

# Maritime Fuel Cell Generator Project

Joseph W. Pratt

Sandia National Laboratories

June 9, 2016



Photo by author

Project ID # MT013

This presentation does not contain any proprietary, confidential, or otherwise restricted information

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



## Project Concept

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

## Project Scope

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

- 100 kW (net) fuel cell and H<sub>2</sub> storage inside a 20-foot container.
- 9-month deployment on land and over the ocean. (Honolulu-Kahului)
- Strategic set of project partners, encompassing both the H<sub>2</sub>-fuel cell and maritime communities.

# Project Overview

## Timeline:

- Start: Sept. 2013
- End: June 2016
- 80% complete

## Budget:

- Total: \$2.4M
  - DOE Share: \$885k
    - \$40k received in FY13
    - \$720k received in FY14
    - \$125k received in FY15
  - DOT/MARAD\* Share: \$825k
    - \$700k received in FY13
    - \$125k planned in FY15
  - Contractor Share (est.): \$700k
- Non-DOE cost share pct. (est): 63%

## MT Barriers Addressed:

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

## Partners:

- Sandia (*project manager*)
- Young Brothers, Ltd.
- Foss Maritime
- Hydrogenics (*sub w/ cost share*)
- Hawaii Natural Energy Institute (HNEI)
- American Bureau of Shipping (ABS)
- US Coast Guard (USCG)
- Hydrogen Safety Panel
- Hawaii Center for Advanced Transportation Technologies (HCATT)
- PNNL (*subcontractor*)

# Collaboration: Without all partners working together this project would not be possible.

Partner		Project Roles
	DOE	Sponsorship, steering
	DOT/MARAD	Sponsorship, steering, and facilitation of maritime relationships
	Young Brothers & Foss Maritime	Site preparations, prototype operation and routine maintenance
	Hydrogenics ( <i>sub w/ cost share</i> )	Design, engineer, build, commission, and support prototype unit
	HNEI	Hydrogen supply logistics facilitation
	HCATT	Hydrogen provider
	ABS	Prototype design to maritime product standards
	US Coast Guard	Review and acceptance of prototype design and operation
	PNNL H <sub>2</sub> Safety Program	Prototype and project safety review by HSP; Hydrogen Emergency Response Training for First Responders
	Sandia	Mgmt. and coord., H <sub>2</sub> materials, systems, risk expertise, H <sub>2</sub> supply logistics, tech/biz data collection and analysis



Logos used with permission

## Relevance – Overall Project Objectives

- ✓ **Lower the technology risk** of future port fuel cell deployments by providing performance data of H<sub>2</sub>-PEMFC technology in this environment.
- ✓ **Lower the investment risk** by providing a validated business case assessment for this and future potential projects.

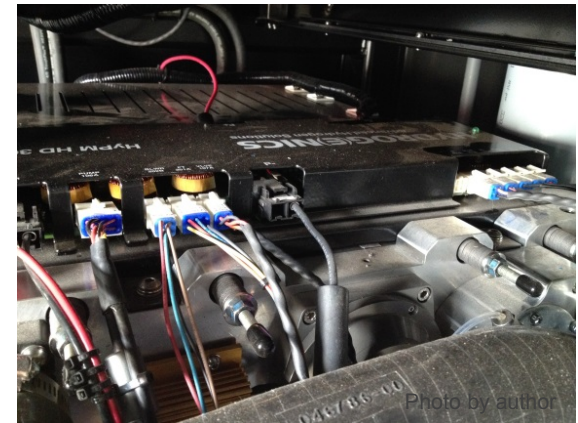


- ✓ **Enable easier permitting and acceptance** of H<sub>2</sub>-FC technology in maritime applications by assisting USCG and ABS develop hydrogen and fuel cell codes and standards.
- ✓ **Act as a stepping stone** for more widespread shipboard fuel cell APU deployments.
- ✓ **Reduce port emissions** with this and future deployments.

Photo by author

# Relevance – FY16 Impact as related to Project Objectives

- FY16 Impact: **Lower technology and business risk**
  - ✓ Deployment
  - ✓ Technical performance data collection and analysis
  - ✓ Business case and economic data collection and analysis
- FY16 Impact: **Lower port emissions**
  - ✓ Eliminated > 5,400 kWhr of diesel power generation (as of April 2016)
- FY16 Impact: **Enable easier permitting and use**
  - ✓ Working with HNEI and HI-DOT/Harbors for on-dock refueling
- FY16 Impact: **Maintain hydrogen infrastructure capability on Oahu in support of this and future strategic projects**
  - ✓ Support Hickam station



# Approach: Project Phases and Selected Milestones

## 1. Establish team and define prototype

- ✓ Team charter/MOU
- ✓ Agree upon prototype functional specifications
- ✓ Initial briefings with code/safety officials

(FY14 Q1)

RED: Completed in FY16

## 2. Design prototype, H<sub>2</sub> supply logistics

- ✓ Preliminary prototype design
- ✓ Final prototype design
- ✓ Hydrogen supply plan
- ✓ Safety reviews completed

(FY14 Q2-Q3)

- ✓ On-site H<sub>2</sub> familiarity and safety training
- ✓ Site preparations complete
- ✓ Prototype FAT
- ✓ On-site commissioning

## 3. Build prototype and site prep

(FY14 Q4 - FY15 Q4)

- ✓ Operational control by host
- ☐ Technical and business case analyses

## 4. Deploy on dock and on barge

(FY15 Q4-FY16Q3)

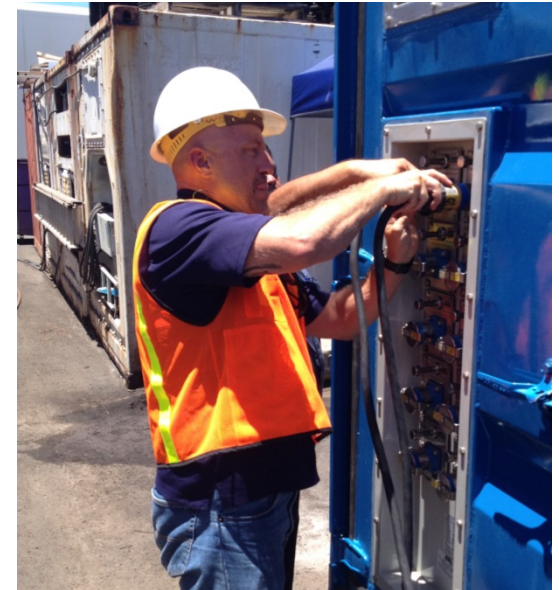
# Accomplishment: Completed on-site commissioning

- Twelve days, with Hydrogenics on-site
- Prepped the unit for run after shipping
- First fill
- Ran for over 32 hours, up to 10 reefers
- Found and fixed a number of issues



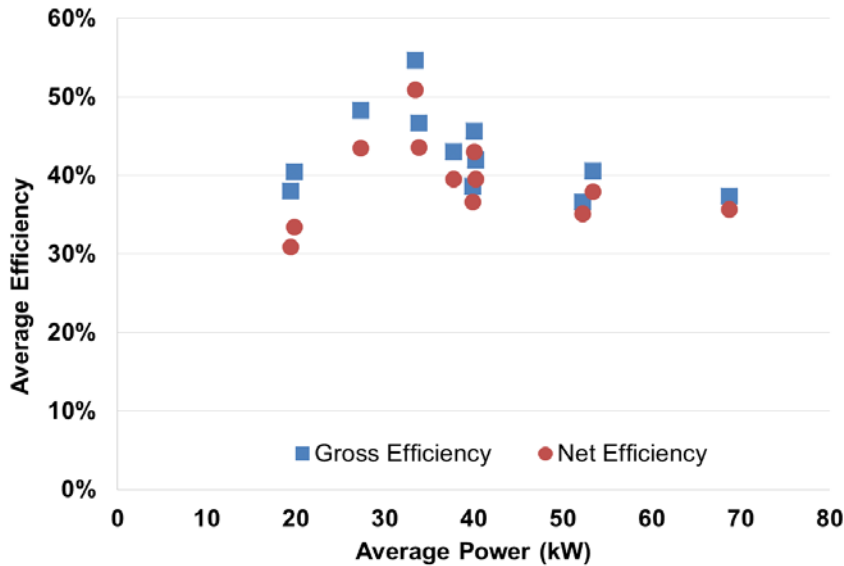


# Accomplishment: Operational turnover to YB and running since August 2015 with over 200 hrs (as of April 2016)

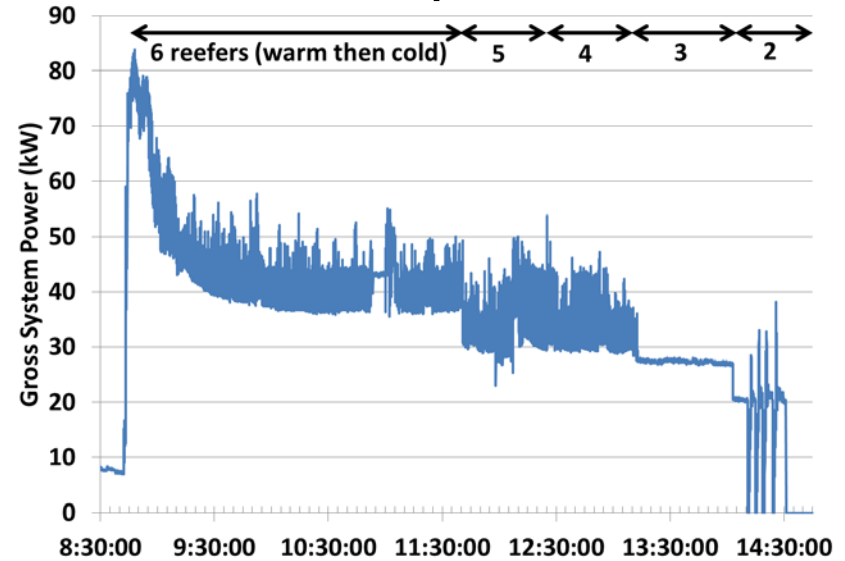


# Accomplishment: Run data collection and preliminary analyses

*Efficiency analysis*



*Run profiles*



*Maintenance and problem logs (technical and non-technical)*

#	Date of Event	DETAILED EVENT DESCRIPTION	LESSONS LEARNED	OUTCOME	EVENT DESCRIPTION	EQUIPMENT/SUBSYSTEM INVOLVED	PRIMARY FACTOR
1	9/28/2015	USCG visit		Results in little or no downtime or expense	Logistical	External	Logistical
2	10/4/2016	Chris goes to labor negotiations	He will be gone 3-4 days for 3-4 weeks. No one will operate the unit	Results in significant downtime and/or expense	Logistical	Labor/manpower	Logistical
3	10/4/2016	Trog is on vacation	Not enough manpower to monitor and operate the unit	Results in little or no downtime or expense	Logistical	Labor/manpower	Logistical
4	10/19/2015	Moved unit to Pier 40 but failed to start unit because of fault. Unit remained at the side of maintenance building		Results in less than one week of downtime and/or moderate expense	Equipment Malfunction	Fuel Cell	Inadequate Non-working Equipment
5	10/19/2015	High bar compressor breaks down		Results in significant downtime and/or expense	Equipment Malfunction	Compressor	Inadequate Non-working Equipment
6	10/19/2015	Inverter fault. Send fault data to manufacturer for inspection. System cannot go into AC output mode		Results in significant downtime and/or expense	Electrical Issue	Electrical, Interconnection, Power Management	Maintenance Required
7	10/??/2015	Local ABS visit, Gavin gave tour		Results in little or no downtime or expense	Logistical	External	
8	10/??/2015	Two barges are out of service.		Results in less than one week of downtime and/or moderate	External Issues on Site	Barge	Maintenance Required

# Accomplishment: Eight fills at Hickam with over 450 kg total hydrogen dispensed (April 2016)



Photo by author



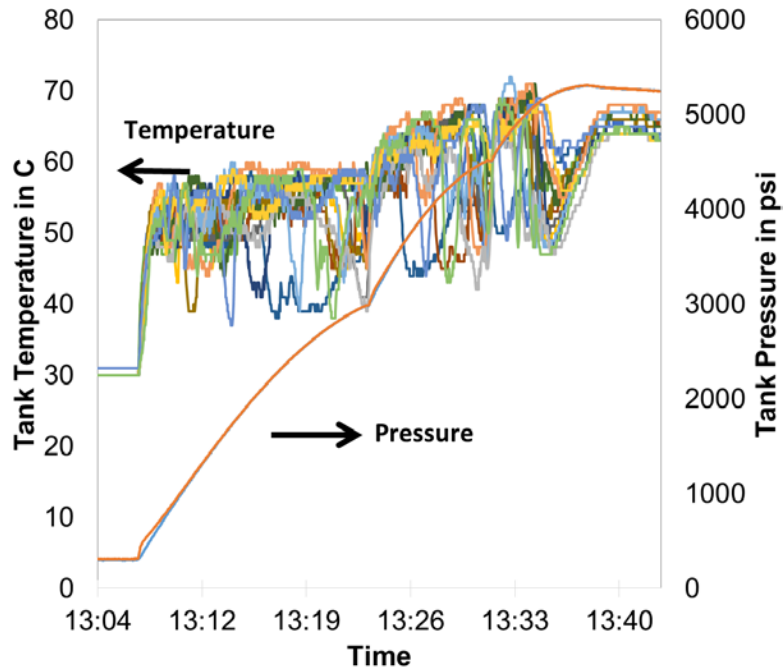
Photo by author



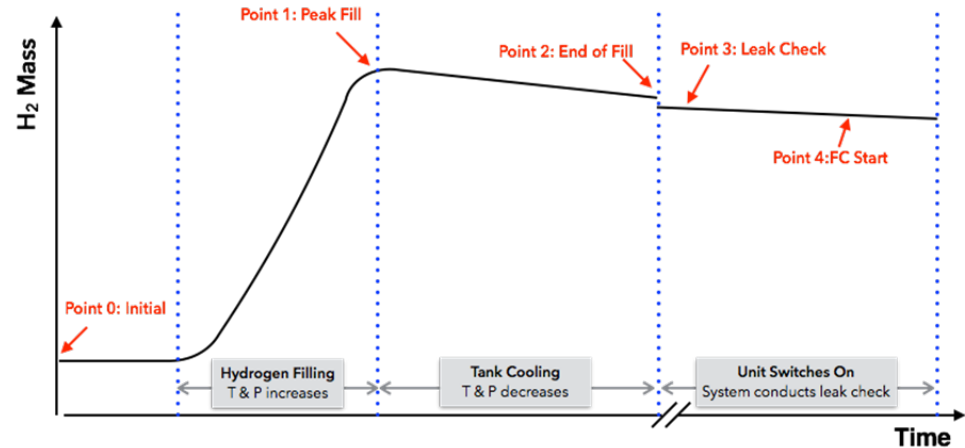
Photo by Mitch Ewan/HNEI, used with permission

Planned:  
Fill with  
HNEI tube  
trailer

# Accomplishment: Fill data analysis



*Fill profiles*



*Fill amount*

# Accomplishment: Identified primary technical and non-technical reasons for lack of use

- Technical: Inverter issues
  - Multiple hardware and configuration issues cause startup problems
  - “One-off” gives supplier little incentive to support
  - Identifies inverters at these power levels as a potential cost and reliability roadblock to widespread fuel cell generator deployment
- Non-technical: Manpower issues
  - Imperfect operation and limited familiarity leads to more attention needed than a typical generator
  - Current operations personnel are supporting other duties
  - Site recommends a dedicated person
  - Better operator feedback may help



# Accomplishment: Continued Broad Outreach Campaign

## Ribbon Cutting at Young Brothers, August 26, 2015

- 8 Speakers
  - US Senator Schatz (HI)
  - Hawaii State Leadership
  - Project Sponsors & Partners
- Demo/Tours of the Unit
- 55 Attendees
  - Energy Industry Early Adopters (business), Military/Government, and Project Partners
- Reported in 36 unique outlets receiving over 10.5 million page views



# Accomplishment: Continued Broad Outreach Campaign

## Outreach materials:

- Fact sheets
- Website: [maritime.sandia.gov](http://maritime.sandia.gov)
- Postcard
- Posters
- Keychains for YB personnel
- Summary PR video on Vimeo
- Local web-TV appearance (ThinkTech Hawaii, YouTube)
- Three public presentations

**Maritime Hydrogen Fuel Cell**

**Safety is the First Priority**

Integrated into the Design and Use of the Generator

**Completed Failure Mode Effects Analysis (FMEA)**

- Identified potential failure points and devised mitigation tactics based on three core principles:
  - Not allowing accumulation of a hazardous amount of hydrogen.
  - Minimizing stored energy and ensuring releases are not hazardous.
  - Preventing damage by external events.

**Independent Design Review and Approval**

- Facility handling is acceptable but a top pick is preferred to avoid damage and the resulting equipment downtime.
- Allow at least 7% of separation between the generator's access door and the adjacent container or structure when operating.
- Revisit the generator when individuals need to enter to the release zone; treating the zone is acceptable.
- In the case of fire or ground fire, generator workers should not enter the zone of potential hydrogen release.

**Scenario-Specific Operational Safety Controls**

- U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Fuel Cell Technologies Office
- U.S. Department of Transportation Maritime Administration
- Young Brothers, Limited
- Foss Maritime Company

**Project Partners**

- Sandia National Laboratories
- U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Fuel Cell Technologies Office
- U.S. Department of Transportation Maritime Administration
- Young Brothers, Limited
- Foss Maritime Company
- The United States Coast Guard & Local Waterfronts Office
- American Bureau of Shipping

Learn more about the project at [maritime.sandia.gov](http://maritime.sandia.gov)

**Maritime Hydrogen Fuel Cell**

The hydrogen fuel cell designed by Hydrogenics Corp. has a similar outward appearance and functionality to a maritime diesel generator

20 ft x 20 ft container  
300 kW (120 plugs)  
75 kg of H<sub>2</sub> (1,000 psi)  
Designed for roughly 200 reefer-hours of continuous operation

Hydrogenics fuel cells have a long track record of supplying off-road clean power for a wide range of applications, including forklifts, emergency backup systems, and vehicles. An analysis by Sandia and DOE showed that due to recurring loads in maritime auxiliary power applications, a hydrogen fuel cell, which stores the fuel, is more energy efficient than a diesel engine. A hydrogen fuel cell only supplies power when it is needed. The maritime hydrogen fuel cell program is a demonstration of this analysis in a commercial port setting.

The project began its field trial in August 2015 with a six-month deployment funded by Young Brothers.

A subsidiary of Foss Maritime Co., its facility in the Honolulu area. The U.S. Department of Energy Fuel Cell Technologies Office is funding the pilot. The pilot hydrogen fuel cell will reduce a total generator capacity used to provide power for refrigerated containers on board and on-berth barges.

Hydrogenics Corp. designed and manufactured a commercial off-board hydrogen fuel cell unit, which includes the fuel cell stack, multiple storage systems, and power conversion equipment. The unit has a standard shipping container, the unit has a standard generator and functionality similar to maritime diesel generators that are currently in use.

**GLENN HONG**  
President, Young Brothers, Ltd.

01:24

HD :: vimeo

**Maritime Hydrogen Fuel Cell**

Hydrogen fuel cell demonstration project at Honolulu Harbor

Hydrogen fuel cells have a long track record of supplying off-road clean power for a wide range of applications, including forklifts, emergency backup systems, and vehicles. An analysis by Sandia and DOE showed that due to recurring loads in maritime auxiliary power applications, a hydrogen fuel cell, which stores the fuel, is more energy efficient than a diesel engine. A hydrogen fuel cell only supplies power when it is needed. The maritime hydrogen fuel cell program is a demonstration of this analysis in a commercial port setting.

The project began its field trial in August 2015 with a six-month deployment funded by Young Brothers.

A subsidiary of Foss Maritime Co., its facility in the Honolulu area. The U.S. Department of Energy Fuel Cell Technologies Office is funding the pilot. The pilot hydrogen fuel cell will reduce a total generator capacity used to provide power for refrigerated containers on board and on-berth barges.

Hydrogenics Corp. designed and manufactured a commercial off-board hydrogen fuel cell unit, which includes the fuel cell stack, multiple storage systems, and power conversion equipment. The unit has a standard shipping container, the unit has a standard generator and functionality similar to maritime diesel generators that are currently in use.

**Operational Safety Controls**

- U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Fuel Cell Technologies Office
- U.S. Department of Transportation Maritime Administration
- Young Brothers, Limited
- Foss Maritime Company
- The United States Coast Guard & Local Waterfronts Office
- American Bureau of Shipping

**Maritime Hydrogen Fuel Cell**

**Safety is the First Priority**

Integrated into the Design and Use of the System

**Completed Failure Mode Effects Analysis (FMEA)**

- Identified potential failure points and devised mitigation tactics based on three core principles:
  - Not allowing accumulation of a hazardous amount of hydrogen.
  - Minimizing stored energy and ensuring releases are not hazardous.
  - Preventing damage by external events.

**Independent Design Review and Approval**

- Facility handling is acceptable but a top pick is preferred to avoid damage and the resulting equipment downtime.
- Allow at least 7% of separation between the generator's access door and the adjacent container or structure when operating.
- Revisit the generator when individuals need to enter to the release zone; treating the zone is acceptable.
- In the case of fire or ground fire, generator workers should not enter the zone of potential hydrogen release.

**Scenario-Specific Operational Safety Controls**

- U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Fuel Cell Technologies Office
- U.S. Department of Transportation Maritime Administration
- Young Brothers, Limited
- Foss Maritime Company

**Project Partners**

- Sandia National Laboratories
- U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Fuel Cell Technologies Office
- U.S. Department of Transportation Maritime Administration
- Young Brothers, Limited
- Foss Maritime Company
- The United States Coast Guard & Local Waterfronts Office
- American Bureau of Shipping

**Young Brothers Maritime Fuel Cell**

3:25 / 4:09



**Maritime Hydrogen Fuel Cell Project**

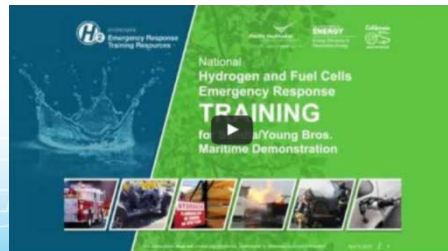
Demonstrating the feasibility of a hydrogen fuel cell in a marine environment

Hydrogen fuel cells provide efficient, clean power for a wide range of applications. The maritime project will demonstrate a clean energy power alternative to diesel generators for self-generated applications.

The hydrogen fuel cell will be deployed by Young Brothers Ltd., a subsidiary of Foss Maritime Co., at its facility in the Honolulu harbor and then on barges between its Hawaii harbor locations.

# Accomplishment: Continued training

- Provided resources for YB internal training
  - “Train the trainer” (April 2015 training)
  - On-line training video (hosted at h2tools.org)
  - Training FAQ sheet
  - Reached over 100 additional YB operational personnel
- On-site hands-on training
  - Direct from the manufacturer
  - Trained over 20 potential users



<https://h2tools.org/content/maritime-fuel-cell-project-and-hydrogen-safety-training>



# Responses to Previous Year Reviewers' Comments

- **“The benefits (e.g., economics, emissions, and noise) to the site operator need to be made more obvious”**
  - Reply: The project report will include an assessment of benefits considering the data and information gathered during the deployment.
- **“These results should be disseminated among the right companies or regulatory agencies for this marine application to keep it from being just a “one-off” demonstration.”** *(and three other similar comments)*
  - Reply: The project results have been continually conveyed through the project’s outreach efforts, and this is anticipated to continue after the deployment has concluded.
- **“Questions around using hydrogen on board ships/vessels in the context of international standards need to be examined in more detail.”**
  - Reply: This project has opened the door to collaboration with US and international maritime codes and regulations in the area of hydrogen as a shipboard fuel and for bulk shipping of hydrogen. Sandia has established a Zero Emission Hydrogen Vessel Working Group to bring together stakeholders of all kinds.
- **“Some air quality measurements are needed as soon as possible.”**
  - Reply: The project includes assessment of fuel cell performance in the port/marine environment. The fuel cell technology used has been tested in a wide range of conditions including those encountered at the site. Additional protective filters special for the maritime environment have been included.

# Remaining Project Challenges and Barriers

**Project Challenge:** Obtain sufficient usage for a robust technical and business case analysis

- ✓ **Planned Resolution:** Continue solving logistical and technical problems. Flexibility with usage method (empty vs. loaded reefers). Pursue subsequent usage opportunities.

**Project Challenge:** Accomplish on-site refueling

- ✓ **Planned Resolution:** Continue working with HI-DOT/Harbors on approval and HNEI on delivery trailer.

**Project Challenge/Market Barrier:**

Deployment successfully concludes but progress and results are not widely known.

- ✓ **Planned Resolution:** Continued careful planning and prioritization of outreach activities.



Photo by author

## Down the Road...



### Planned Future Work

- Deployment and data collection
  - On the dock, on the barge
  - Hydrogen fueling/delivery
  - Business effects
- Finish deployment
- Produce technical and business case analyses
- Continue outreach based on project results
- Transition generator to follow-on usage (TBD)

# Technology Transfer: This project is part of Hydrogenics' commercial development strategy for containerized PEM fuel cell solutions

## Development Process

- 2013: Hickam AFB - Gen 1: 66kW, Backup power
- 2014: Raglan Mine - Gen 2: 200kW, Baseload power
- **Early 2015: Maritime - Gen 2+H: 100kW with H<sub>2</sub> storage, Portable Power**
- Mid-2015: Kolon - Gen 2: 1 MW
  - Commercial product issued
  - Trial run complete
  - Moving to large scale volume
  - 20MW-50MW order expected 2016
  - Will drive down cost of fuel cells due to volume



Slide by Hydrogenics, used with permission

## Summary: Addressing Several MT Program Goals and Barriers

- Enabling faster permitting and acceptance for this and future maritime hydrogen and fuel cell deployments.
- Enabling technical and business case validation, lowering technology and business risk.
- Maintaining hydrogen infrastructure capability in the State of Hawaii in support of future FCEV rollout.
- Direct and indirect user experience with hydrogen and fuel cell technology in the far-reaching maritime and port sector.



Image by Hydrogenics, used with permission

### ***The Maritime Fuel Cell Project:***

*A wholly-collaborative effort with early and continuous stakeholders feedback that will successfully break down non-technical barriers to hydrogen and fuel cell use.*

# On behalf of the team, Thank You!

