Maritime Fuel Cell Generator Project

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June 14, 2018

Project ID # MT013

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We have built and deployed a containerized hydrogen fuel cell generator for reefer power on land and sea.

<u>Project Concept</u>

Fuel cell unit replaces diesel generators, reducing fuel cost and emissions.

<u>Project Scope (2013-present)</u>

Design, build, and deploy a containerized fuel cell system to supply portable power for refrigerated containers ("reefers").

- 100 kW (net) fuel cell and H_2 storage inside a 20-foot container, ~ 4kW B.O.P.
- 9-month deployment on land and over the ocean. (Honolulu-Kahului)
- Strategic set of project partners, encompassing both the H_2-fuel cell and maritime communities.
- Upgrade the MarFC, find a post-Hawaii (June 2017) deployment site and re-deploy.

Project Overview

Timeline:
- Start: July 2017
- End: December 2018
- 50% complete

Budget:
- Total: $1.16M
  - DOE FY17: $279K
  - DOT/MARAD* FY17: $250K
  - Contractor Share (est.): $202K
  - DOE FY18 Planned: $0K
  - DOT/MARAD FY18 Planned: $329K

MT Barriers Addressed:
- A: Inadequate standards
- E: Financing mechanisms (Lack of cost and performance data)
- F: Inadequate user experience

Partners:
- Sandia *(project manager)*
- Massport
- Air Liquide *(cost share)*
- Airgas *(cost share)*
- Hydrogenics *(sub w/ cost share)*

*DOT/MARAD: US Department of Transportation, Maritime Administration

Relevance – Overall Project Objectives

- ✓ **Lower the technology risk** of future port fuel cell deployments by providing performance data of H_2-PEMFC technology in this environment. (*Barrier: E*)
- ✓ **Lower the investment risk** by providing a validated economic assessment for this and future potential projects. (*Barrier: E*)

- ✓ **Enable easier permitting and acceptance** of H_2-FC technology in maritime applications by assisting USCG and ABS develop H_2+FC codes and standards. (*Barrier: A*)
- ✓ **Engage potential adopters/end users** of hydrogen fuel cells to enable more widespread acceptance of the technology. (*Barrier: F*)

Approach: July 2017 - Present

- Modify Project Team to Support Massport Deployment for “Reefers.”
- Upgrade the MarFC generator, Conduct Reliability Tests.
- Determine Optimal Refueling Scenario, Generate H_2 Cost Estimates.
- Define Needed Refueling Hardware for Use at Massport.
- Engage with Massport to Secure Legal Agreement for Deployment.
- Plan for 3-month Phase 1 deployment (moderate-use schedule).
- Plan for 3-month Phase 2 deployment (heavy-use schedule).

Collaboration/Coordination: Reconfigured Project Team

Sandia National Laboratories (Project Lead, Pratt → Klebanoff)

U.S. Department of Transportation Maritime Administration ($)

Hydrogenics (Fuel Cell Provider)

Massport (Deployment Site)

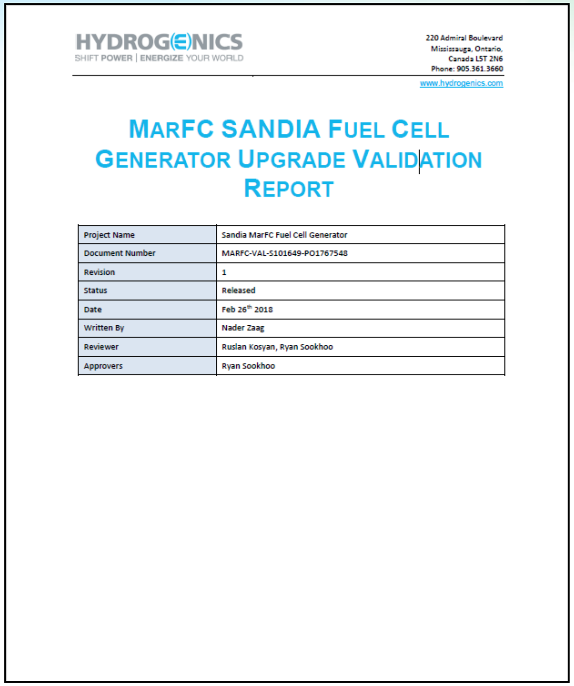
Air Liquide (H_2 Provider)

Airgas (H_2 Delivery)

MarFC Repair, Upgrade and Testing by Hydrogenics

Based on the deployment the prior year
in Honolulu, Hydrogenics repairs/upgrades the unit:

	Improvement	
1	Fix inverter	*
2	Operator interface	*
3	Battery duration	
4	Extended run testing at factory	
5	H2 detectors, filters	
6	Coolant water thermocouple	
7	Battery charger	
8	Coolant line pressure	
9	FC rack pressure transducer	
10	DI water tank and monitor	
11	Upgrade internal cooling fans	
12	Notification email system	
13	Monitor power at plugs	
14	Fix tank temperature jump issue	
15	Modify rack to allow single module failure	
16	Modify generator for sub-zero operation	*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MARFC SANDIA FUEL CELL GENERATOR UPGRADE VALIDATION REPORT

Project Name	Sandia MarFC Fuel Cell Generator
Document Number	MARFC-VAL-S101649-PO1767548
Revision	1
Status	Released
Date	Feb 26th 2018
Written By	Nader Zaag
Reviewer	Ruslan Kosyan, Ryan Sookhoo
Approvers	Ryan Sookhoo

Hydrogenics MarFC upgrade report to Sandia

MarFC Repair, Upgrade and Testing by Hydrogenics

Operator interface:

Problem: Operators of the generator during deployment could not tell from the outside what the unit was doing during start-up (~ 6.5 minutes).

Solution: Hydrogenics added a 12” extreme ruggedized display to the front panel of the unit. A state flow chart is given on start-up that indicates the current state of operation. Additionally, the operator can access sub screens which display additional operational information including the power being output on each plug, system pressures and temperatures, etc.

Display Location

12" Outdoor Waterproof Display

Also, the MarFC generator start-up time has been reduced by 2 minutes via a new inverter and optimizations of the FC start procedure.

MarFC Repair, Upgrade and Testing by Hydrogenics

Inverter upgrade:

Problem: During the Honolulu deployment, a primary source of system failure was attributed to the main inverter.

Solution: Working with ABB's maritime group based in Finland, Hydrogenics modified the MarFC to include a proven ruggedized HESS-880 converter solution. The complete solution includes other electronic components including 440VAC to 230VAC step down transformer and filtering of the AC output.

One of 3 HESS-800 ABB Converter Building Blocks

MarFC Repair, Upgrade and Testing by Hydrogenics

Modify MarFC for Sub-zero Temperature Operation:

Problem: With the generator being deployed to the Port of Massachusetts (Massport), the MarFC generator is required to operate in sub-zero temperatures.

Solution: The changes to allow sub-zero operation were as follows:

1. The unit was retrofitted with two 4 kW heaters
2. The fuel cell and inverter coolant was changed to one rated to -36 degrees C.
3. Operational software was modified to allow sub-zero temperature operation.

Heater Type	Electric
Heat Output	13,600 Btu/hr.
Maximum Area Heated @ Temperature Change	1,810 cu. ft. @ 10° F 910 cu. ft. @ 20° F 600 cu. ft. @ 30° F 450 cu. ft. @ 40° F
Airflow	100 cfm
Wattage	4,000 W
Voltage	208V AC/240V AC
Current	16.7 A
Electrical Phase	Single
Overall	
Height	19 5/16"
Width	15 3/4"
Depth	4"
Housing	
Material	Painted Steel
Color	White
Control Type	Thermostat
Temperature Setting	40° to 90° F
Power Source	Wire Leads
Specifications Met	ETL Listed
Mounting Location	Wall
Mount Type	Recess, Surface
Mobility	Stationary

heater specification sheet

MarFC Repair, Upgrade and Testing by Hydrogenics

Indoor/Outdoor Testing of the MarFC in Toronto, December 2017

Indoor Testing: After the 15 repairs and upgrades were made to the unit, Hydrogenics tested it indoors from 11/29/2017 – 12/12/2017, to gain confidence in the operation of the new systems. Multiple stop-starts were conducted to exercise the start-up improvements.

Outdoor Testing: From 12/22/2017 – 1/3/2018, the internal heaters for the unit were successfully tested. During this test, the ambient temperature was as low as -20 degrees C. The heaters provided an internal container temperature + 25 degrees C above the cold ambient.

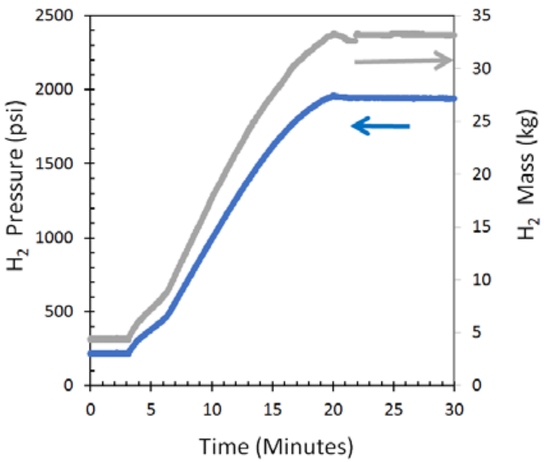
Indoor Testing at Hydrogenics, Mississauga Canada (near Toronto)

Outdoor Testing at Hydrogenics,

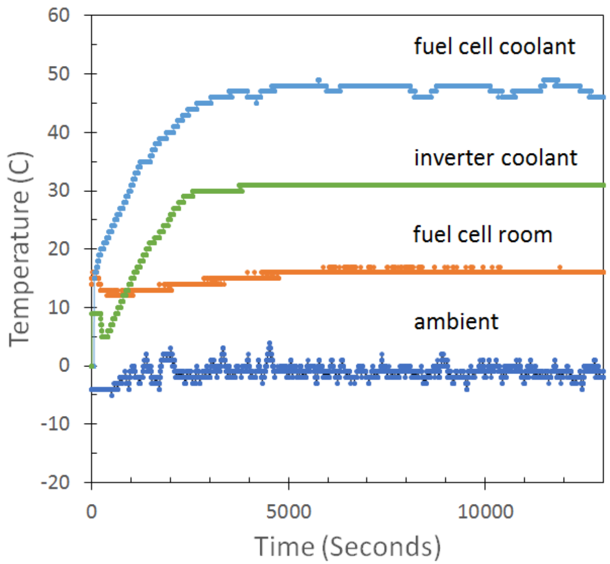
MarFC Repair, Upgrade and Testing by Hydrogenics

Outdoor Testing Data: Different test data were logged during the outside test, including output power to the reefers, temperatures of the fuel cell and inverter coolants and container interior.

Outdoor Testing at Hydrogenics



H_2 Refueling



System Temperatures

Conclusions from Upgrade/Testing Activity

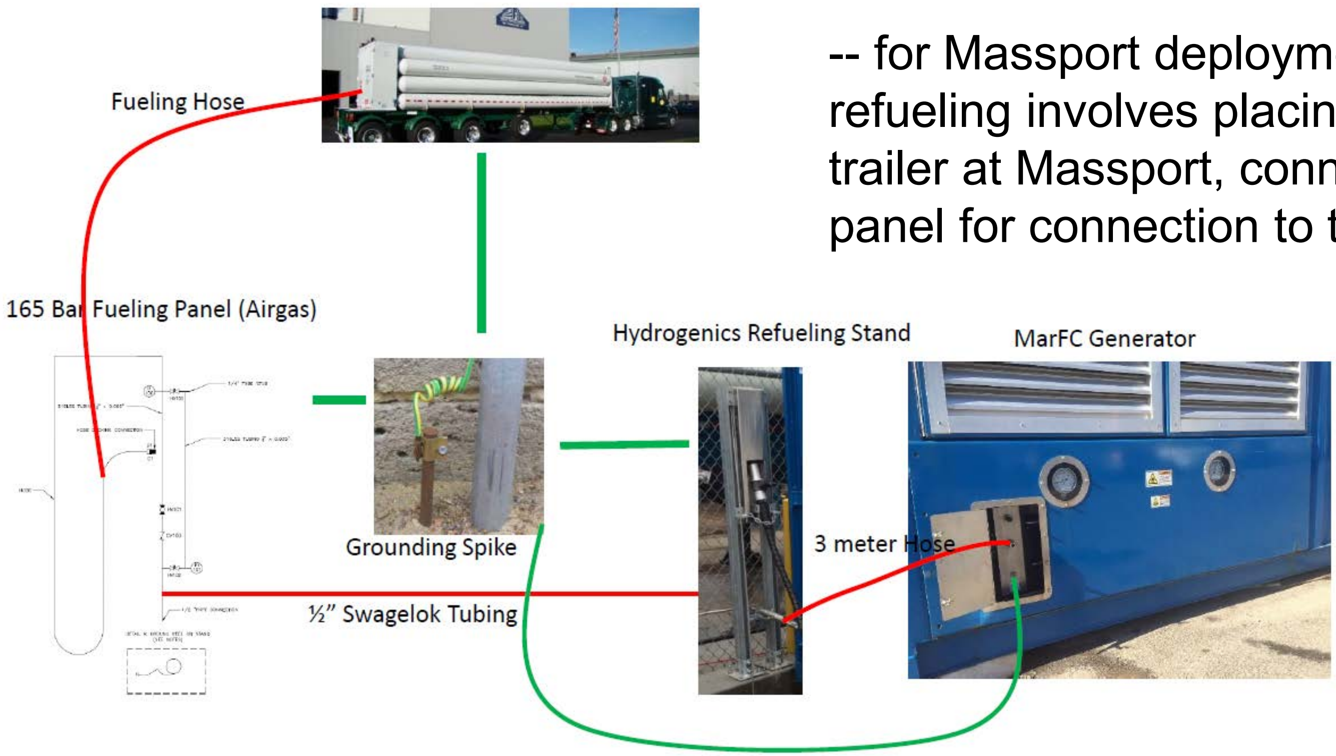
- ✓ The inverter solution is now extremely robust and the start-up concerns have been resolved
- ✓ The new inverter is water-cooled, removing waste heat from the MarFC interior.
- ✓ 2 minute improvement in the start-up time.
- ✓ Rugged system display screen makes it easy for the operator to ascertain the state of the MarFC, especially during start-up.
- ✓ MarFC can now operate in weather down to -25 degrees C.
- ✓ System allows monitoring of the power at each reefer plug.
- ✓ The fuel cell coolant system has been improved for serviceability.

Overall, we have full confidence in the upgrades performed and the ABB inverter solution. All of the major concerns from the Honolulu deployment have been addressed.

Optimal Refueling Scenario Developed by Air Liquide/Airgas and Hydrogenics

The Maritime fuel cell needs ~ 67 kg of 350 bar H_2 for refueling. The relatively small amount of hydrogen (compared to a trailer) makes mobile H_2 delivery inefficient, comparatively costly.

-- for Massport deployment, optimal refueling involves placing a 165 bar tube trailer at Massport, connecting to a refueling panel for connection to the MarFC.



Looking for a New Deployment Site for the MarFC

Sandia/Massport could not agree on terms and conditions

Scripps Institution of Oceanography (San Diego, CA):

- Well versed in hydrogen fuel-cell technology through the MARAD Zero-V hydrogen fuel cell research vessel feasibility project. Potential to take the unit out on the water on a coastal research vessel.
- Scripps is very motivated to reduce their emissions on vessels and in dockside operations.
- We are currently reviewing the Scripps legal and technical requirements.

We are also exploring other port opportunities in the Northeast and on the West Coast....

(“Any proposed future work is subject to change based on funding levels”)

Responses to Previous Year Reviewers' Comments

"The project faced many challenges that prevented it from achieving its goals. The number of technical issues that caused downtime was too high, and the system never made it onto the barge as planned. This type of demonstration project should show potential customers that fuel cells are a viable candidate to replace incumbent technologies, but in this project, the high amount of downtime probably sent the opposite message."

-- the unit has undergone extensive modification to address the technical issues that led to unacceptable downtime. Testing of the unit indicates it can now be deployed reliably.

"Design of the inverter appears not to match requirements."

-- the inverter has been replaced and successfully tested.

"Labor/manpower issues are unacceptable..."

-- new potential deployment sites and partners are being identified and screened to ensure the labor support for the deployment is acceptable and provided.

Remaining Project Challenges and Barriers

- To find a deployment site that does not require indemnification
- To find a deployment site that does not require liability insurance beyond the current Sandia limit of $3,000,000.
- Cost of delivered hydrogen is still currently high (> $50/kg).

("Any proposed future work is subject to change based on funding levels")

Future Work

- More data is needed to complete technical and economic evaluation.
- Sandia, FCTO, and MARAD are actively engaged in arranging a subsequent demonstration project.

Photo by Sandia

- Future evaluations and operating experiences will enable answering the question of whether this technology will be able to compete with incumbent technology in the future, and how.

("Any proposed future work is subject to change based on funding levels")

Summary

- The project team was reconfigured to support a deployment at Massport.
- The MarFC hardware was upgraded to provide much better reliability, an improved operator interface, reduced start-up time, and operation down to -25 degrees C.
- H_2 (gas) trailer drop-off identified as the lowest-cost refueling scenario for Massport operation of the MarFC generator.
- Defined the needed refueling stantion for ease of H_2 delivery to the MarFC generator.
- Sandia and Massport could not reach agreement on terms and conditions.
- Currently looking for a new Port deployment partner on the East and West coasts.

Thank You!

Photo by author