Feasibility of Hydrogen Fuel Cell Research Vessels

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Hydrogen Properties:

- Is typically a gas, but can be a liquid (LH₂) if made very cold (20 K).
- LH₂ evaporates very fast (4,000 gallons will evaporate in ~6 seconds).
- More buoyant than helium. Goes straight up at ~40 mph.

Overall, H₂ is very similar to natural gas (which is ~ 90% methane, CH₄).

**H₂ is NOT a Greenhouse Gas, unlike natural gas which is a potent GHG.**

**If spilled, LH₂ evaporates from the water leaving no residue.**

H₂ can be ignited given an ignition source and the right H₂/air mixture.

Energetically, a kg of H₂ has about the same energy as a gallon of diesel fuel.
A typical LH$_2$ trailer can deliver 4000 kg of hydrogen at a time.

LH$_2$ Refueling Trailer, Emeryville CA

A typical high-pressure delivery trailer can deliver ~ 300 kg at a time.

350 bar H$_2$ Refueling Trailer, SFO
When hydrogen is used in a *Fuel Cell* it produces ZERO pollution or greenhouse gas at point of use

\[ 2 \text{H}_2 + \text{O}_2 \rightarrow 2 \text{H}_2\text{O} \]

- commercially available
- more energy efficient than diesel generators
- eliminates emissions at the point of use
- eliminates fuel spills, greatly reduces noise
- emissions can only arise from \( \text{H}_2 \) production/delivery
- no “thermal runaway” possible (unlike batteries)

### Going In:
- \( \text{H}_2 \) and air

### Going Out:
- Electricity
- Waste Heat
- Warm humidified air
The GHG-reducing potential for H$_2$ fuel cell technology lies in using renewable hydrogen.

More information on the calculation of GHG emissions from H$_2$ fuel cell technology can be found in: L.E. Klebanoff, J.W. Pratt et al., Transportation Research D 54, 250 (2017).

-- the equivalent GHG emissions (making & burning) for diesel fuel is 87.4 grams CO$_2$ (eq.)/MJ$_{fuel}$

-- the “criteria pollutant” (smog) emissions like NO$_X$, PM, HC is dramatically reduced with fuel cell technology, no matter how the hydrogen is made (not shown).
Hydrogen Technology is Here and Growing

Fuel Cell Electric Vehicles Can:
✓ Refuel in 5 minutes
✓ Have a 300 - 400 mile range (limited by H₂ storage)
✓ Only clean water vapor as the tailpipe emissions
✓ No need to plug in.

And it’s not just fuel cell cars:

Fuel Cell Forklifts | Fuel Cell Buses | Fuel Cell Lighting

H₂ Stations in CA (CA Fuel Cell Partnership)
If you want to learn more about hydrogen technology…..

--published by CRC Press in 2012

Topics:
- Ways of storing hydrogen
- Hydrogen fuel cells and IC engines
- $\text{H}_2$ Storage Systems
- $\text{H}_2$ Codes and Standards

-- available on Amazon

More information about hydrogen gas ($\text{H}_2$) and liquid hydrogen ($\text{LH}_2$) can be found in:

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

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<tr>
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<tr>
<td>Technical</td>
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Work Funded by The U.S. Department of Transportation (DOT), Maritime Administration (MARAD) through MARAD’s Maritime Environmental and Technical Assistance (META) program.
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 $\text{H}_2$ fuel cell research vessel that meets or exceeds the requirements of such vessels operating along U.S. coastlines?
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
- Range: 2400 nm
- Speed: 10 knots
- 10,900 kg of LH$_2$
- Berths: 20 scientists
- Cost to Build: $80M
- Quiet
- No Fuel Spills, No engine emissions
- Feasible with today’s technology
- Designed for California’s educational and R&D needs

Scripps is seeking funding through federal sources because $80M is beyond their traditional State funding channels.

What if H₂/Fuel Cells Provide Partial Vessel Power, in a Hybrid Arrangement? What Would That Look Like?

➢ Diesel engines supplemented with H₂/Fuel Cells
➢ LH₂ Storage: 733 kg
➢ Diesel Engines: ~ 1200 kW; Fuel Cells: ~ 800 kW
➢ Capital Cost: ~ $34M
➢ ~ 27% annual reduction in GHG emissions
➢ 75% of the Sproul Missions can be performed on H₂ alone.
➢ Much better performance than a Battery Hybrid

The Scripps Institution of Oceanography (SIO) current coastal/local research vessel, the R/V Robert Gordon Sproul, is nearing the end of its service life and will soon require replacement. We compared three potential “variants” for an R/V Sproul replacement vessel (SRV): a Baseline SRV consisting of a traditional diesel-electric powertrain, a Battery Hybrid SRV (battery/diesel-electric) and a Hydrogen Hybrid SRV (hydrogen fuel cell/diesel-electric).

Work Funded by The U.S. Department of Transportation (DOT), Maritime Administration (MARAD) through MARAD’s Maritime Environmental and Technical Assistance (META) program.
July 23, 2021: Scripps Announces $35M in Funding of the Hydrogen Hybrid by the State of California

“Our vision is to build an uncompromising, fully capable oceanographic research vessel that can be powered independently from fossil fuels, and be free from the criteria pollutants and greenhouse gas emissions that diesel-powered ships emit,” said Bruce Appelgate, associate director and head of ship operations at Scripps Oceanography. “In doing so, we hope to both serve our scientists and students while being a world leader for transformational change to clean, nonpolluting shipboard power systems.”

Bruce Appelgate, Scripps Institution of Oceanography, at Press Conference

- Funding from the State of CA: $35M
- 3-Year Design/Build/Qualify Program
- Project to begin October 2021

H₂ Vessel Feasibility Questions Encountered and Passed

- Will they float? ✓
- Can they go fast enough, up to 35 knots? ✓
- Can they carry a decent number of people (~150)? ✓
- Do they have sufficient range before needing refueling? ✓
- Can the hydrogen suppliers provide the needed LH₂ per day? ✓
- Can the hydrogen suppliers provide renewable LH₂? ✓
- Can they be refueled fast enough for commuter service? ✓
- Would the technology be supported by CA Ports? ✓
- Are there deep cuts in well-to-waves (WTW) GHG emissions? ✓
- Are there deep cuts in WTW criteria pollutant emissions? ✓
- Can they satisfy regulatory requirements to gain an Approval in Principal? ✓
- Would the U.S. Coast Guard find any “show stopping” issues? ✓
- Would it be commercially attractive? TBD
- Can suitable refueling sites be found for these vessels? ✓
- Would there be support from local government (City Hall, others)? ✓
Thanks to all my friends and colleagues!
For more information on H₂/Fuel Cell Maritime Projects visit: https://maritime.sandia.gov

- Past and current maritime projects
- Download reports

Thank You!

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