle.

FY 2004 Publications/Presentations

1. Bloom, E. G. Polzin. *Performance of STAR Fuel Processor from Nuvera Fuel Cells, Inc.* Report of results from testing at Argonne National Laboratory issued for the US Department of Energy. Issued April 2004, Dated February 2004.