

Maritime H₂ Fuel Cell Market Transformation Studies at Sandia

Lennie Klebanoff

Sandia National Laboratories

Livermore, CA 94551

*Hydrogen Fuel Cell Technologies
Interagency Working Group Webinar*

May 19, 2020



*Sandia HQ:
Albuquerque NM*



*Livermore CA
(SF Bay Area)*

- Sandia is the largest National Lab in the U.S.
 - U.S. Department of Energy (DOE) ~13,000 employees
 - ~ US \$3.2B/yr from DOE, other federal agencies, and private industry
 - H₂ Program in Livermore, CA (SF Bay Area)
- Hydrogen program: 60+ years of work, in a wide range of areas (H₂ storage, production, delivery, development of regulations, **market transformation**), which we apply to enable impactful clean energy solutions
- **Market Transformation: Zero Emission H₂/Fuel Cell Maritime Program:**



Non-maritime Sandia Fuel Cell Market Transformation

Bringing zero emission fuel cell technology into new applications, understanding and surmounting technical barriers, improving energy efficiency and reducing emissions.



Mine Locomotive
(1999 - 2002)



Early Market H₂ Storage
Requirements (2010-2011)



PEM Fuel Cells on Commercial
Aircraft (2010-2011)



Fuel Cell Mobile Lighting
(2010 - 2014)



NEV_x Fuel Cell Range Extender
(2013 - 2014)



Fuel Cell Locomotives
(2019 - present)

First Maritime Fuel Cell Project: MarFC

-- Develop a fuel-cell system for the marine environment that will reduce emissions and be a viable alternative to diesel-based systems.--

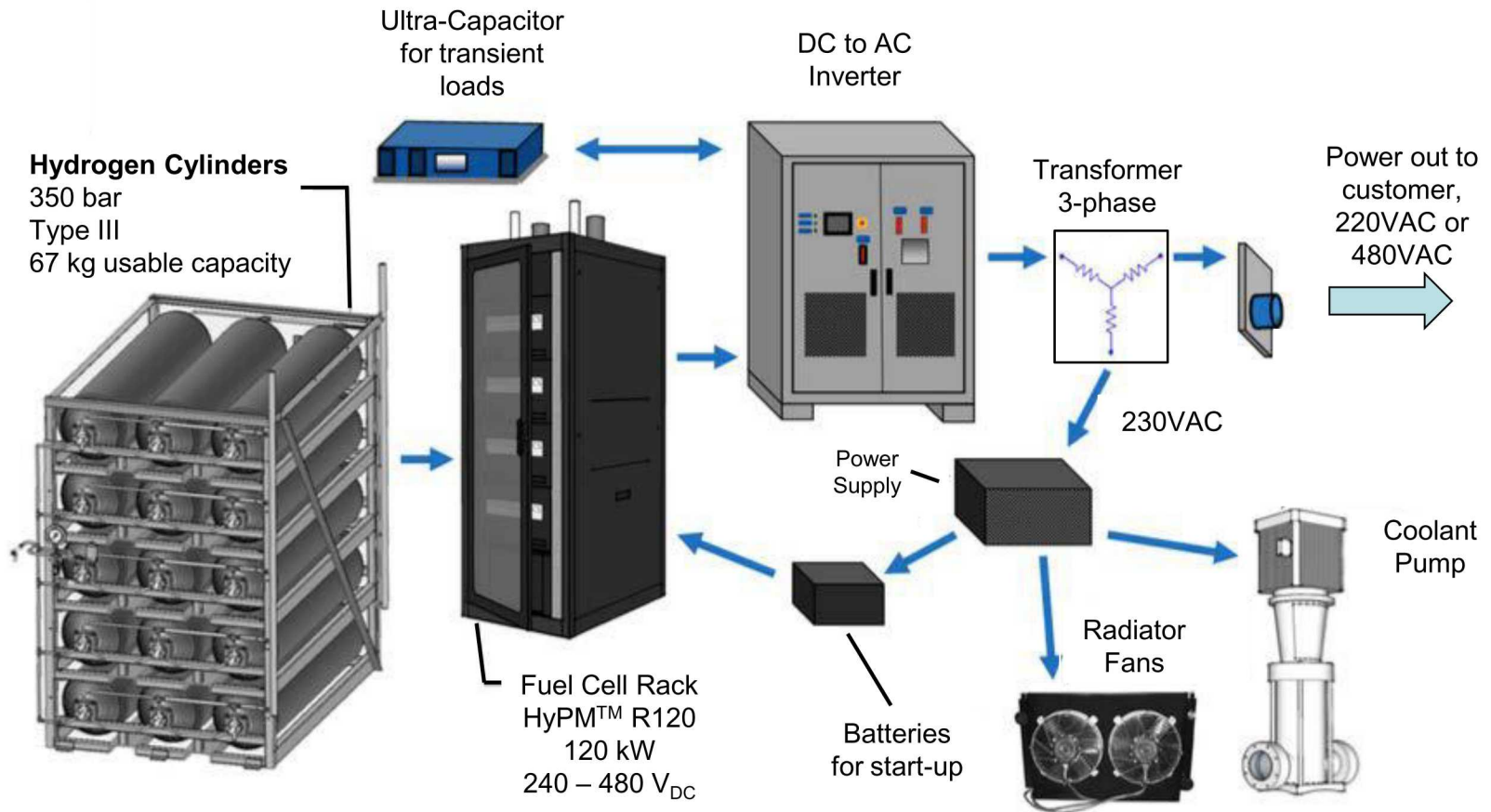
- ✓ **Lower the technology risk** of port fuel-cell deployments by gathering performance data of H₂-PEM fuel cells in the marine environment.
- ✓ **Lower the investment risk** by understanding capital and O&M costs.



- ✓ **Enable easier permitting and acceptance** of H₂-FC technology in maritime applications by engaging the USCG and ABS.
- ✓ **Engage potential adopters/end users** of hydrogen fuel cells to enable more widespread acceptance of the technology.

Funded by DOE FCTO and MARAD

Essential MarFC Components



First MarFC Deployment: Power to Refrigerated Containers (Reefers), Young Brothers, Honolulu Hawaii (2015 – 2016)



MarFC Powering Reefers

Second MarFC Deployment: Shore Power to the *R/V Robert Gordon Sproul* of the Scripps Institution of Oceanography (2019- present)



Photo Credit:
Bruce Appelgate
Scripps Institution
of Oceanography

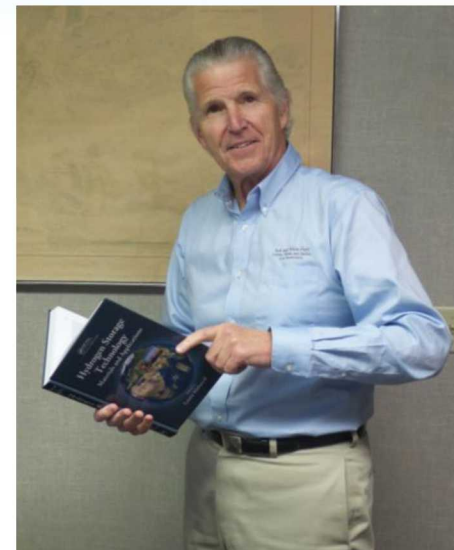
by understanding the powering of vessels with fuel cells from the pierside, this project will open up auxiliary and primary power applications of fuel cells onboard vessels.

H₂ Vessel Work Begins in 2014

A progressive maritime passenger transportation company offering sightseeing cruises, ferries and charter service in San Francisco.



The R&W Fleet is concerned about the effect of their vessels, and that of all maritime vessels, on the environment and on human health.



Tom Escher
President of R&W Fleet

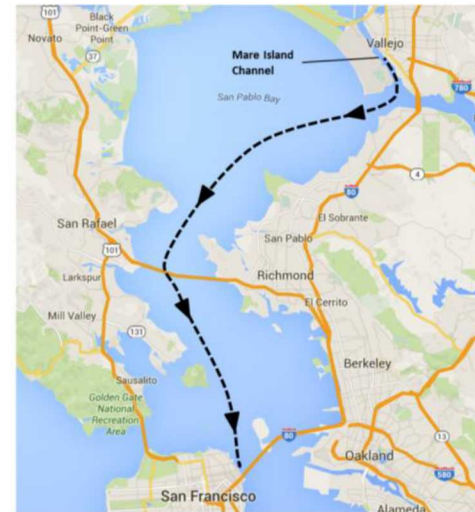
The R&W Fleet approached Sandia with the question: Can H₂/fuel cell technology reduce vessel emissions to zero? What would be involved?



Work Funded by The U.S. Department of Transportation (DOT), Maritime Administration (MARAD) through MARAD's Maritime Environmental and Technical Assistance (META) program.

SF-BREEZE: The first study to show that H₂ fuel cells can be used in maritime propulsion, and how to do it.

High-speed H₂ Ferry



Route:
San Francisco
to Vallejo, CA

| | Ferry | Hydrogen Station |
|------------|---|------------------|
| Technical | ✓ | ✓ |
| Regulatory | ✓ | ✓ |
| Economic | <i>Higher than conventional now, today's market acceptance to be determined</i> | |

Project Integrates Ship Designers, Regulators, H₂ Experts and End Users



*USCG MSC and Design
and Eng. Stds.*



*USCG Sector
San Francisco*



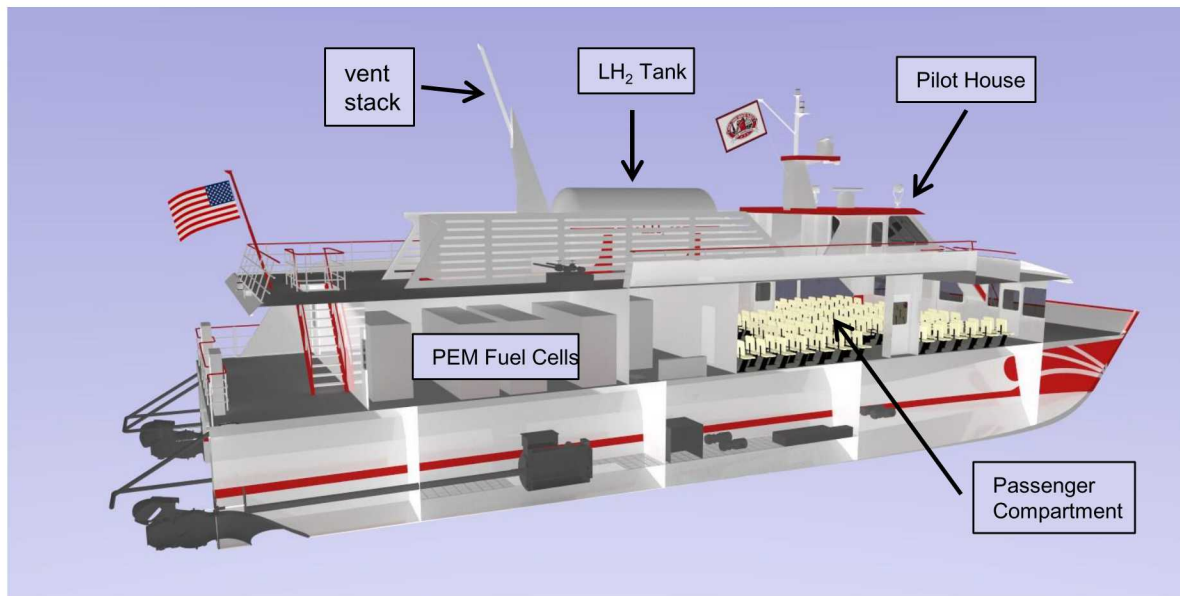
*USCG Liquid Gas
Carrier NCOE*



*American Bureau
of Shipping*



SF-BREEZE Design

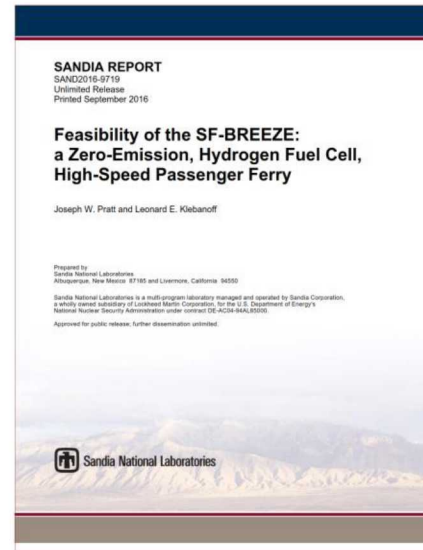
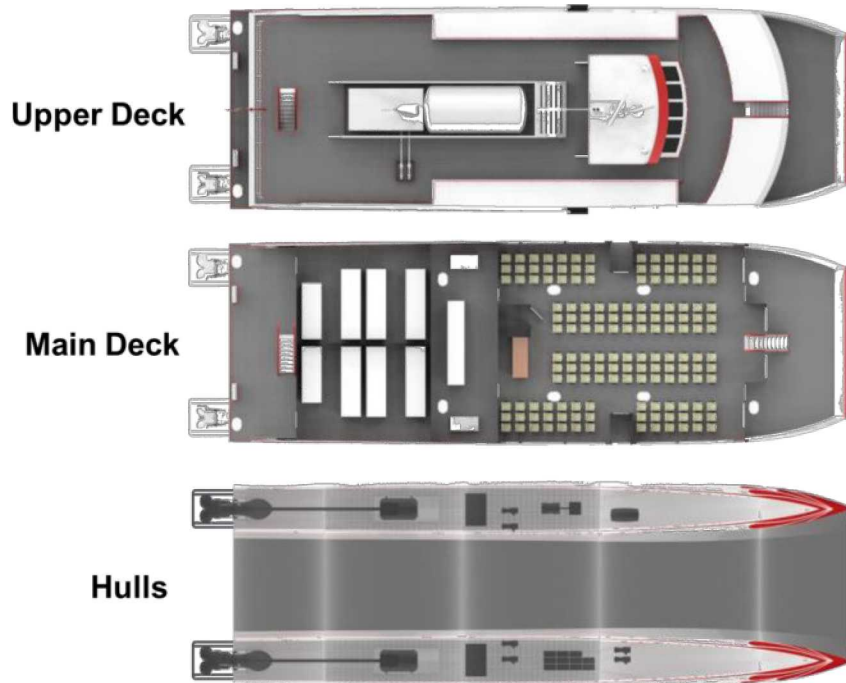


Design generated by Elliott Bay Design Group

SF-BREEZE details



- Fuel: ~2,000 kg LH₂ per day
- Propulsion power 4.4 MW, installed: 4.92 MW
- Passengers: 150
- Service Speed: 35 knots
- Length 109' x Beam 33' x Depth 11.25'
Full Load Draft ~ 4.6'
- **Emissions: Zero**
- **Fuel Spills: Zero**



The SF-BREEZE Project Led to the Zero-V Hydrogen Fuel Cell Research Vessel

Overall Feasibility Question: Is it technically and economically possible to create a zero-emissions H₂ fuel cell research vessel that meets or exceeds the requirements of such vessels operating along U.S. coastlines?



Lennie Klebanoff
Sandia National Laboratories



Bruce Appelgate
Scripps Institution of Oceanography



Zoltan Kelety
Scripps Institution of Oceanography

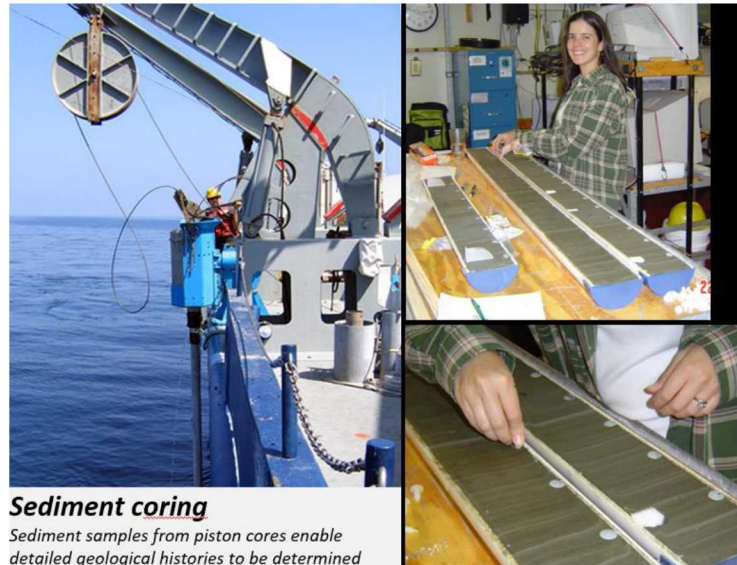


Gerd Petra Haugom (L) Hans-Christian Wintervoll
DNV GL



Glosten Participants: (L-R) Ian McCauley, Sean Caughlan, Robin Madsen and Catherine Farish.

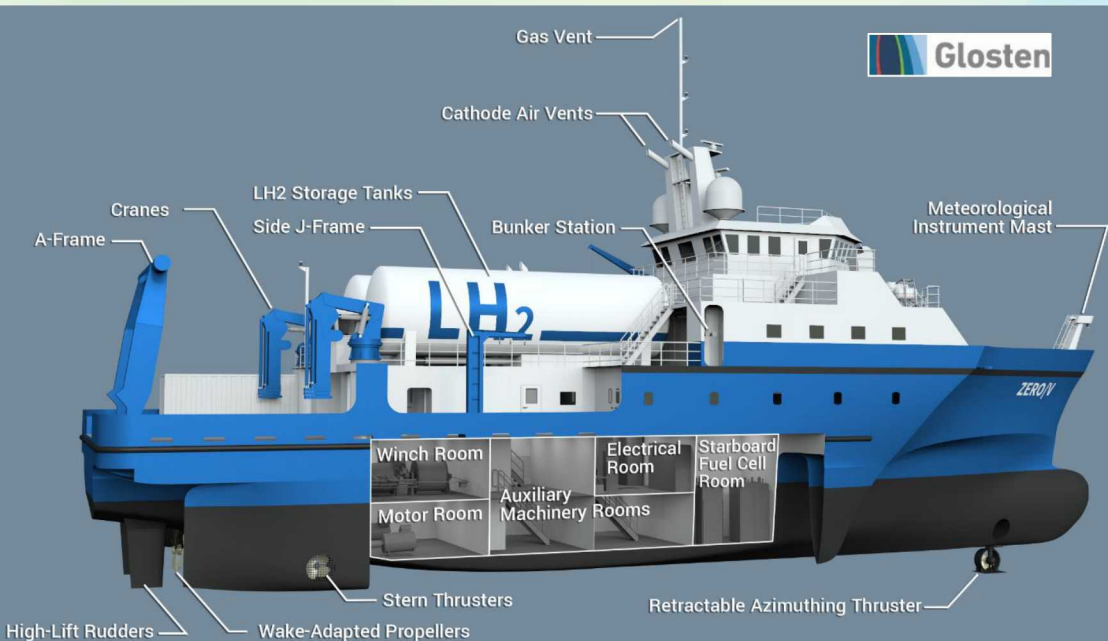
Scripps Missions Define the Zero-V Performance



The Zero-V has very different performance needs:

- Desired calm water speed: 10 knots (instead of 35 knots for the SF-BREEZE)
- Desired range: 2,400 nautical miles (instead of 100 nm for the SF-BREEZE)
- Endurance: 14 days (instead of 4 hours for the SF-BREEZE).

A zero-emission research vessel is feasible NOW using existing technology



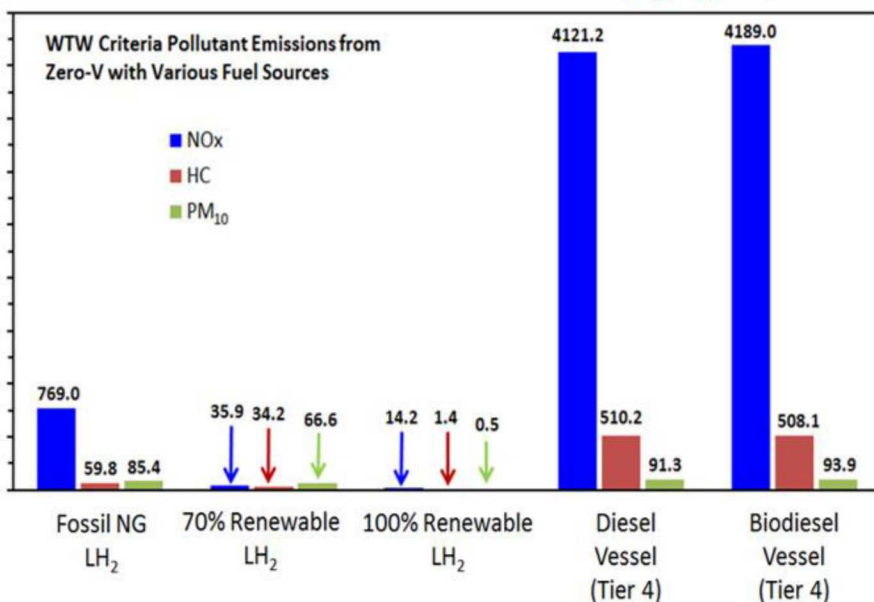
- Oceanographic research vessel for coastal / regional operations
 - Uses clean hydrogen: **No fossil fuels!**
 - Zero emissions: **Clean/no GHGs!**
 - Carries no diesel: **No oil spills!**
 - All-electric propulsion: **Quiet!**
 - **FEASIBLE** with existing technology
 - Outstanding scientific capabilities
 - Advanced instrumentation
 - Designed for California's educational and R&D needs
- "A bold, transformative game-changer"– Bruce Appelgate, Scripps***



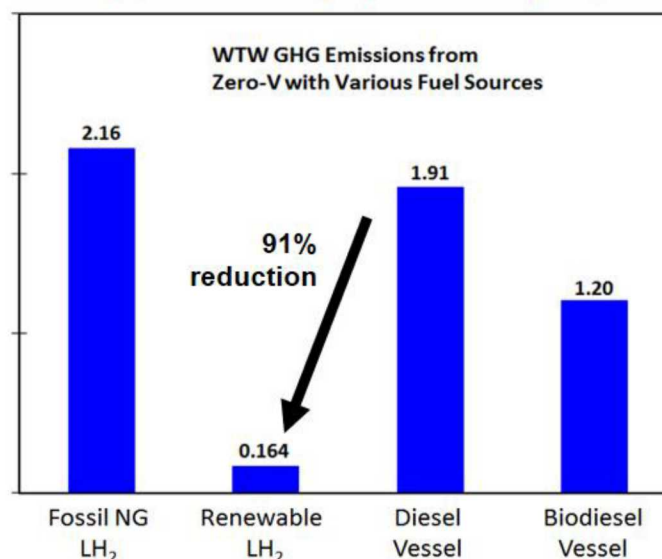
The zero-emission research vessel (Zero-V) concept vessel has a range of 2,400 nm, speed of 10 knots, with berths for up to 20 scientists, supporting general-purpose missions. Anticipated cost to build: \$80 million.

Emissions from LH₂ Production (the Zero-V itself is zero-emissions):

Well-To-Waves Criteria Emissions (kg / year)



Well-to-Waves Greenhouse Gas Emissions
(1,000 MT CO₂ equivalent / year)



Using H₂ from any source, dramatic reductions in criteria pollutants below Tier 4 are provided. Using renewable hydrogen, a 91% reduction in CO₂ (eq.) emissions is obtained.

More information on the calculation of GHG emissions from H₂ fuel cell technology can be found in: L.E. Klebanoff, J.W. Pratt et al., Transportation Research D **54**, 250 (2017).

A H₂ Fuel Cell Ferry Is Under Construction!

-- Funded by the State of California Air Resources Board (CARB)



The Water Go Round: The world's first commercial hydrogen fuel cell ferry, and first hydrogen fuel cell vessel in the Western Hemisphere.

- Aluminum catamaran, 70' long, 84 passenger (reconfigurable), 22 knot top speed
- Scheduled arrival in San Francisco Bay late 2020.

Project Lead



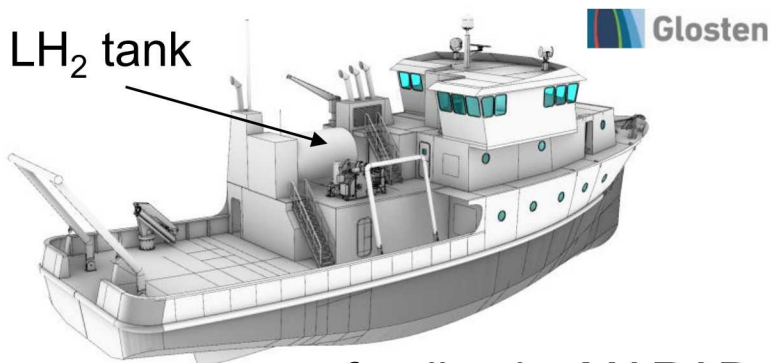
Funding & Administration



Other Ongoing H₂ Fuel Cell Maritime Projects

H₂ Hybrid Research Vessel as a Replacement for the *R/V Robert Gordon Sproul*

-- how does a H₂/diesel hybrid compare with a battery/diesel hybrid?



--funding by MARAD

H₂ Gas Dispersion Analyses for Vessels

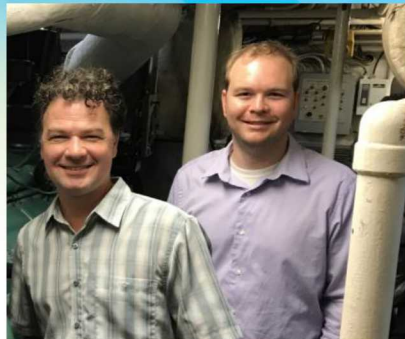
- Vent Stack and the effects of wind
- Fuel Cell Room
- Bunkering
- funding by MARAD



“The Brain Trust:” Representatives from all the class societies, the US Coast Guard, MARAD and Sandia

H₂ @ Ports Working Group (Just Starting), DOE HFTO

Objective: To develop a small working group amongst key international H₂ maritime stakeholders to share information, promote safe H₂ regulatory development, and identify knowledge gaps to guide future R&D. International efforts to bring H₂/Fuel cell technology to ships have been uncoordinated, which has slowed the regulatory developments. This working group aims to ameliorate these difficulties.

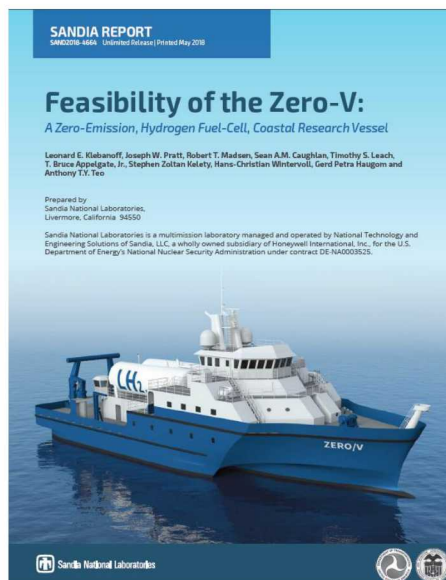


Thanks to all
my friends and
colleagues!

For more information on Sandia H₂/Fuel Cell Maritime Projects visit:

<https://maritime.sandia.gov>

- Past and current maritime projects
- Download reports



Special Thanks To Our Sponsors:
**Sujit Ghosh, Carolyn Junemann,
Bryan Vogel, Michael Carter MARAD**

Pete Devlin, Sunita Satyapal, DOE HFTO

The U.S. Department of Transportation (DOT), Maritime Administration (MARAD) through MARAD's Maritime Environmental and Technical Assistance (META) program and the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy Hydrogen Fuel-cell Technologies Office (HFTO).

Lennie Klebanoff

(925) 294-3471

lekleba@sandia.gov

Thank You!!