II.F.1 Bio-Fueled Solid Oxide Fuel Cells

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Subcontractors

- FuelCell Energy (FCE), Danbury, CT
- Sacramento Municipal Utility District (SMUD), Sacramento, CA

Project Start Date: October 1, 2010
Project End Date: September 30, 2014

Overall Objectives

Demonstrate the operation of a bio-fueled solid oxide fuel cell (SOFC) integrated with a cost-effective contaminant control system in a waste-to-energy application

Fiscal Year (FY) 2014 Objectives

- Complete the fabrication of the 2-kW$_e$ bio-fueled SOFC module
- Integrate the biogas cleanup skid and the SOFC skid and carry out a successful field demonstration with biogas at the Cal-Denier Dairy Farm
- Prepare a detailed cost analysis and economic assessment of the biogas-fueled SOFC system

Technical Barriers

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

- Cost Effective Separation of Impurities and High-Efficiency Electricity Production from Renewable Feed Stocks
- SOFCs are known to provide the highest possible net efficiency for Combined Heat and Power (CHP) applications. Hence, there is a need to demonstrate successful operation of SOFC on biogas and this project serves this need
- Impurities present in biogas (such as organic sulfur species and siloxanes) poison the catalysts and SOFC stacks, reducing their efficiency and lifetime, and must be removed to a concentration of less than 10 ppbv

Technical Targets

This project will demonstrate the operation of a bio-fueled SOFC integrated with a cost-effective contaminant control system in a waste-to-energy application. The specific targets/goals are:

- Develop and demonstrate the efficacy of a sorbent-based gas clean-up system to remove harmful impurities from biogas such as sulfur and siloxane to less than 0.1 ppmv
- Demonstrate operation of a 2-kW$_e$ biogas-fueled SOFC stack integrated with a biogas cleanup system in a waste-to-energy application
- Demonstrate the economic viability of our biogas cleanup technology

FY 2014 Accomplishments

- Project partner FCE has completed the fabrication of the 2-kW$_e$ SOFC module, which is currently being tested at their facility using simulated gases
- Interface requirements between the biogas cleanup skid and SOFC skid have been identified and TDA has completed the design of the interface skid
- TDA in collaboration with SMUD has completed an assessment of the site modifications needed at the Cal-Denier Dairy test site
- Integrated field tests with cleanup and SOFC skids are scheduled to start at the Cal Denier Dairy Farm in August 2014

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INTRODUCTION

The energy potentially available from bio-waste approaches 1.46 quadrillion Btu, only a small amount of which is currently utilized. The use of this domestic renewable source will reduce U.S. dependence on fossil fuels and greenhouse gas emissions. Fuel cells have a great potential for immediate use in biogas based distributed hydrogen and power generation systems, if cost-effective gas clean up system were available. Distributed fuel cell power generation is becoming a viable alternative to buying power from a central grid, particularly for dairy farms, food industries and waste water treatment plants that produce anaerobic digester gas (ADG). However, impurities (such as organic sulfur species and siloxanes contaminants in the ADG) must be removed from the ADG to prevent degradation of the fuel cell stacks and poisoning of the catalysts used in the fuel processor. Even for the more sulfur-tolerant SOFCs, the sulfur and siloxane concentrations must be reduced to less than 0.1 ppmv.

In the previous SBIR Phase I and Phase II projects, TDA developed a low-cost, high-capacity sorbent that can remove sulfur-bearing odorants from natural gas and liquefied petroleum gas. TDA demonstrated the performance of the desulfurization sorbent first in bench scale and then in the field, integrated with fuel cell systems (with fuel cell stacks, fuel processor and all auxiliary items). The technology was commercialized under the SulfaTrap™ name, and spun-off SulfaTrap, LLC as a separate business in 2013 and are now supplying multi-ton quantities to fuel cell generators operating around the world on natural gas and liquefied petroleum gas. In this Phase III research TDA in collaboration with FCE, will demonstrate the ability of our sorbent to operate in a regenerable manner to carry out bulk desulfurization of biogas, which will then be used in a 2-kW_e bio-fueled SOFC generator. Successful demonstration of the integrated system will enable widespread adoption of small-scale high-efficiency bio-fueled SOFC-based combined heat and power systems.

APPROACH

TDA's approach is to use an ambient temperature gas clean-up system to remove all contaminants to ppbv levels. The purification system includes a bulk desulfurization system (regenerable) followed by an expendable polisher (Figure 1). The key requirement for the sorbent is tolerance to high levels of moisture (biogas is expected to have at least 4,000 ppmv moisture) to eliminate the energy penalty for biogas compression and chilling that are needed with conventional gas cleanup systems. The commercial systems are also known to contribute to the formation of very complex sulfur species that are difficult to remove, such as the di- and tri-sulfides. TDA's polishing bed is designed to remove siloxanes and the organic sulfur species. In collaboration with SMUD integrated field tests with a 2-kW_e bio-fueled SOFC module from FCE will be carried out with TDA biogas desulfurization sorbents at Cal-DeNier Dairy, Grand Valley, CA.

RESULTS

Prototype Biogas Cleanup Unit

The regenerable desulfurizer demonstration skid is designed to test TDA's regenerable sulfur sorbent from a gas treatment slipstream. Suitable slipstreams could come from landfills, waste water treatment plants or dairy farms (ADG), or natural gas pipelines. The flowrate through the skid is adjustable, but system design was based on a nominal 50 scfm. The system is equipped with an online H_2S sensor that can be manually set to measure H_2S concentration at the inlet or outlet of the regenerable beds, or downstream of the polisher bed. Other instrumentation includes the O_2 sensor for verifying that post-regeneration purge has been completed, as well as and various pressure and temperature transmitters and indicators.

The fabrication of the prototype system was completed in FY 2013. Figure 2 shows the picture of the prototype test system. The entire system is compactly mounted on a powder-coated steel skid that is 8 feet long and 4 feet wide. The height of the skid is roughly 6 feet. All electrical components have been constructed for a Class 1, Div 2 hazardous location with a Z-purge on the electronics boxes. The skid is designed to be operated outdoors in any weather. System automation is implemented with LabVIEW software running on a National Instruments cRIO controller. The automation is headless, meaning there is no laptop or other computer required for the system to operate. All data will be logged to a file for later viewing and analysis. The user can also connect wirelessly to the system to view the current system state and change settings such as adsorption time or temperature.

In FY 2014, shakedown and system checkout were performed, verifying all aspects of the safety systems, normal operations and regeneration capabilities of the demonstration unit with the reactors fully loaded with the

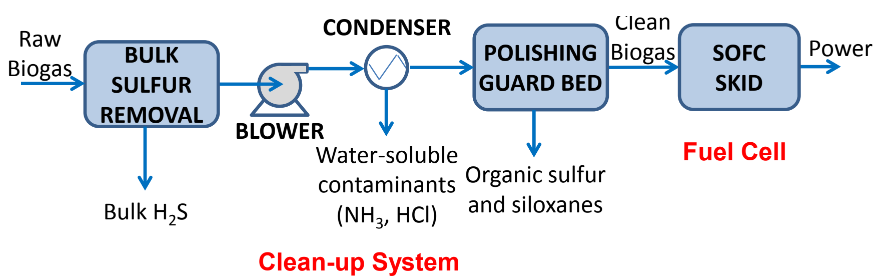

FIGURE 1. TDA's Biogas Clean-Up System Integrated with a SOFC

FIGURE 2. TDA's Biogas Clean-Up Skid

FIGURE 3. FCE's Integrated 2-kW$_e$ Bio-Fueled SOFC Skid

SulfaTrap™ sorbent. The final system automation program modifications that are needed for remotely controlling and monitoring the desulfurizer skid have been completed and verified. The skid will operate in an autonomous manner, but can be viewed either locally or through the internet with this program. The skid-mounted cellular router makes this remote connection possible; it also allows data retrieval.

SOFC Module Development at FCE

FCE completed the fabrication of the 2-kW$_e$ bio-fueled SOFC skid. Figure 3 shows FCE's integrated 2-kW$_e$ bio-fueled SOFC skid with the tilted façade feature. The electrical balance of plant was assembled concurrently with mechanical balance of plant and the hot components section (fuel cell, reformer, anode gas oxidizer) was completed subsequently. Prior to completion of the hot components section both the 16-cell SOFC stack and the 25-cell SOFC stack were tested for gas tightness. The 16-cell stack was then compressed and installed in the hot components section. FCE has completed the programming of the programmable logic controller. Full functional test of the power conversion system was completed by FCE. The power conversion system consists of a DC/DC converter that boosts the fuel cell output of 10-13 VDC to regulated 24 VDC, useful for the second power conversion system stage. The second stage consists of a DC/AC inverter that converts 24 VDC to 120/240 VAC. This inverter is a commercial device originally designed for solar photovoltaic applications and FCE had made appropriate modifications to operate it with a fuel cell power source. Functional testing of the DC/DC converter had verified the high efficiency of power conversion as stated by the manufacturer. Power quality was verified as well as minimum input voltage necessary for operation. Functional testing of the DC/AC inverter showed that the inverter could be grid-connected with power export and sell capability. Testing also showed that the inverter supports island mode operation where the unit is disconnected from the grid and is powered internally from the fuel cell. The HMI for the bio-fueled SOFC had been completed.

The 2-kW$_e$ bio-fueled SOFC skid is undergoing factory testing at FCE. Prior to factory testing, which is a live testing procedure, the unit is being dry tested (functional testing). This initially consists of instrument checkout and major component testing, where natural gas fuel is not involved. This testing is now complete and successful. The next step will be testing with natural gas and then a change out of SOFC stacks. The 16-cell SOFC will be replaced by a 25-cell SOFC prior to shipment to the SMUD demonstration site.

Site Conditioning

In order to demonstrate the capabilities of the regenerable desulfurizer skid, the apparatus will be taken to the Cal-Denier Dairy farm in Galt, California. In preparation for this we completed an assessment of the plumbing and electrical modification requirements at the site. TDA has designed an interface skid that will be built on-site to tie the two skids, i.e., TDA's desulfurization skid and FCE's SOFC

FIGURE 4. Cal-Denier Demonstration Pad

skid. Figure 4 shows the enclosed building and covered demonstration pad area of the farm. The electrical service to the building is 480-VAC 3-phase power and a spare 150 amp circuit breaker is available to power the demonstration skid. The electrical requirements of the skid are 50 mp of 480-VAC 3-phase so there is excess power already available on-site. The far side of the pad has an I-Power Energy Systems ENI 65-kW combined heat and power generator that is currently operating and generating electricity with the biogas from the digester pond. The raw biogas is compressed to about 1-2 psig with a regenerative blower in the enclosed area in the demonstration pad, which has been identified as the place for locating the two demonstration skids. We have identified the outlet of the regenerative blower as a convenient place to tee in a supply line to the desulfurizer skid. The outlet from the desulfurization skid can either be fed to the SOFC skid (during integrated testing) or flared (during stand-alone operation). A sample of the biogas H_2S level was conducted and the levels were between 2,000 and 2,500 ppmv. TDA's desulfurization skid was shipped to the site on July 24, 2014. We will install the "interface skid" onsite in the week of August 4, 2014 and will commence stand-alone operation in the week of August 11, 2014.

CONCLUSIONS AND FUTURE DIRECTIONS

Successful demonstration is key for wide spread utilization of the SOFCs and TDA's biogas clean-up technologies in biogas applications. The remaining activities include:

- Integration of the biogas cleanup skid and the SOFC skid
- Successful field demonstration with biogas at Cal DeNier Dairy Farm
- Detailed cost analysis and economic assessment of the biogas-fueled SOFC system

FY 2014 PUBLICATIONS/PRESENTATIONS

1. Jayaraman, A., Alptekin, G., Schaefer, M., Cates, M., Ware, M., Hunt, J., Tiangco, V.M. "Novel Sorbents to Clean Up Biogas for Fuel Cell CHP Systems" at the 2013 Fuel Cell Seminar & Exposition held between October 21–24, 2013 in Columbus, OH.

2. Jayaraman A., Alptekin, G., "Bio-Fueled Solid Oxide Fuel Cells" at the DOE EERE Annual Merit Review Meeting held between June 16–20, 2014 in Washington, D.C.