The Zero-V: Feasibility of a Liquid Hydrogen Fueled Coastal Research Vessel

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• 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:
Hydrogen Properties:

- Is typically a gas, but can be a liquid (LH$_2$) if made very cold (20 K).
- LH$_2$ evaporates very fast (4,000 gallons will evaporate in ~7 seconds)
- More buoyant than helium. Goes straight up at ~40 mph.

Overall, H$_2$ is very similar to natural gas (which is ~ 90% methane, CH$_4$).

**H$_2$ is NOT a Greenhouse Gas, unlike natural gas which is a potent GHG.**

**If spilled, LH$_2$ evaporates from the water leaving no residue.**

H$_2$ can be ignited given an ignition source and the right H$_2$/air mixture.

**Energetically, a kg of H$_2$ has ~ the same energy as a gallon of diesel.**

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 H\(_2\) production/delivery
- no “thermal runaway” possible

**Going In:**
H\(_2\) and air

**Going Out:**
Electricity
Waste Heat
Warm humidified air
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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<thead>
<tr>
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<th>Ferry</th>
<th>Hydrogen Station</th>
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<tbody>
<tr>
<td>Technical</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Regulatory</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Economic</td>
<td>Higher than conventional now, today’s market acceptance to be determined</td>
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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?

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

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

The larger range pushes us into large quantities of stored hydrogen, making the Zero-V a stepping stone to very large H₂ vessels.
The R/V Zero-V: General Characteristics

Hull Type: Trimaran
Material: Aluminum
Length: 170 ft.
Beam: 56 ft.
Draft: 12 ft.
Freeboard: 9 ft.

Displacement: 1,175 LT
Cruise Speed: 10 knots
Range: 2,400 nm
Endurance: 15 days
Station Keeping: Dyn. Positioning
Air Emissions: Water Vapor

Berths: 18 science
(8 double, 2 single)
11 crew (singles)

-- satisfies all 13 Scripps science missions for a coastal research vessel
The R/V Zero-V: Science Capabilities

<table>
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<th>Feature</th>
<th>Specification</th>
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| A-Frame                  | 20,000 lbs SWL  
20’ vertical clearance  
12’ outboard reach        |
| Main Cranes (2)          | 8,000 lbs SWL over the side                        |
| Portable Crane           | 8,000 lbs SWL                                      |
| Side Frame               | 5,000 lbs SWL                                      |
| Trawl Winch              | 10,000m 3/8 3x19 wire                              |
| Hydro Winch              | 10,000m 0.322 EM  
10,000m ¼” 3x19 wire         |
| Multi Beam Sonar         | Kongsberg EM712                                    |
| Underwater Noise         | ICES up 8 knots                                    |
| Main Lab                 | 825 ft²                                            |
| Wet Lab                  | 575 ft²                                            |
| Computer Lab             | 175 ft²                                            |
| Aft Deck                 | 1,775 ft²                                          |
| Side Deck                | 525 ft²                                            |
| Van Spaces               | 2                                                  |
| Science Payload          | 50 LT                                              |
- \(\text{LH}_2\) Tanks: 2 Type C tanks, \(~5500\) kg of \(\text{LH}_2\) each
- Power: 10 \(\times\) 180 kW PEM fuel cell racks (Hydrogenics)
- Propulsion: 2 \(\times\) 500 kW PM motors
- Bow Thruster: 500 kW, retractable azimuthing
- Stern Thrusters: 2 \(\times\) 500 kW tunnel
- Propellers: Wake-adapted fixed pitch
- Rudders: High-lift
Locations where $\text{H}_2$ vapors are expected to exist or may exist under normal or abnormal conditions. These spaces cannot have ignition sources or gas paths to safe areas.
The GHG Reduction from Using H$_2$ Technology REALLY Depends on How the H$_2$ is Made

WTT: “Well-to-Tank” emissions associate with fuel production and delivery.

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

More information on the calculation of GHG emissions from H$_2$ fuel cell technology can be found at: L.E. Klebanoff, J.W. Pratt et al., Transportation Research D 54, 250 (2017).
The Zero-V Dramatically Reduces Well-to-Waves Emissions

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.
How Would the Zero-V Refuel?

- Discussed bunkering with Linde and Air Products. Both recommended mobile refueling of the Zero-V:
  - Bunker from trucks
    - No shore infrastructure
    - Currently used for filling LH$_2$ storage tanks across US
    - Trailer delivers approximately 4,000 kg of LH$_2$
    - 3 trailers to fully fuel the Zero-V. Typical bunkering with 1-2 trailers (most missions <8,000 kg). Can fully refuel in 3.5-4 hours.
    - Use 2 trailers simultaneously, one bunkering each tank
Where Would the Zero-V Refuel?

Nimitz Marine Facility (Mar-Fac) at the Scripps Institution of Oceanography, San Diego CA

We also confirmed refueling is possible at Pier 54 of the Port of SF, and Wharf 5 at the Port of Redwood City
Vessel Cost Estimate

**Capital Cost:**

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<tr>
<td>Contract Design Engineering</td>
<td>$2.5M</td>
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<tr>
<td>Vessel Construction</td>
<td>$76M to $82M</td>
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<tr>
<td>Program Costs</td>
<td>$4M to $8M</td>
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<td>(5-10% of construction cost)</td>
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**Operations and Maintenance (O&M) Cost:**

- Using a comparison to annual operating costs for the R/V New Horizon (retired from Scripps), it is estimated that the Zero-V operating costs using conventional hydrogen would initially be ~7.7% higher than for an equivalent diesel fueled vessel.
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*

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.
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 2500 kg of 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 Bay Area 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)? ✓


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Sujit Ghosh, MARAD

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Thank You!!

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