X.3 Maritime Fuel Cell Generator Project

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Subcontractor:
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Project Start Date: September 15, 2013
Project End Date: 2017

Overall Objectives

- Lower the technology risk of future port fuel cell deployments by providing performance data of hydrogen polymer electrolyte membrane fuel cell technology in this environment.
- Lower the investment risk by providing a validated economic assessment for this and future potential projects.
- Enable easier permitting and acceptance of hydrogen fuel cell technology in maritime applications by assisting the U.S. Coast Guard and American Bureau of Shipping develop hydrogen and fuel cell codes and standards.
- Engage potential adopters and end users of hydrogen fuel cells to enable more widespread acceptance of the technology.

Fiscal Year (FY) 2017 Objectives

- Lower technology risk and lower investment risk through technical performance analysis and economic analysis.
- Enable easier permitting and acceptance by continually engaging the U.S. Coast Guard and Class Societies (e.g., American Bureau of Shipping) on other projects, which proves usefulness of the Maritime Generator project in developing these standards and guidelines.
- Engage potential adopters such as numerous potential hosts for subsequent demonstration, teaching them about the technology and potential benefits.

Technical Barriers

This project addresses the following technical barriers from the Market Transformation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

(A) Inadequate standards and complex and expensive permitting procedures

(E) A lack of flexible, simple, and proven financing mechanisms

(F) Inadequate user experience for many hydrogen and fuel cell applications

Technical Targets

No specific technical targets have been set.

FY 2017 Accomplishments

The data analysis and reporting was completed in FY 2017. This showed the following:

- During the demonstration period the generator ran for 278 h and produced 7,285 kWh of electricity. It had an average gross power output of 29.4 and reached 91 kW over a continuous 5-minute period. It was able to handle all electrical requirements of the reefer systems.
- Efficiency measurements illustrate the inherent higher part-load efficiency of fuel cell power systems compared to diesel generators, for example, up to a 30% efficiency gain at 30% load.
- Technical issues caused significant downtime with the inverter being the most frequent technical issue and the one causing the longest cumulative down time.
- Nontechnical issues also were responsible for limiting the run time of the unit, with availability of on-site labor the most frequent reason.
- The generator was filled with 428 kg of hydrogen during the demonstration period and all fills were smooth and trouble free.
- The marine environment had no effect on the condition of the stainless steel piping components during the 9-month demonstration period.
- Economic analysis shows that even with fuel cell costs reaching the DOE target of $50/kW, the capital cost of the generator system is projected to remain three times higher than today's comparable diesel generator due to the balance of plant, in particular the hydrogen storage tanks and the power conversion equipment.

- The economic analysis also shows that today's hydrogen prices make fuel to be a major operating expense and hinders the ability of today's fuel cell systems to achieve cost parity with today's diesel systems.

INTRODUCTION

Fuel costs and emissions in maritime ports are an opportunity for transportation energy efficiency improvement and emissions reduction efforts. Ocean-going vessels, harbor craft, and cargo handling equipment are still major contributors to air pollution in and around ports. Diesel engine costs continually increase as tighter criteria pollutant regulations come into effect and will continue to do so with expected introduction of carbon emission regulations. Diesel fuel costs will also continue to rise as requirements for cleaner fuels are imposed. Both aspects will increase the cost of diesel-based power generation on the vessel and on shore.

Although fuel cells have been used in many successful applications, they have not been technically or commercially validated in the port environment. One opportunity to do so was identified in Honolulu Harbor at the Young Brothers Ltd. wharf. At this facility, barges sail regularly to and from neighbor islands and containerized diesel generators provide power for the reefers while on the dock and on the barge during transport, nearly always at part load. Due to inherent efficiency characteristics of fuel cells and diesel generators, switching to a hydrogen fuel cell power generator was found to have potential emissions and cost savings.

APPROACH

This project developed and demonstrated a nominally 100 kW, integrated fuel cell prototype for marine applications (Figure 1). This project brought together industry partners in this prototype development as a first step towards eventual commercialization of the technology. To be successful, the project incorporated interested industry and regulatory stakeholders: an end user, technology supplier and product integrator, and land- and maritime-based safety and code authorities. Project costs were shared by the primary stakeholders in the form of funds, in-kind contribution, and material and equipment either loaned or donated to the project. Co-funding was provided by the Department of Transportation, Maritime Administration's Maritime Environmental and Technical Assistance program.

The project had four phases:

1. Establishment and specification (September 2013–December 2013)
2. Detailed design and engineering (January 2014–March 2015)
3. Prototype fabrication/site construction (October 2014–June 2015)
4. Demonstration at Young Brothers and analysis (August 2015–June 2016)

RESULTS

From the period of August 2015 to June 2016 the generator was used by Young Brothers at their dock (Figure 2) on 52 different days for a total of 278 h. It averaged 29.4 kW (gross) during this period for a total energy generation output of 7,285 kWh and achieved a 5-minute continuous peak power of 91.3 kW (gross). As shown in Figure 3, its net energy efficiency ranged from 36% to 54% over the load range of 16% to 62%. By comparison, the net

FIGURE 1. The maritime fuel cell generator, with integrated hydrogen storage, PEM fuel cell power generation, and power inverter equipment can power up to 10 reefers with a total rated output of 100 kW at 240 VAC

FIGURE 2. The generator (blue) in the "Icehouse" area powering reefers (white)

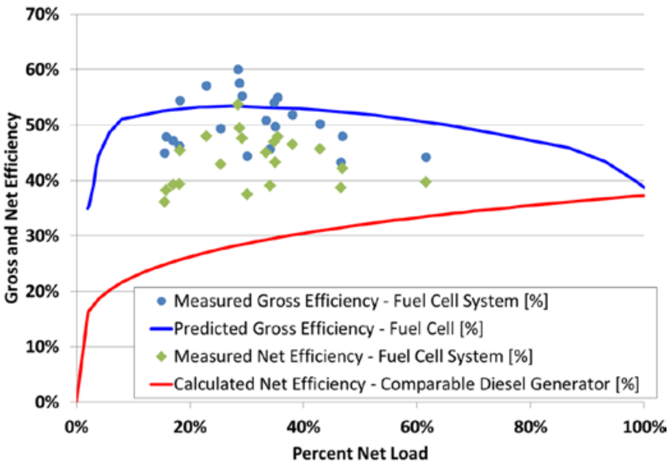

FIGURE 3. Comparison of measured fuel cell efficiencies with predicted fuel cell efficiency (blue line) and comparable diesel engine efficiency (red line). The measured gross efficiency compares well with the predicted fuel cell efficiency. The measured net efficiency of the fuel cell system shows a higher efficiency than the diesel generator at part load, and nearly 30 percentage points higher at the 30% net load point.

efficiency of a comparable diesel generator efficiency is from 25% to 34% in this same load range. Using no diesel fuel and producing zero emissions at the point of use, during the demonstration period the fuel cell generator displaced 865 gallons of diesel fuel, over 16 MT of CO_2 emissions, and avoided nearly 150 combined kilograms of criteria pollutants (NO_x, CO, hydrocarbons, particulate matter, and SO_x) as compared to an existing Young Brothers 350 kW Tier 3 diesel generator.

The deployment experienced numerous technical issues with the generator that limited its use. The primary technical issue during the deployment was an inconsistent startup which was attributed to a communication problem between the overall system controller, inverter, and fuel cell rack. This in turn led to problems with draining of the startup battery, and the overall result was many aborted attempted starts and non-use until the problem could be identified and fixed. The generator's fuel cells also experienced higher-than-anticipated consumption of deionized water, which was exacerbated by the high ambient temperature along with a small deionized water reservoir, causing the operators to have to fill the reservoir more than expected. The consumption was within specification of the fuel cells and not a serious issue, but nonetheless was an unanticipated inconvenience. The generator did not experience any safety-related events and did not exhibit any serious signs of wear or deterioration in the seaport environment. The technical lessons learned from the deployment will be used by the manufacturer to modify this generator for subsequent testing as well as to improve next generation products.

One objective of this deployment was to gather real-world experience with operating hydrogen fuel cell equipment. A flawlessly operating generator would likely have been integrated smoothly into the existing Young Brothers operations. However, the technical issues meant that time needed to be spent by Young Brothers staff to assist in troubleshooting and performing minor maintenance. Many times, Young Brothers staff was not available due to numerous other activities needed to maintain normal operation of the facility. The testing revealed that a dedicated operator would have been needed to maintain continuous operation of the generator because of its technical issues.

Figure 4 shows the results of an economic analysis of capital and operating costs of the hydrogen fuel cell generator were determined for three cases: (1) the deployment, (2) a notional deployment with full usage, and (3) a future deployment where fuel cell and hydrogen costs have come down. These were compared to that of a diesel generator at current costs of equipment and fuel. This presents a worst-case scenario for the fuel cell generator since expected stricter emissions regulations and increase fossil fuel costs are expected in the future (e.g., a doubling of today's diesel fuel cost in 10 yr), the result being continually higher diesel equipment and fuel costs as time goes on.

The analysis showed that even with fuel cell costs reaching the DOE target of $50/kW, the capital cost of the generator system is projected to remain three times higher than today's comparable diesel generator due to the balance of plant. Large portions of the balance of plant cost are the

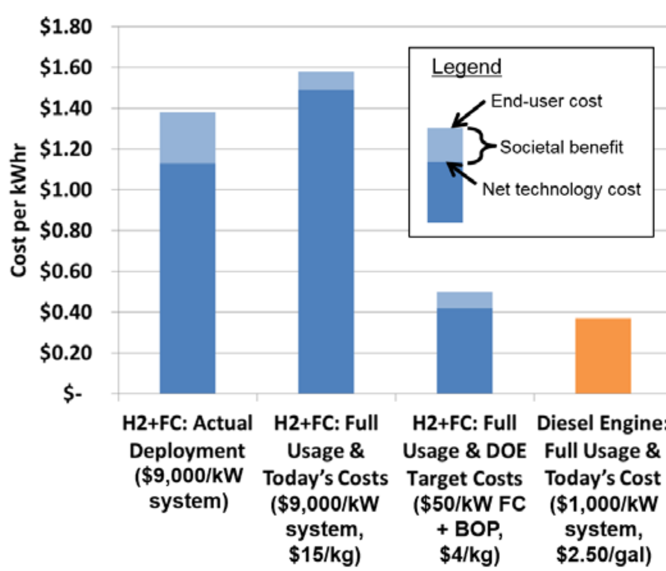

FIGURE 4. Summary economic evaluation of the 100 kW fuel cell generator for the deployment and projected full usage, with comparison to a notional 100 kW diesel generator. Today's highest cost factors are hydrogen fuel, hydrogen storage tanks, and power conditioning equipment.

power conditioning (inverter) and hydrogen storage tubes, where future cost reductions (to approximately 1/3 of today's costs) are necessary to enable competitiveness. The analysis also revealed that fuel is the major operating expense for these systems. While this demonstration enjoyed free fuel from the Hickam station, this will not be the case in true commercial adoption. Today's difference in hydrogen costs (high) and diesel costs (low) is expected to significantly decrease in the future as hydrogen costs decrease and diesel costs increase, but the current differential hinders the ability of today's fuel cell systems to achieve cost parity with today's diesel systems.

CONCLUSIONS AND UPCOMING ACTIVITIES

As the first validation of a self-contained hydrogen fuel cell generator at a port, this project showed that it is possible to reduce maritime-related emissions through the use of hydrogen fuel cells, and identified paths forward to more widespread adoption of the technology in the marine sector. This includes not only the use of a generator for reefer power but other applications as well. These include port equipment, electrical resiliency against grid outages, auxiliary power for vessels, and vessel propulsion power. Establishing hydrogen equipment usage at port also has the benefit of establishing a local hydrogen infrastructure hub that can be leveraged to provide hydrogen for regional transportation uses. Future usage of the generator by other hosts will continue to collect the information needed to completely assess the business case as well as provide opportunity for continued development of the technology.

The DOE–Maritime Administration–Sandia National Laboratories project leads are currently working to arrange a follow-on demonstration at a different partner following upgrade and refurbishment of generator features by the manufacturer. It is expected that this generator will continue to be demonstration by various partners in the future, displacing additional diesel generator emissions and breaking down market barriers to widespread hydrogen fuel cell technology deployment at each stop.

FY 2017 PUBLICATIONS/PRESENTATIONS

1. J.W. Pratt and S.H. Chan, "Maritime Fuel Cell Generator Project," Sandia National Laboratories Report #SAND2017-5751, May 2017. Available from: maritime.sandia.gov

2. J. Pratt, "Maritime Fuel Cell Generator Project," DOE Annual Merit Review, June 7, 2016, Washington, DC, Sandia National Laboratories presentation #SAND2017-3799 PE.