Maritime Fuel Cell Generator Project

Joseph W. Pratt

Sandia National Laboratories

June 10, 2015

Project ID # MT013

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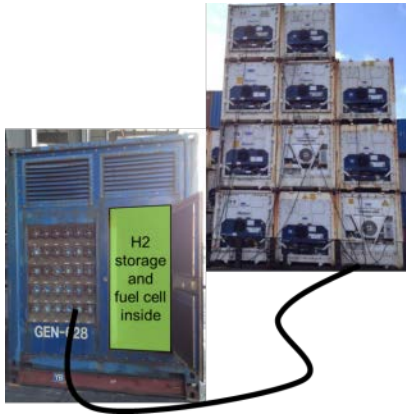
Project Background



Project Concept

PEMFC unit replaces diesel generators, saving 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) PEMFC and H_2 storage inside a 20-foot container.**
- **6-month deployment on land and over the ocean.**
- **Strategic set of project partners, encompassing both the H_2-fuel cell and maritime communities.**

All photos by author

Project Overview

Timeline:

- Start: Sept. 2013
- End: Dec. 2015
- 60% complete

Budget:

- Total: $2.4M
  - DOE Share: $885k
    - $40k received in FY13
    - $720k received & planned in FY14
    - $125k received &planned in FY15
  - DOT/MARAD* Share: $825k
    - $700k received in FY13
    - $125k planned in FY15
  - Contractor Share (est.): $700k
- 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)

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

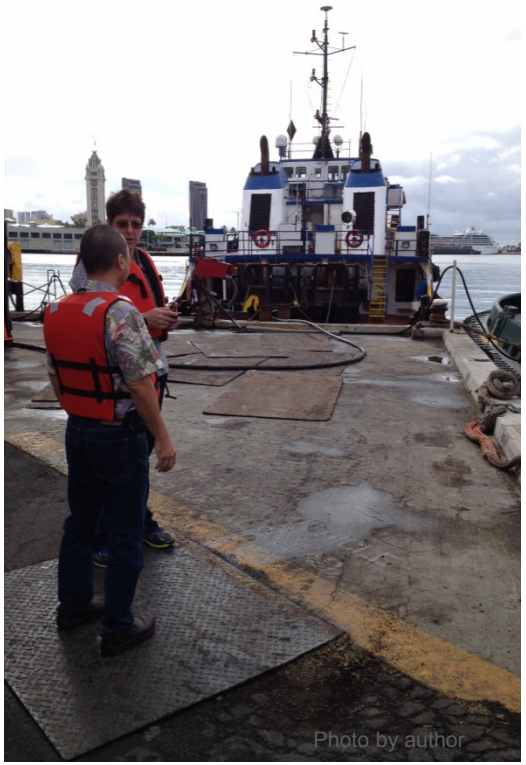
Collaboration: Without all partners working together this project would not be possible.

Partner	Project Roles
U.S. DEPARTMENT OF ENERGY	DOE: Sponsorship, steering
DOT/MARAD	Sponsorship, steering, and facilitation of maritime relationships
YOUNG BROTHERS Your Neighbor Island Partner; FOSS	Young Brothers & Foss Maritime: Site preparations, prototype operation and routine maintenance
HYDROGENICS SHIFT POWER | ENERGIZE YOUR WORLD	Hydrogenics *(sub w/ cost share)*: Design, engineer, build, commission, and support prototype unit
HNEI Hawai'i Natural Energy Institute University of Hawai'i at Mānoa	HNEI: Hydrogen supply logistics facilitation
HCATT Hawaii Center for Advanced Transportation Technologies	HCATT: Hydrogen provider
ABS	ABS: Prototype design to maritime product standards
SECTOR HONOLULU	US Coast Guard: Review and acceptance of prototype design and operation
Pacific Northwest NATIONAL LABORATORY	PNNL H_2 Safety Program: Prototype and project safety review by HSP; Hydrogen Emergency Response Training for First Responders
Sandia National Laboratories	Sandia: Mgmt. and coord., H_2 materials, systems, risk expertise, H2 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_2-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_2-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.



Relevance – FY15 Impact as related to Project Objectives

- FY15 Impact: **Enable new maritime-specific regulations for hydrogen and fuel cells**
  - ✓ Obtain final USCG design and operating approval
- FY15 Impact: **Enable new user experiences**
  - ✓ Hydrogen awareness training for over 100 personnel
  - ✓ Begin deployment with first-hand usage
- FY15 Impact: **Lower technology and business risk**
  - ✓ Begin deployment and data collection
  - ✓ Provide product development leverage for technology supplier
- FY15 Impact: **Maintain hydrogen infrastructure capability on Oahu in support of this and future strategic projects**
  - ✓ Support Hickam station, prove feasibility of two H_2 supply methods
  - ✓ Provide leverage for a new, high capacity hydrogen delivery trailer

Photo by author

Approach: Project Phases and Selected Milestones

1. Establish team and define prototype

(FY14 Q1)

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

RED: Completed in FY15

2. Design prototype, H_2 supply logistics

(FY14 Q2-Q3)

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

3. Build prototype and site prep

(FY14 Q4 - FY15 Q2)

- ✓ On-site H_2 familiarity and safety training
- ✓ Site preparations complete
- ✓ Prototype FAT
- ❑ On-site commissioning

4. Deploy on dock and on barge

(FY15 Q2-Q4)

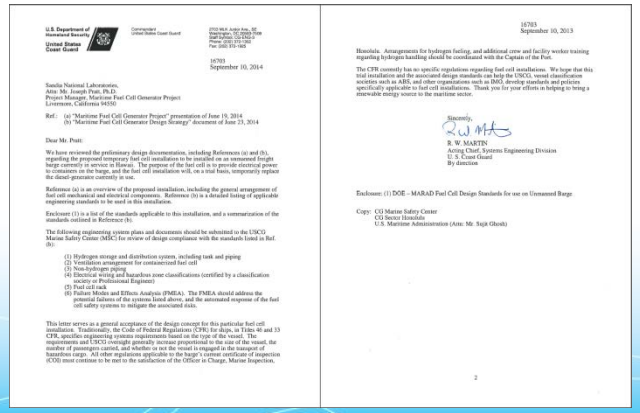
- ❑ Operational control by host
- ❑ Technical and business case analyses

A complete list of milestones and deliverables is given in the reviewer's backup section

Accomplishment: Continued win-win relationship with USCG and ABS

- Received design basis approval letter
- Submitted final design package

"The CFR currently has no specific regulations regarding fuel cell installations. We hope that this trial installation and the associated design standards can help the USCG, vessel classification societies such as ABS, and other organizations such as IMO, develop standards and policies specifically applicable to fuel cell installations. Thank you for your efforts in helping to bring a renewable energy source to the maritime sector."



U.S. Department of Homeland Security
United States Coast Guard

Commandant
United States Coast Guard

16703
September 10, 2014

Sandia National Laboratories,
Attn: Mr. Joseph Pratt, Ph.D.
Project Manager, Maritime Fuel Cell Generator Project
Livermore, California 94550

Ref: (a) "Maritime Fuel Cell Generator Project" presentation of June 19, 2014
(b) "Maritime Fuel Cell Generator Design Strategy" document of June 23, 2014

Dear Mr. Pratt:

We have reviewed the preliminary design documentation, including References (a) and (b), regarding the proposed temporary fuel cell installation to be installed on an unmanned freight barge currently in service in Hawaii. The purpose of the fuel cell is to provide electrical power to containers on the barge, and the fuel cell installation will, on a trial basis, temporarily replace the diesel generators currently in use.

Reference (a) is an overview of the proposed installation, including the general arrangement of fuel cell mechanical and electrical components. Reference (b) is a detailed listing of applicable engineering standards to be used in this installation.

Enclosure (1) is a list of the standards applicable to this installation, and a summarization of the standards outlined in Reference (b).

The following engineering system plans and documents should be submitted to the USCG Marine Safety Center (MSC) for review of design compliance with the standards listed in Ref. (b):

(1) Hydrogen storage and distribution system, including tank and piping
(2) Ventilation arrangement for containerized fuel cell
(3) Non-hydrogen piping
(4) Electrical plans and hazardous zone classifications (certified by a classification society or Professional Engineer)
(5) Fuel cell rack
(6) Failure Modes and Effects Analysis (FMEA). The FMEA should address the potential failures of the systems listed above, and the automated response of the fuel cell safety systems to mitigate the associated risks.

This letter serves as a general acceptance of the design concept for this particular fuel cell installation. Traditionally, the Code of Federal Regulations (CFR) for ships, in Titles 46 and 33 CFR, specifies engineering systems requirements based on the type of the vessel. The requirements and USCG oversight generally increase proportional to the size of the vessel, the number of passengers carried, and whether or not the vessel is engaged in the transport of hazardous cargo. All other regulations applicable to the barge's current certificate of inspection (COI) must continue to be met to the satisfaction of the Officer in Charge, Marine Inspection.

16703
September 10, 2013

Honolulu. Arrangements for hydrogen fueling, and additional crew and facility worker training regarding hydrogen handling should be coordinated with the Captain of the Port.

The CFR currently has no specific regulations regarding fuel cell installations. We hope that this trial installation and the associated design standards can help the USCG, vessel classification societies such as ABS, and other organizations such as IMO, develop standards and policies specifically applicable to fuel cell installations. Thank you for your efforts in helping to bring a renewable energy source to the maritime sector.

Sincerely,

R. W. MARTIN
Acting Chief, Systems Engineering Division
U. S. Coast Guard
By direction

Enclosure: (1) DOE – MARAD Fuel Cell Design Standards for use on Unmanned Barge

Copy: CG Marine Safety Center
CG Sector Honolulu
U.S. Maritime Administration (Attn: Mr. Sujit Ghosh)

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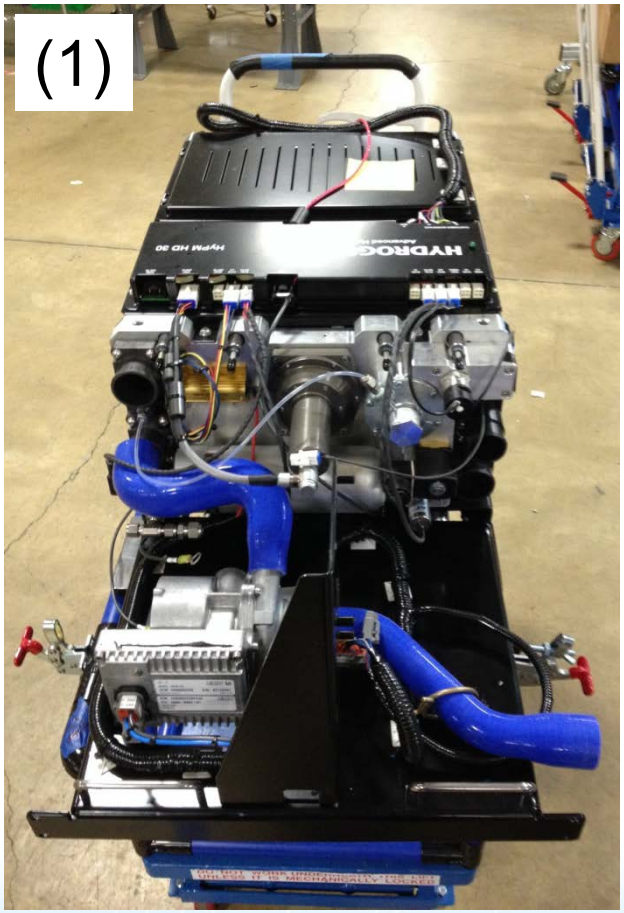
-R. W. Martin

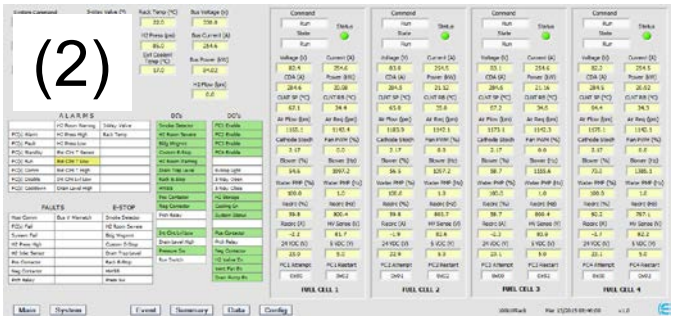
Acting Chief, Systems Engineering Division

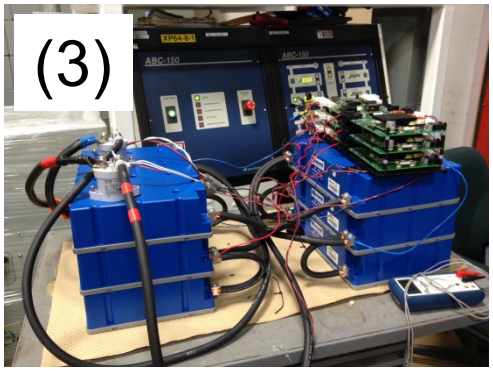
U.S. Coast Guard

Sept. 10, 2014

Accomplishment: Prototype Build Progress *(Hydrogenics Subcontract)*







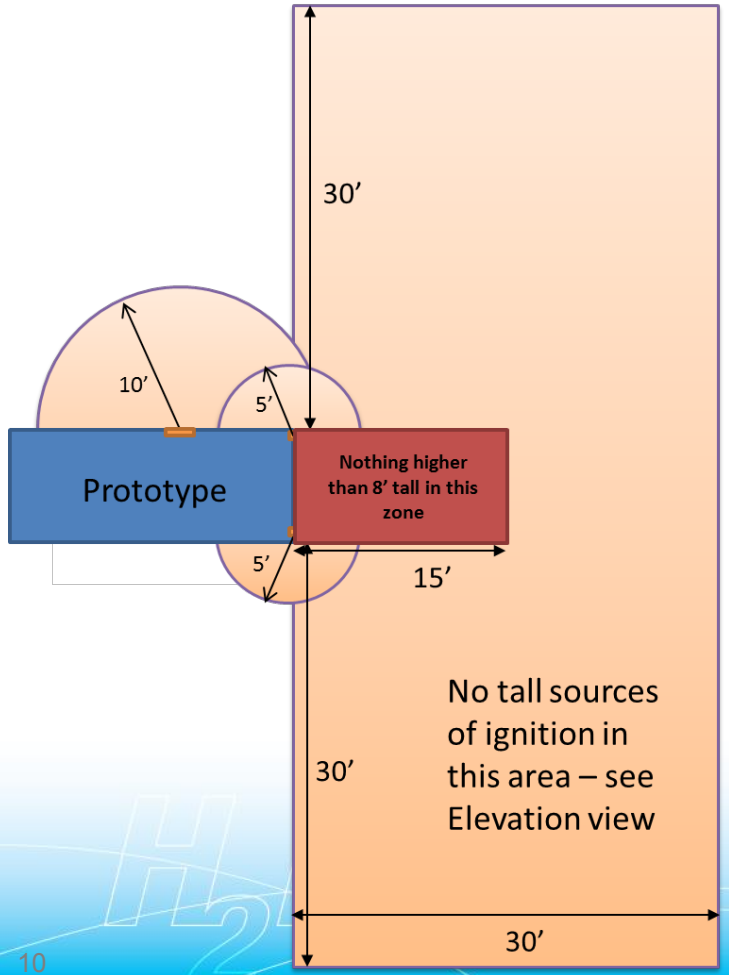
Photos by Hydrogenics, used with permission

(1) Fuel cell power module (2) User interface (3) Ultracap testing
(4) Custom inverter (5) Container modification

Accomplishment: Performed site-specific risk assessment

Original proposed setbacks

Un-workable for operations

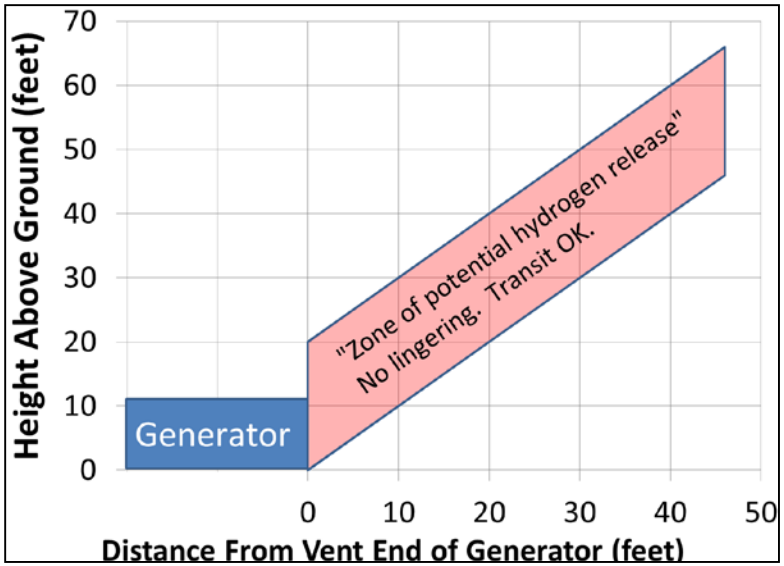


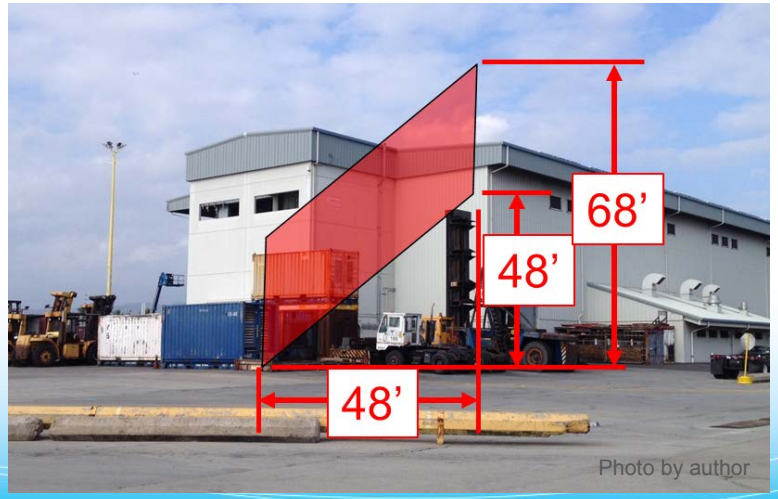
QRA*

Flow Modeling

Release modeling and risk-informed setback

Minimal restrictions, simple





*QRA: Quantitative Risk Assessment

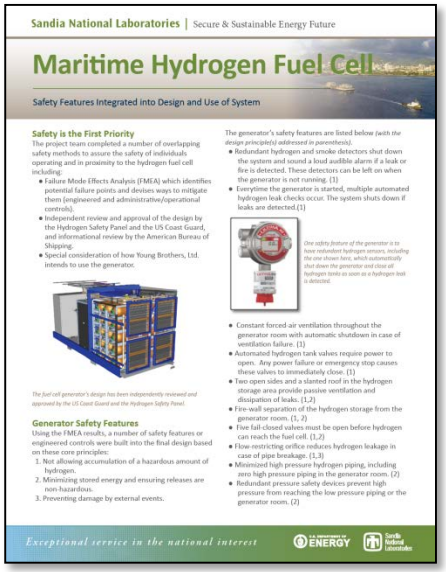
Accomplishment: Resolved hydrogen supply and refueling – Young Brothers has two options

1. Take to Hickam AFB for direct fill
   - Planned method initially
   - Generator will be placed on a chassis by Young Brothers and hauled to/from Hickam by a licensed trucker.

2. Fill on-site at the end of Pier 39 with a hydrogen delivery service (Luxfer-GTM)
   - Lasting impact: Project use/lease agreement enabled production of this new high-capacity trailer (220 kg @ 450 bar).

Accomplishment: Began broad outreach campaign

- Developed project Outreach Plan
- Devised container artwork
- Series of announcements in Young Brothers' *Bulletin*
- Single-page Fact Sheets (Overview, Safety Features)
- Planning for on-site PR event: August 28, 2015
- Identification for other targeted outreach (conferences/workshops, ports, and trade/environmental groups)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Maritime Hydrogen Fuel Cell

Safety Features Integrated into Design and Use of System

Safety is the First Priority

The project team completed a number of overlapping safety methods to assure the safety of individuals operating and in proximity to the hydrogen fuel cell including:

- Failure Mode Effects Analysis (FMEA) which identifies potential failure points and devises ways to mitigate them (engineered and administrative/operational controls).
- Independent review and approval of the design by the Hydrogen Safety Panel and the US Coast Guard, and informational review by the American Bureau of Shipping.
- Special consideration of how Young Brothers, Ltd. intends to use the generator.

The fuel cell generator's design has been independently reviewed and approved by the US Coast Guard and the Hydrogen Safety Panel.

Generator Safety Features

Using the FMEA results, a number of safety features or engineered controls were built into the final design based on these core principles:

1. Not allowing accumulation of a hazardous amount of hydrogen.
2. Minimizing stored energy and ensuring releases are non-hazardous.
3. Preventing damage by external events.

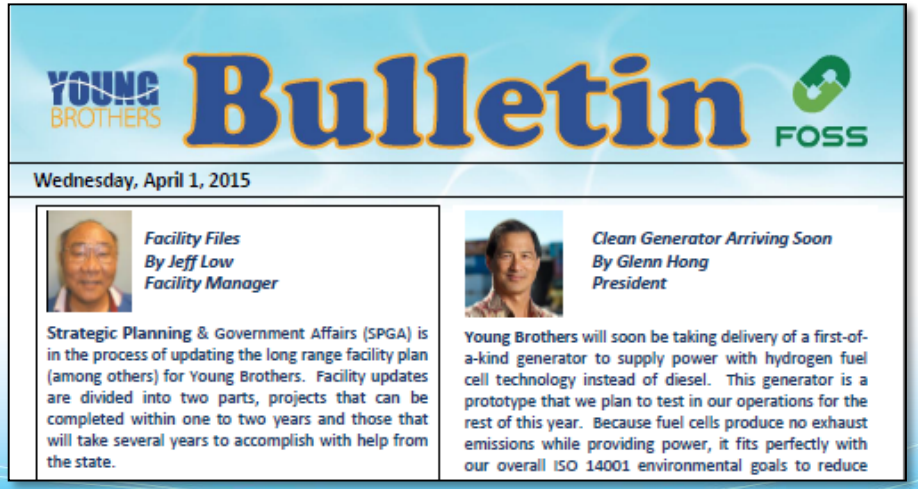
The generator's safety features are listed below (with the design principle(s) addressed in parenthesis).

- Redundant hydrogen and smoke detectors shut down the system and sound a loud audible alarm if a leak or fire is detected. These detectors can be left on when the generator is not running. (3)
- Everytime the generator is started, multiple automated hydrogen leak checks occur. The system shuts down if leaks are detected.(1)

One safety feature of the generator is to have redundant hydrogen sensors, including the one shown here, which automatically shut down the generator and close all hydrogen tanks as soon as a hydrogen leak is detected.

- Constant forced air ventilation throughout the generator room with automatic shutdown in case of ventilation failure. (1)
- Automated hydrogen tank valves require power to open. Any power failure or emergency stop causes these valves to immediately close. (1)
- Two open sides and a slanted roof in the hydrogen storage area provide passive ventilation and dissipation of leaks. (1,2)
- Fire-wall separation of the hydrogen storage from the generator room. (1, 2)
- Five fail-closed valves must be open before hydrogen can reach the fuel cell. (1,2)
- Flow-restricting orifice reduces hydrogen leakage in case of pipe breakage. (1,3)
- Minimized high pressure hydrogen piping, including zero high pressure piping in the generator room. (2)
- Redundant pressure safety devices prevent high pressure from reaching the low pressure piping or the generator room. (2)

Exceptional service in the national interest


YOUNG BROTHERS Bulletin FOSS

Wednesday, April 1, 2015

Facility Files
By Jeff Low
Facility Manager

Strategic Planning & Government Affairs (SPGA) is in the process of updating the long range facility plan (among others) for Young Brothers. Facility updates are divided into two parts, projects that can be completed within one to two years and those that will take several years to accomplish with help from the state.

Clean Generator Arriving Soon
By Glenn Hong
President

Young Brothers will soon be taking delivery of a first-of-a-kind generator to supply power with hydrogen fuel cell technology instead of diesel. This generator is a prototype that we plan to test in our operations for the rest of this year. Because fuel cells produce no exhaust emissions while providing power, it fits perfectly with our overall ISO 14001 environmental goals to reduce

Accomplishment: Provided H_2 Safety Program for on-site Hydrogen Familiarity and First Responder Training *(PNNL Subcontract)*

- **Twelve 3-hour sessions at two locations**
  - Project overview
  - "Hydrogen 101"
  - Live burner demonstration (thanks to Blue Planet)
  - Managing Hydrogen Related Emergencies
- **Trained over 100 personnel:**
  - First Responders from Honolulu FD
  - First Responders from Maui FD (destination port)
  - First Responders at sea (Resolve Marine and Clean Islands Council)
  - Officers and Enlisted from the USCG – Sector Honolulu
  - Young Brothers managers and personnel
  - American Bureau of Shipping
  - Servco (local Toyota dealer, will be receiving Mirai)
- **Lasting impact: videorecorded for distribution via PNNL's H_2 Safety National Program, use in future deployments, etc.**

Accomplishment: Factory Acceptance Test

- May 2015 with all project partners (verbal update)

Responses to Previous Year Reviewers' Comments

- **"…the team needs to do more quickly on the environmental requirements for the fuel cell, salt, water, drop, tilt, vibration, etc."**
  - Reply: The fuel cell technology used has been tested in a wide range of environmental conditions including those mentioned. Additional protective filters special for the maritime environment have been included.
- **"It may be prudent to include [Ballard] in the program, as they have already gone down a significant cost reduction curve. If not, the project team should comment on the selection process."**
  - Reply: Potential suppliers were solicited through a Federal Business Opportunity posting. Hydrogenics was selected in part because of a commitment to commercialization (a key objective of MT projects) evidenced by a significant cost-share investment.
- **"The timing is a weakness. The late award to Hydrogenics has put the schedule in jeopardy."**
  - Reply: The project team has been able to make up 2 months through a faster-than-anticipated container build and ship process. The deployment will likely be delayed by one month compared to the original project schedule.
- **"Liquid hydrogen should be considered as a fuel."**
  - Reply: It was during pre-project development, see SAND2013-0501. One step at a time… ☺

Remaining Barriers and Challenges

- **Project Challenge**: "The devil in the details": As deployment approaches, unanticipated issues can lead to delays until resolved.
- ✓ **Planned Resolution**: Leverage experience from others to anticipate and resolve issues in a timely manner; constant communication with deployment partner.

- **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.

Proposed Future Work: Following the Plan

- **Remainder of FY15:**
  - Finish build, commission prototype on-site
  - Operational turnover to Young Brothers
  - Deployment and data collection
    - On the dock, on the barge
    - Hydrogen fueling/delivery
    - Business effects
  - Continually evaluate opportunities for improvement during deployment
  - Accelerate education and outreach
- **FY16 work to be accomplished:**
  - Finish deployment
  - Produce technical and business case analyses
  - Continue outreach based on project results

Photo by author

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_2 storage, Portable Power**
- Mid-2015: Kolon
  - Gen 2: 1 MW (of 10 MW total), Baseload power

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.

Photo by author

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.

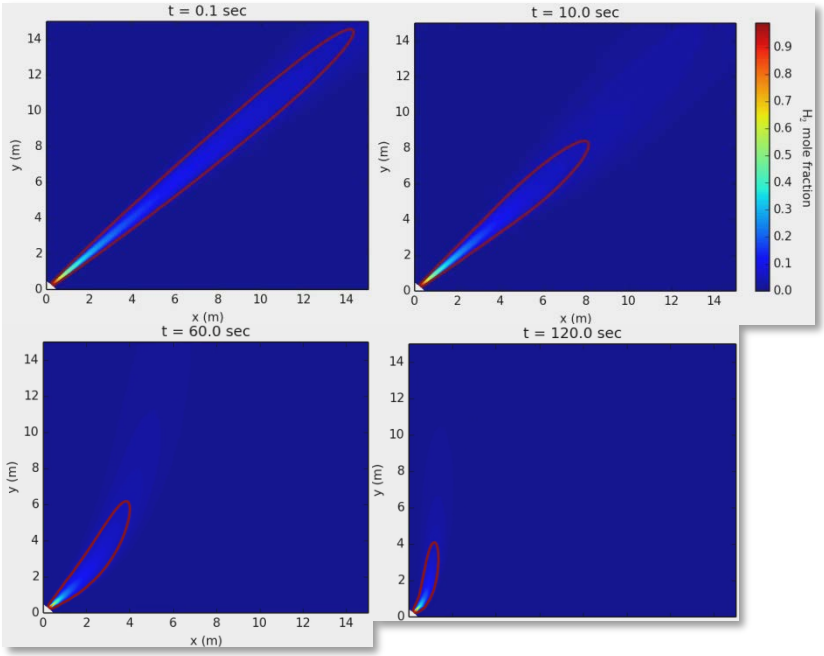
Thank you!

Photo by author

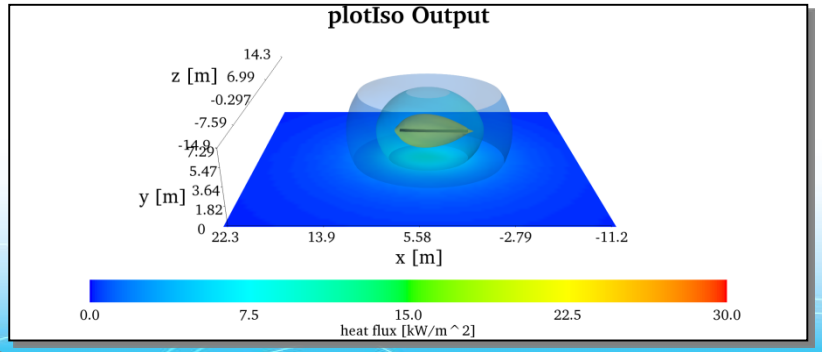
Technical Backup Slides

Flow Modeling and Quantitative Risk Assessment

Flammable plume modeling



Radiative heat flux modeling



HyRAM tool identified immediate jet flame from TPRD opening as only risk area of concern.

- Sources of ignition within the plume are not restricted.
- Low probability of occurrence allows transit by people and equipment; only concern is an incapacitated (immobile) worker.
- Release zone dimensions determined by radiative heat flux modeling and harm probability.

(Work leveraged and contributed to existing FCTO SCS activities)