Sandia National Laboratories

H2FC Hydrogen and Fuel Cells Program

Maritime Fuel Cell Generator Project

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Sandia National Laboratories

June 7, 2017

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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.

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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_2 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_2-fuel cell and maritime communities.

Project Overview

Timeline:

- Start: Sept. 2013
- End: June 2016
- 100% complete

Budget:

- Total: $2.2M
  - DOE Share: $885k
    - $40k received in FY13
    - $720k received in FY14
    - $125k received in FY15
  - DOT/MARAD* Share: $815k
    - $700k received in FY13
    - $115k received in FY15
  - Contractor Share (est.): $500k
- Non-DOE cost share pct. (est): 60%

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)*

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

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

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Partner		Project Roles
(*logo removed*)	DOE	Sponsorship, steering
	DOT/MARAD	Sponsorship, steering, and facilitation
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

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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*)

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- ✓ **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*)

Relevance – FY17 Impact as related to Project Objectives

- FY17 Impact: **Lower technology risk** and **Lower investment risk**
  - ✓ Technical performance analysis
  - ✓ Economic analysis
- FY17 Impact: **Enable easier permitting and acceptance**
  - ✓ Continual engagement with USCG and Class Societies (e.g. ABS) on other projects prove usefulness of the Maritime Generator project in developing these standards and guidelines
- FY17 Impact: **Engage Potential Adopters**
  - ✓ Engaging numerous potential hosts for subsequent demonstration, teaching them about the technology and potential benefits

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 FY17

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 Q4)

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

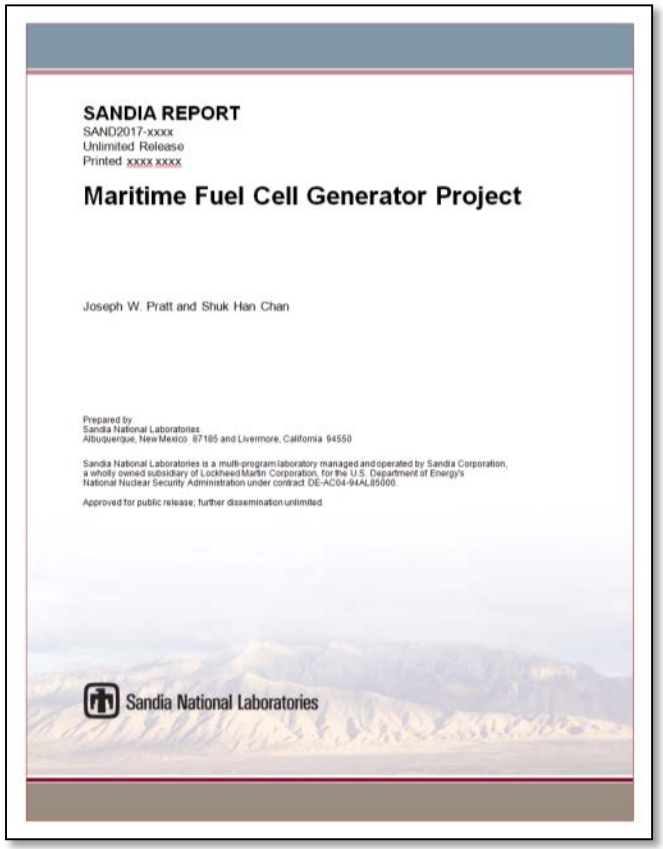
4. Deploy on dock and on barge

(FY15 Q4-FY16Q3)

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

Accomplishment: Completed Data Analysis and Reporting

- Selected results highlighted on the next slides.



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Maritime Fuel Cell Generator Project

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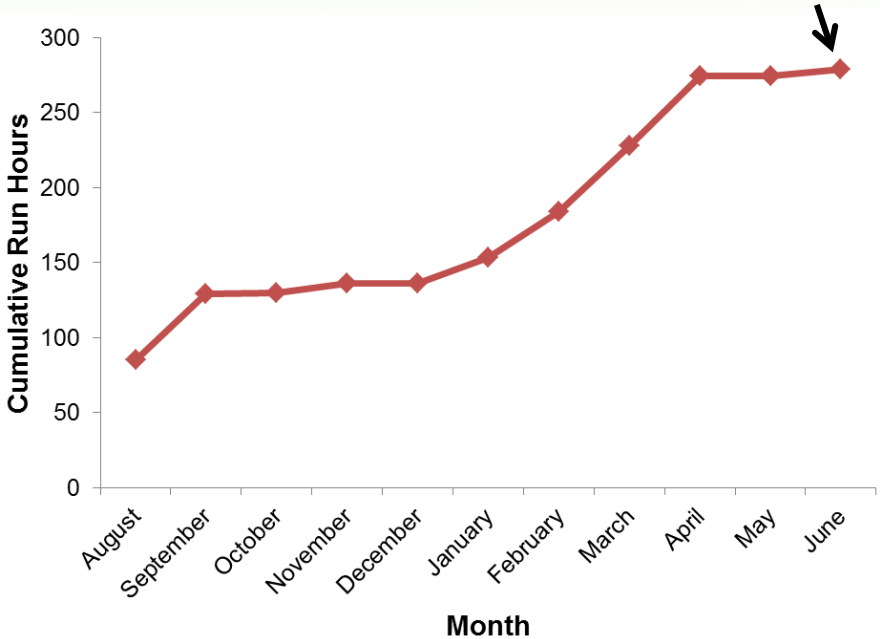
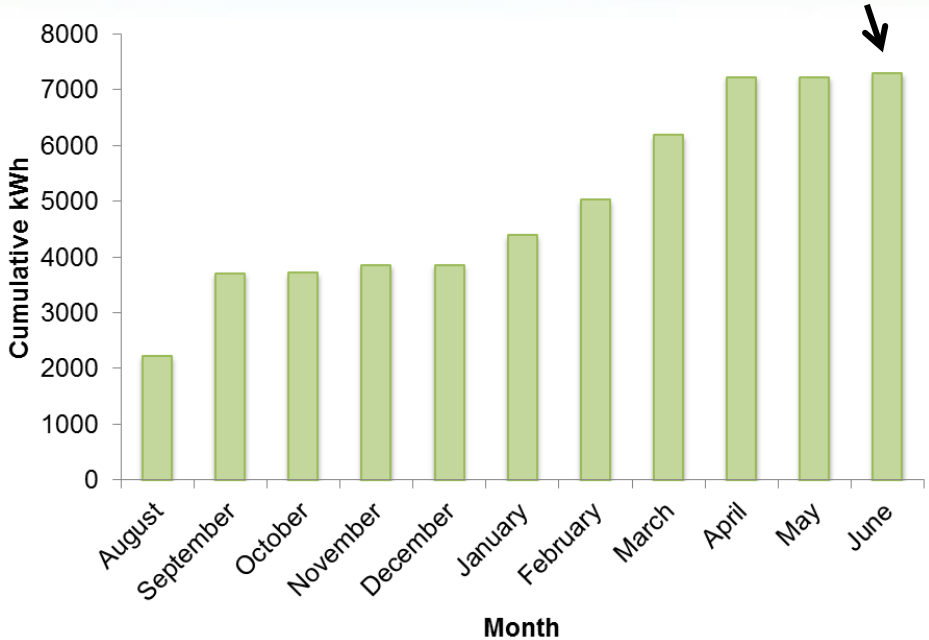
Runtime, Energy Production, and Power Statistics

278 hrs



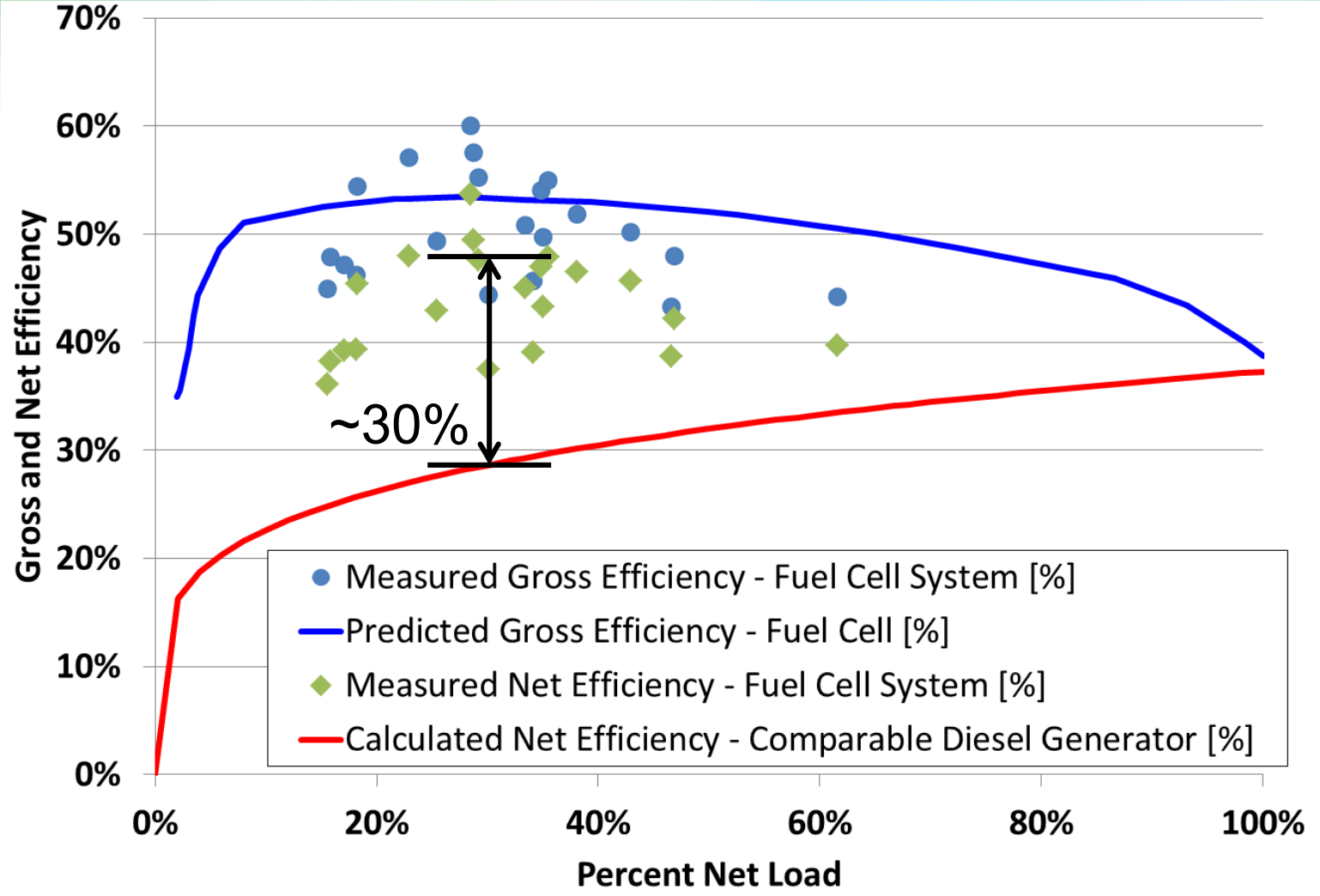
7,285 kWhr



Maximum Continuous Run Time: 11 hr 21 min
Average Gross Power: 29.4 kW
Maximum 5-minute Gross Power: 91 kW

→ The generator was able to meet the power requirements of the reefers

Efficiency

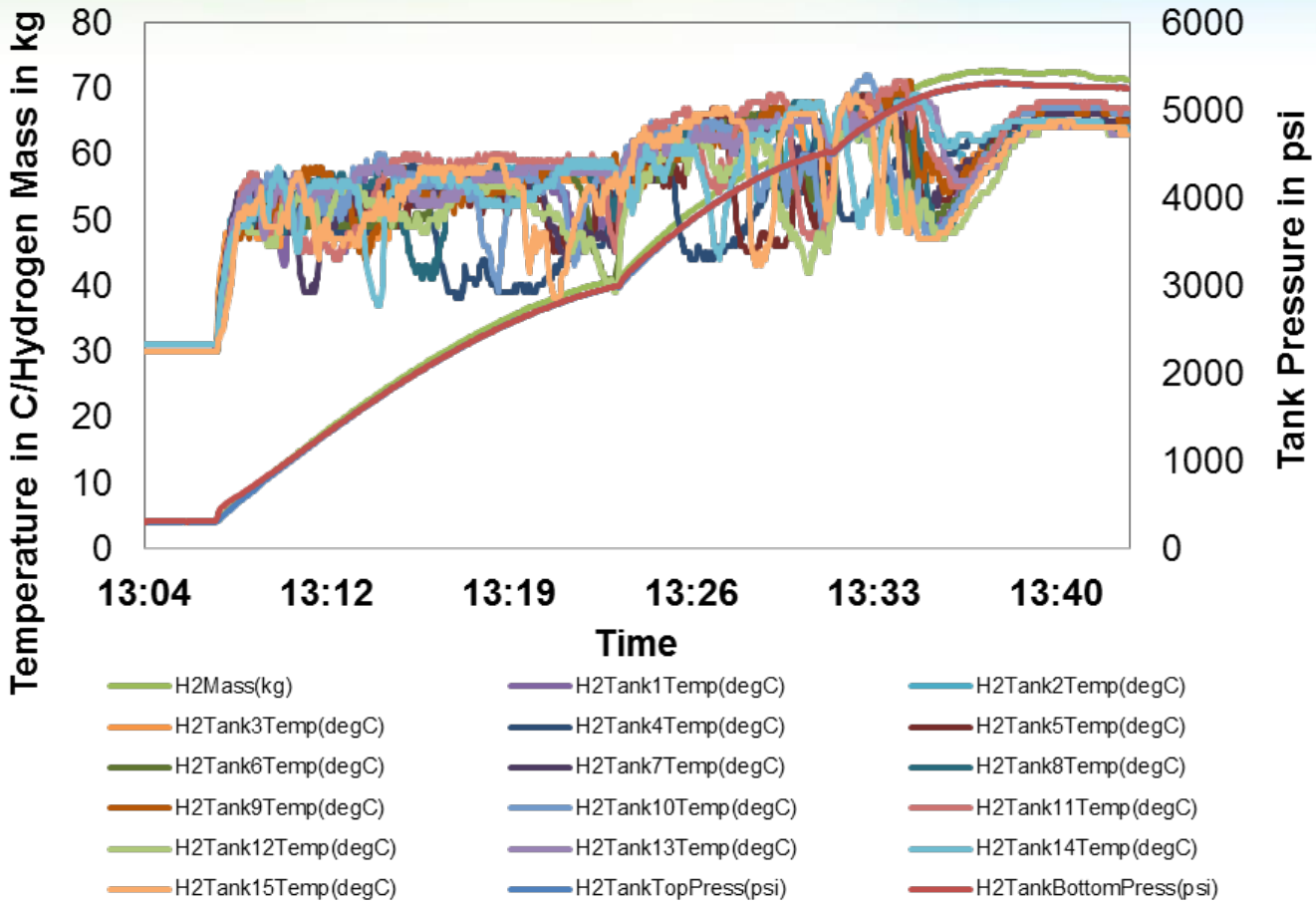


→ Data shows up to ~30% efficiency gain over diesel engine at part loads

Measured efficiency variations at same power likely due to variance in hydrogen consumption measurements

Hydrogen Fueling

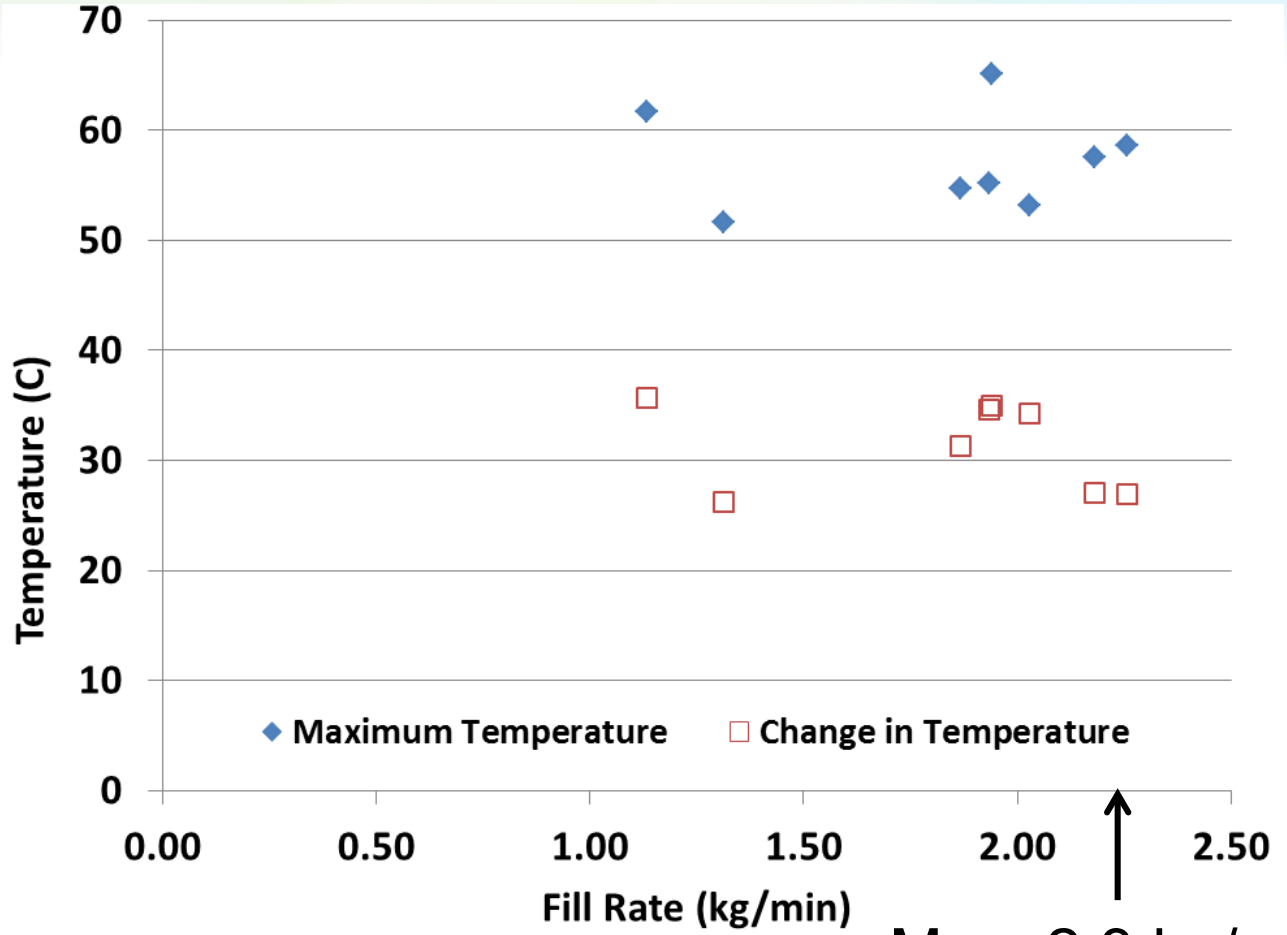
Typical Fill



Total Hydrogen Filled: 428 kg

→ All fills were smooth and trouble-free

Filling Rate and Tank Temperature Rise

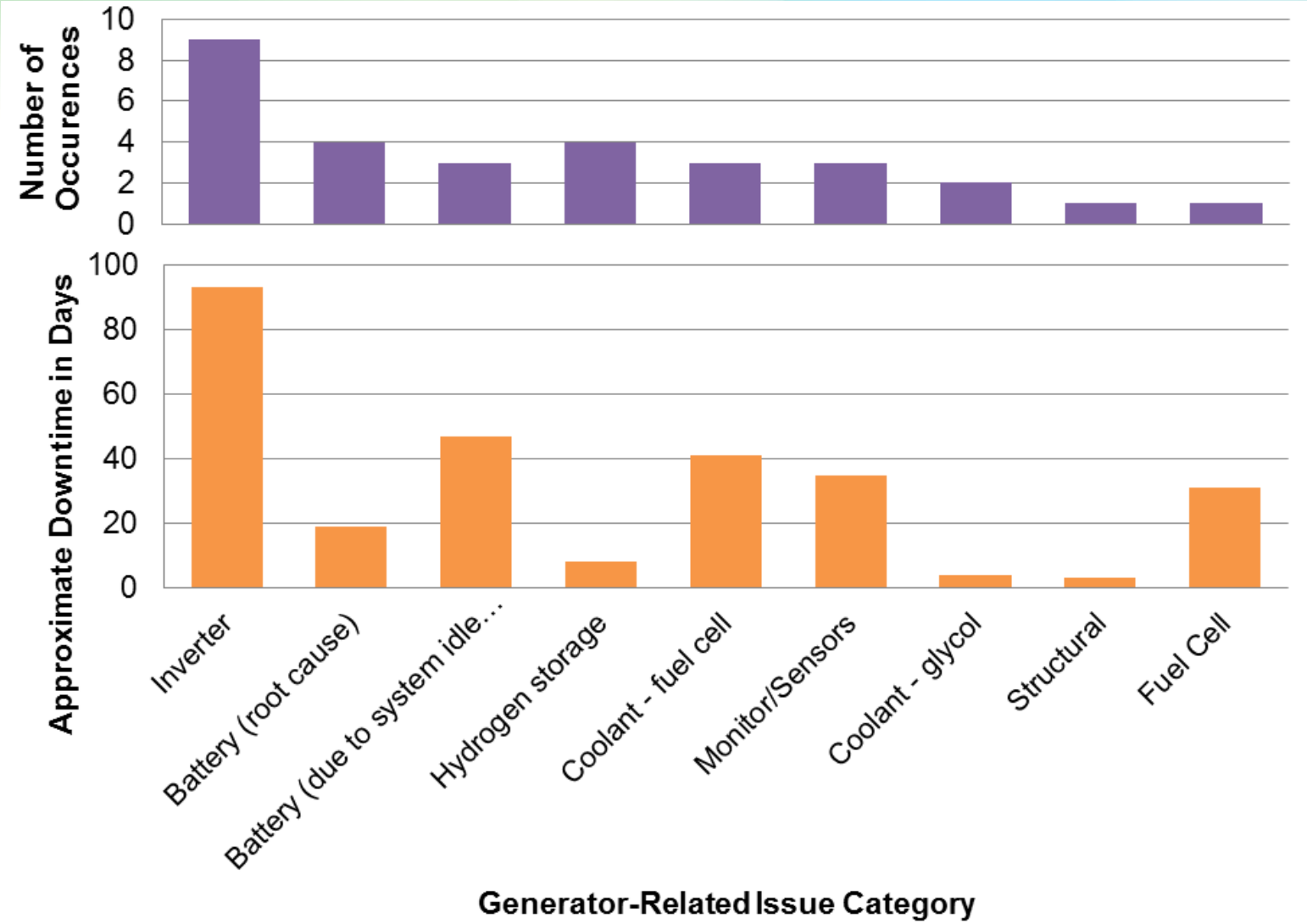


Max: 2.3 kg/min

No correlation between fill rate and maximum tank temperature or temperature rise; rate can likely be higher.

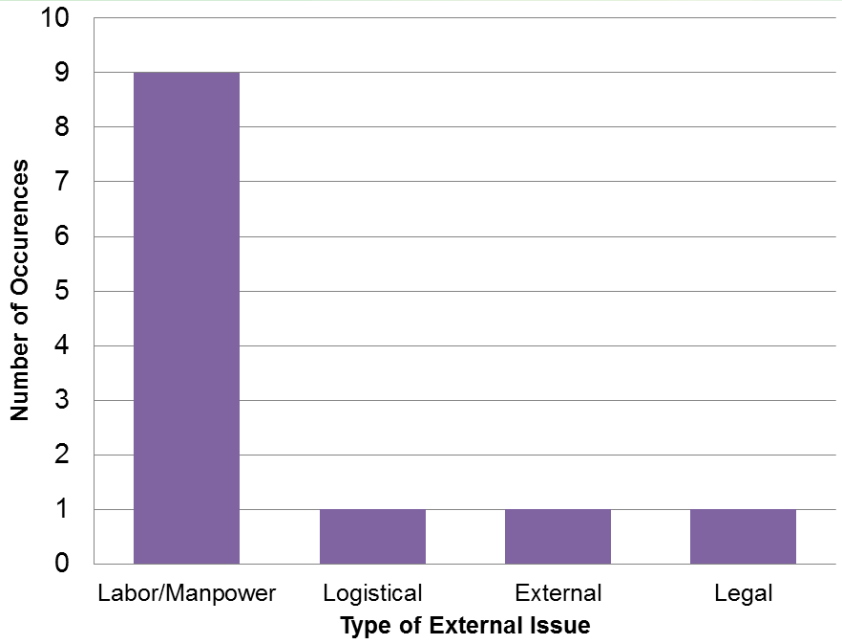
Note: Type III tanks (aluminum liner, carbon fiber over-wrap

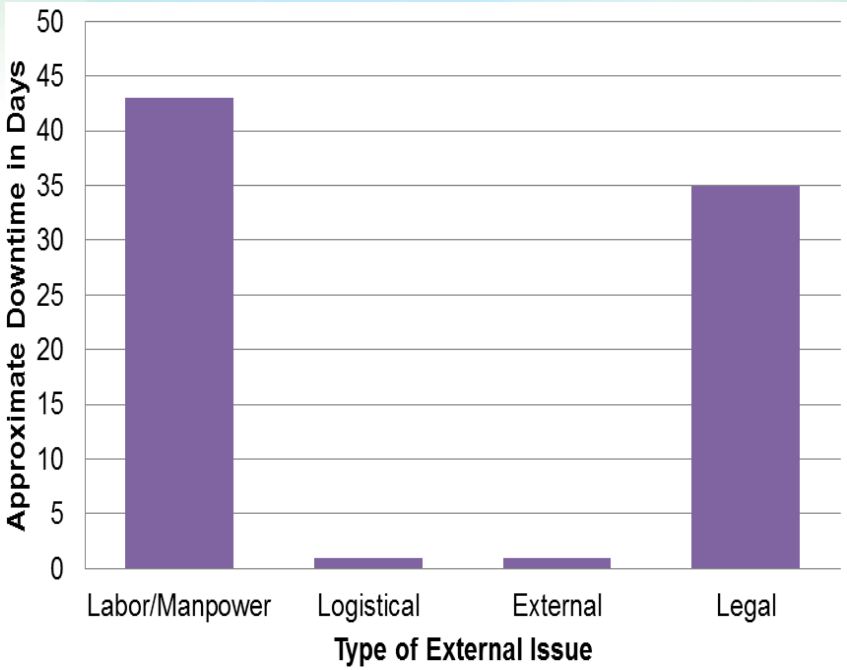
Technical Issues



→ Inverter caused the most issues and downtime

Non-technical Issues





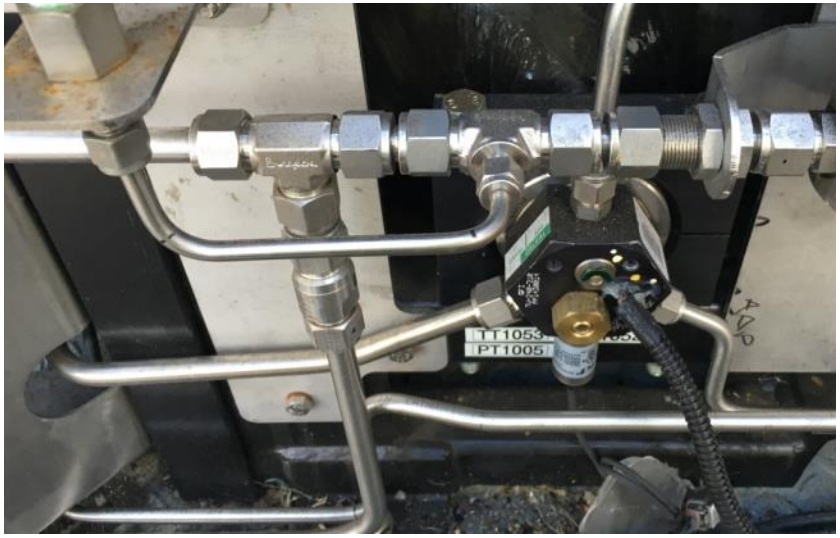
1. Site recommended a dedicated person to be caretaker of the generator in its current state of reliability.
2. Legal issues (*liability* is the big one) should be resolved ahead of time as much as possible. Must be built into schedules.

Effect of Marine Environment

Stainless steel piping under rubber clamp

After 9 months at the harbor, carbon steel surfaces that were unpainted or had trapped moisture showed corrosion.

Stainless steel showed no effects.

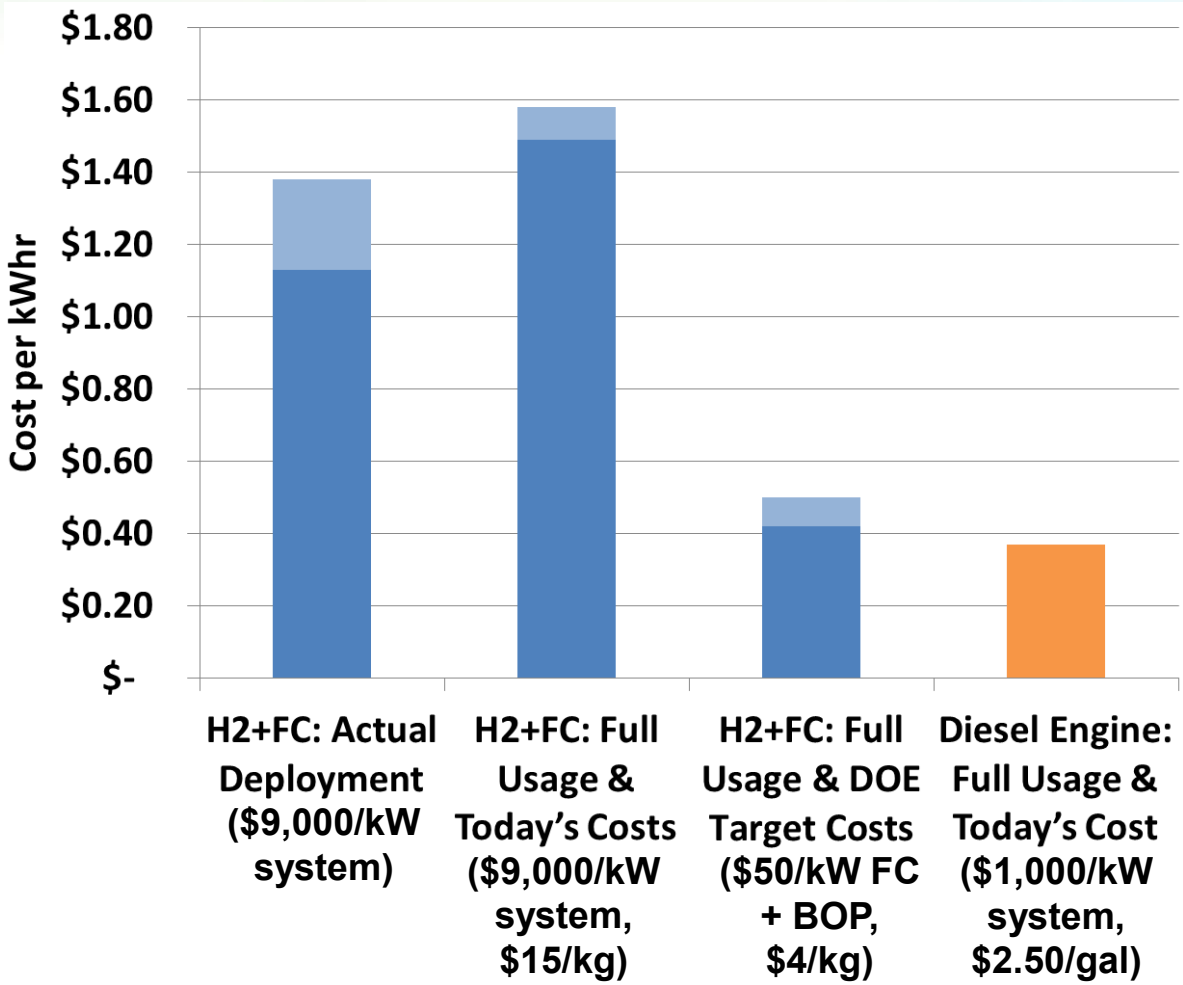


Stainless steel manifold

Painted carbon steel floor with trapped moisture

Photos by author

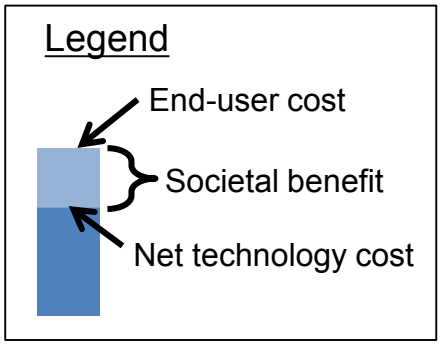
Economic Evaluation – Summary



Highest Cost Factors Today:

- Hydrogen
- H_2 storage tanks
- Power conditioning

Future expected cost increases in diesel technology and fuel, and regional differences in fuel costs are not included here.



Full cost assumptions are detailed in the report.

Responses to Previous Year Reviewers' Comments

- **"Additional deployments of this system are needed. Concrete plans for expanding the number of deployments should be created."** and **"One area of additional need is to evaluate the market share of the various port options, both in Hawaii and at other ports in the United States. This should be part of the future work business case."**
  - Reply: Future deployments of the generator are recognized as very important to successfully and completely address the stated Market Transformation barriers of the project. These plans are discussed in the Future Work section.
- **"It will be important to ensure that the lessons learned developed through this project are well documented and communicated in the project deliverables."** and **"It would be good to disseminate the project results beyond Hawaii to other ports, especially in California and the Northeast"**
  - Reply: The project report has been distributed to all known stakeholders and posted on Sandia's Maritime Program website (maritime.sandia.gov). General presentations are given when the opportunity arises. Targeted outreach of the project and results are being done in conjunction with exploring options for subsequent deployments.

Remaining Project Challenges and Barriers

- The project has concluded; there are no more challenges or barriers to project completion.
- Challenges and barriers remain for widespread technology adoption as described on other slides. With further demonstrations enough data can be obtained to completely understand how to address these.

Photo by author

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.
- The generator is at Hydrogenics for upgrading.
- 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.

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

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

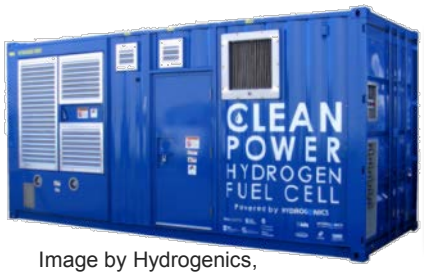
Development Process

- 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
  - 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 economic validation, lowering technology and business risk.
- Maintained 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.



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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!

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