Maritime Fuel Cell Generator Project

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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.

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
- 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)*

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

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 *(sub w/ cost share)*	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_2 Safety Program	Prototype and project safety review by HSP; Hydrogen Emergency Response Training for First Responders
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.
- ✓ **Lower the investment risk** by providing a validated business case assessment for this and future potential projects.

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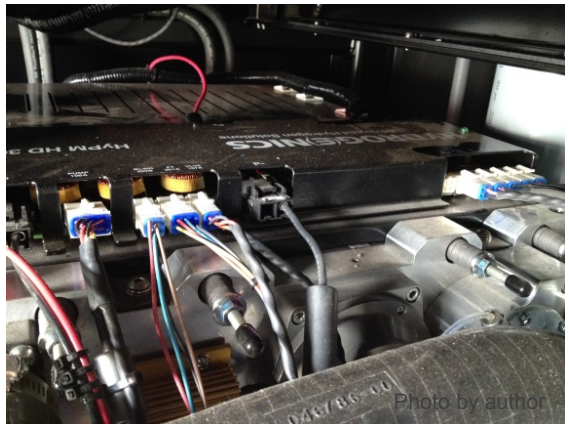
- ✓ **Enable easier permitting and acceptance** of H_2-FC technology in maritime applications by assisting USCG and ABS develop hydrogen and fuel cell codes and standards.
- ✓ **Act as a stepping stone** for more widespread shipboard fuel cell APU deployments.
- ✓ **Reduce port emissions** with this and future deployments.

Relevance – 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

(FY14 Q1)

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

RED: Completed in FY16

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 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

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

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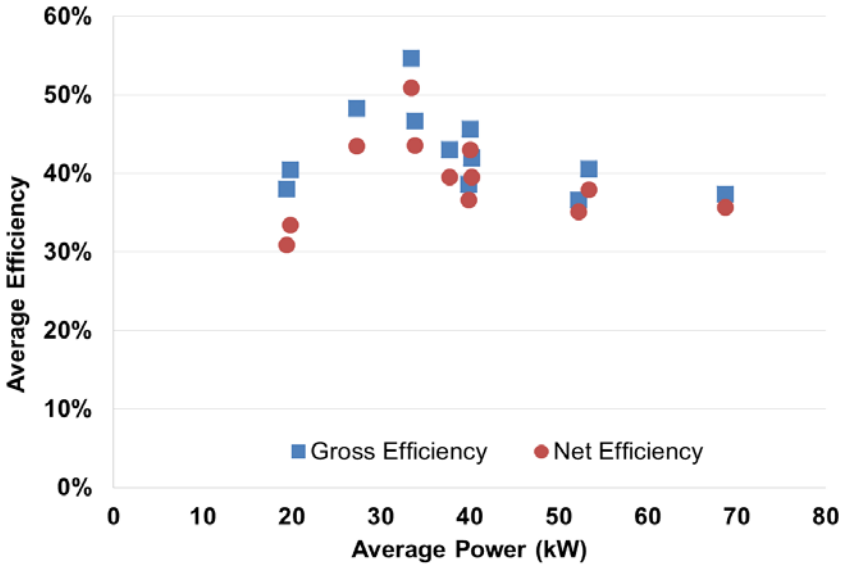
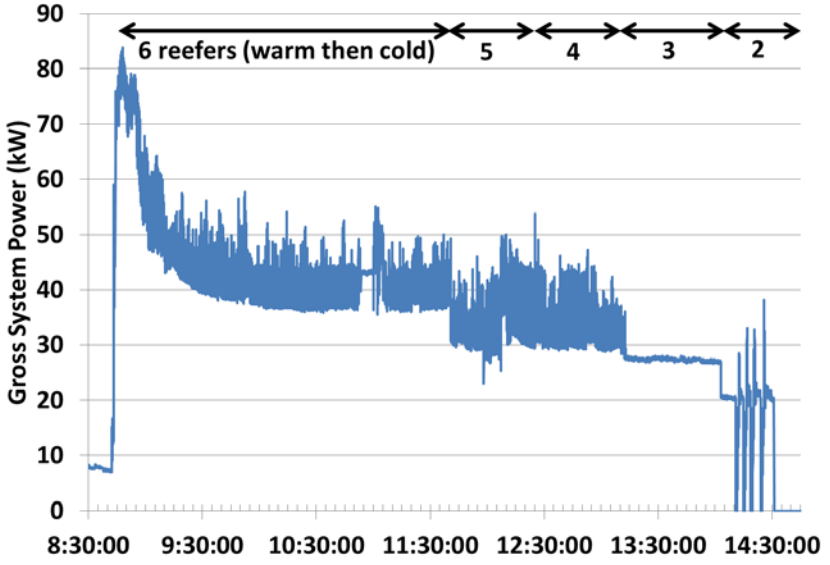
Accomplishment: Run data collection and preliminary analyses

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	Troy 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	
	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)

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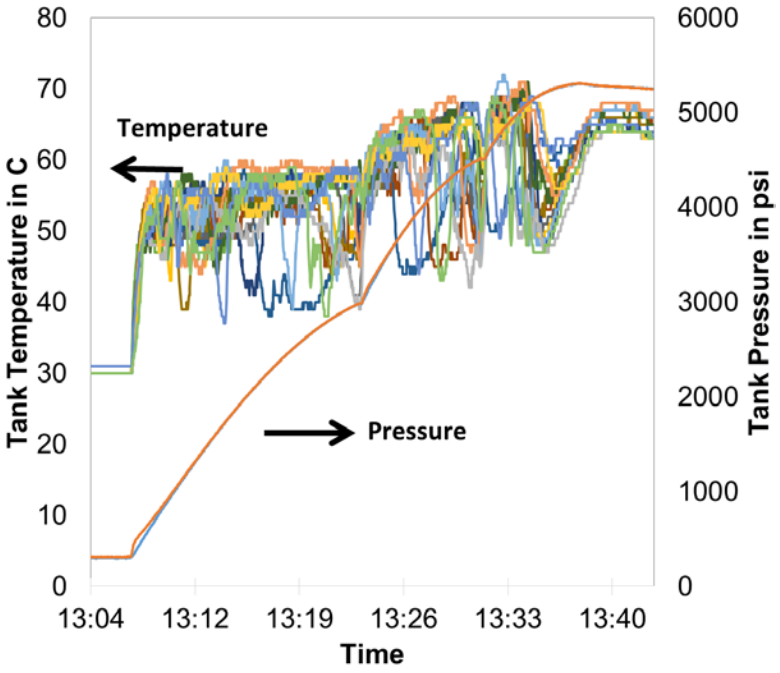
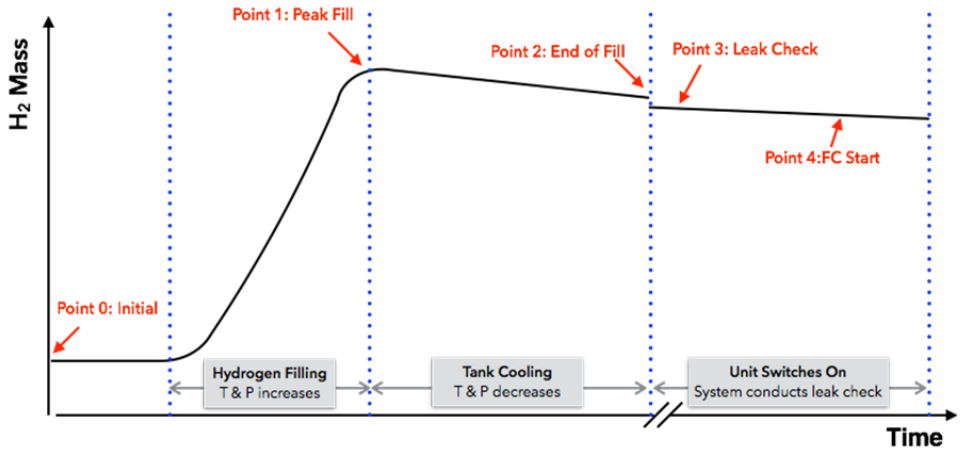
Planned: Fill with HNEI tube trailer

Accomplishment: Fill data analysis



Fill profiles



Fill amount

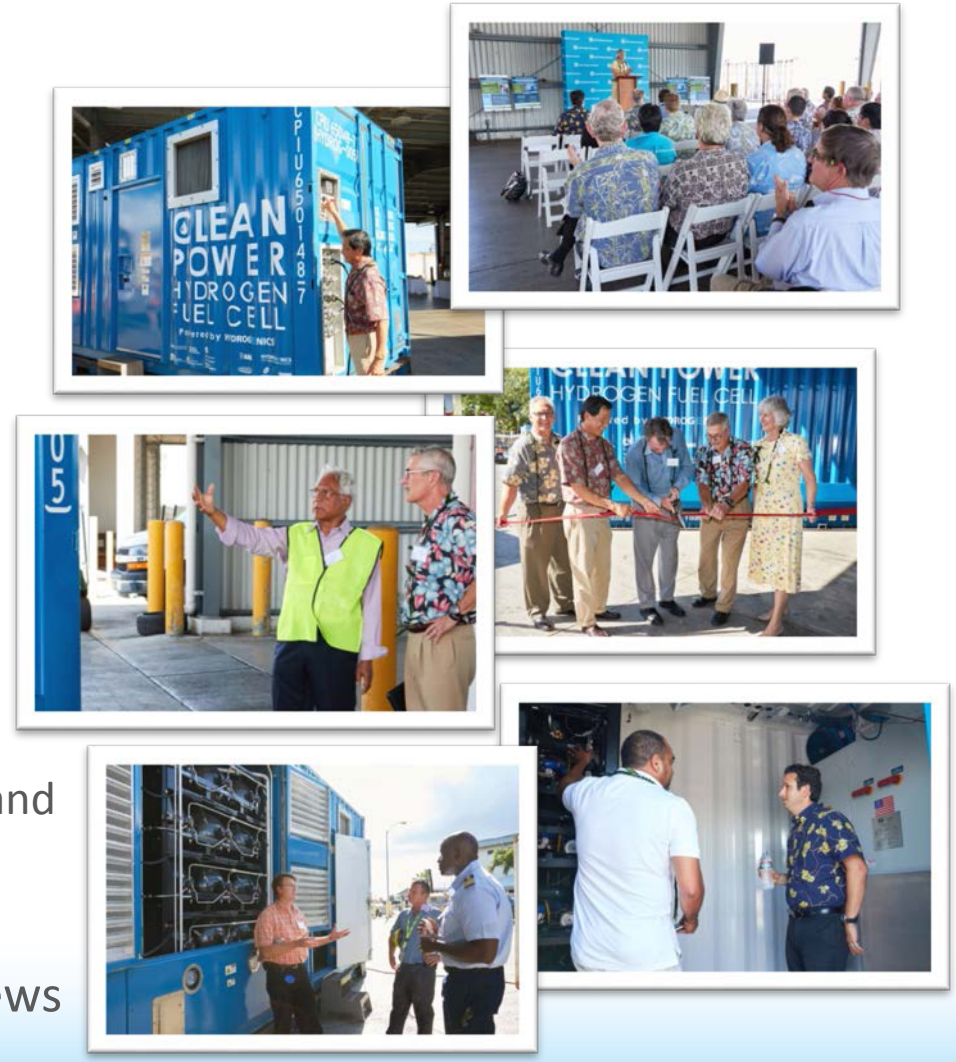
Accomplishment: Identified primary technical and non-technical reasons for lack of use

- 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

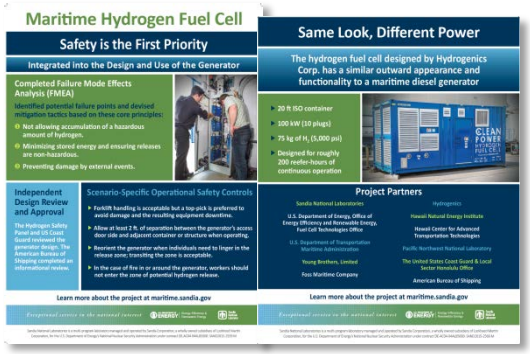
- 8 Speakers
  - US Senator Schatz (HI)
  - Hawaii State Leadership
  - Project Sponsors & Partners
- Demo/Tours of the Unit
- 55 Attendees
  - Energy Industry Early Adopters (business), Military/Government, and Project Partners
- Reported in 36 unique outlets receiving over 10.5 million page views

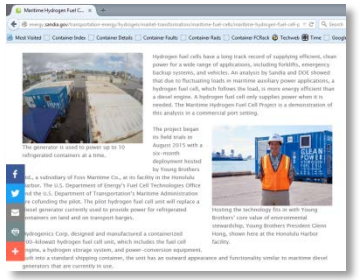


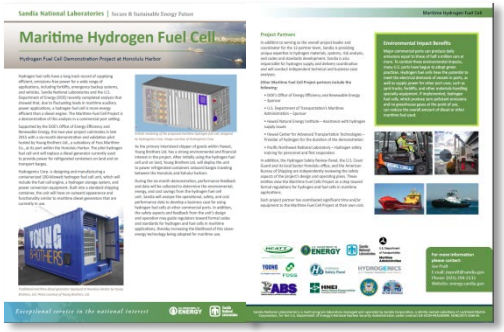
Accomplishment: Continued Broad Outreach Campaign

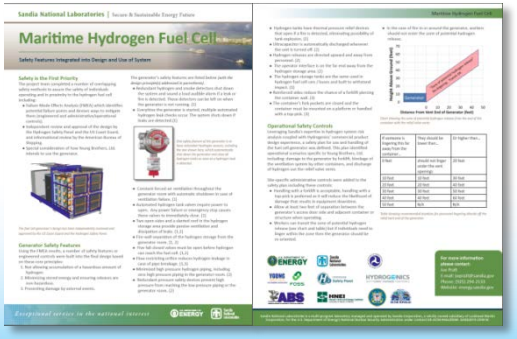
Outreach materials:

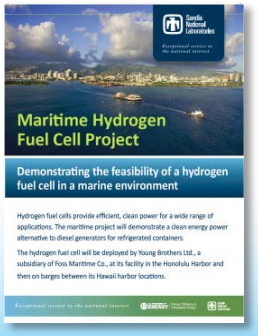
- Fact sheets
- Website: maritime.sandia.gov
- Postcard
- Posters
- Keychains for YB personnel
- Summary PR video on Vimeo
- Local web-TV appearance (ThinkTech Hawaii, YouTube)
- Three public presentations











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.

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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_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

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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.

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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.

On behalf of the team, Thank You!

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