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Feasibility of the Zero/V

A zero-emission, hydrogen fuel-cell, coastal research vessel

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Can a capable oceanographic research vessel have zero emissions?

Motivation for a new research vessel

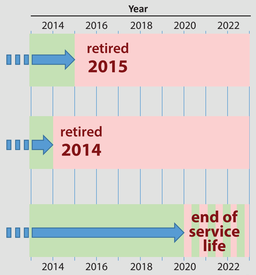
California-based oceanographic vessels used for education and academic research have decreased from 3 to 1, with the remaining vessel approaching its end-of-service. A coastal research vessel is vital to education, research, training, and technology R&D activities in California.

A new vessel is needed.

INTERMEDIATE
R/V *New Horizon*
170 feet / 40-day endurance
12 crew / 19 scientists

REGIONAL
R/V *Pt Sur*
135 feet / 21-day endurance
8 crew / 12 scientists

LOCAL / COASTAL
R/V *Robert Gordon Sproul*
125 feet / 14-day endurance
5 crew / 12 scientists



Abstract

Scripps Institution of Oceanography is exploring options to replace its aging research vessel *Robert Gordon Sproul*, which conducts scientific, educational, and technology development missions offshore California. As part of this effort, we conducted a comprehensive study to determine the technical, regulatory, and economic feasibility of a coastal research vessel powered solely by zero-emission hydrogen fuel cells, and assess the environmental benefits for such a vessel. Our results indicate that it feasible from technical, regulatory, and economic perspectives to design, build and operate a coastal research vessel powered solely by hydrogen fuel cells, using existing and commercially-available technology and services. The conceptual vessel (Zero/V) would offer dramatic environmental benefits, have low airborne and underwater noise signatures, and could be conveniently refueled by LH2 truck trailers at likely ports of call.

Approach

1) Evaluate technical feasibility of LH2 fuel cells
2) Evaluate refueling feasibility
3) Assess criteria pollutant and CO2 emissions
4) Resolve the economics to build & operate
5) Understand the regulatory framework
6) Evaluate the ability of a conceptual vessel to fulfill desired scientific missions

Design Targets: Coastal Research Vessel

Characteristic	Desired Spec
Scientists (overnight)	16 - 20 (overnight)
Scientists (day trip)	45 - 50 (day trip)
Speed, transit	10 kts (SS4), 7 kts (SS5)
Speed, maximum	12 kts
Dynamic positioning	2 kts beam curent 25 kts wind
Sea keeping	100% SS4; >50% SS5
Endurance	21 days
Range	2,500 nm
Main lab	800 sq ft
Wet lab	400 sq ft
Work deck	1,200 sq ft
Computer lab	120 sq ft
Removable vans	2 20-foot ISO
A-Frame SWL	12,000 lbs
Main crane SWL	8,000 lbs @ 12'
Knuckle crane SWL	4,000 lbs
Side CTD frame SWL	5000 lbs
Trawl winch	10,000 m 3/8-inch 3x19 10,000 m .681 FO

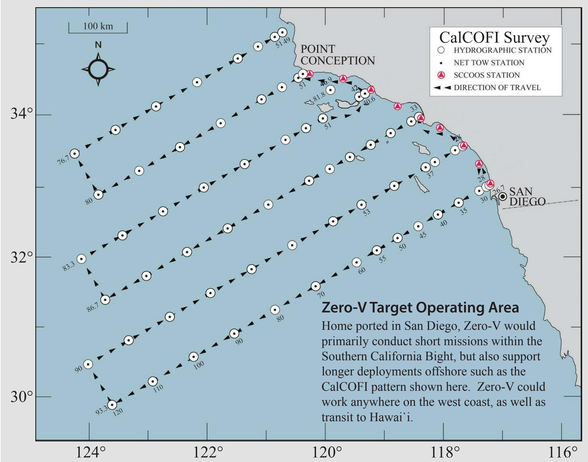
Characteristic	Desired Spec
Multibeam	3600 m max depth
ADCP	75 kHz & 150 kHz
Fisheries sonar	multi-freqency
Echosounder	3.5 & 12 kHz
Acoustic navigation & tracking	USBL or SSBL
Motion reference unit	Survey quality
GPS	Survey quality
Satellite broadband	HiSeasNet
Data Network	yes
Spare Transducer wells	yes
Flow-thu seawater	yes
Walk-in science refer	100 sq ft, -20 deg C
XBT	yes
Met mast & sensors	yes
Gigabit LAN	yes
Overboard handling	Cores, dredges, nets
Support for autonomy	AUVs, UAVs, ROVs
Hydro winch	10,000 m .322 EM 10,000 m 1/4-inch 3x19

Primary Vessel Uses

- University class cruises
- Technology R&D
- Independent student-led research
- Sponsored oceanographic research

Missions and Requirements

Multidisciplinary, general-purpose teaching & research vessel
Frequent short (one day) coastal projects, including seagoing instruction for classes
Occasional long (up to 14-day) offshore deployments, working round-the-clock
Support for all disciplines: biology, chemistry, geology, geophysics, physics
Moorings, towed instruments, acoustic surveys, CTD profiling
Must have excellent slow-speed handling and dynamic positioning
Needs ample laboratory and deck space, and heavy-lift overboarding capabilities
Must support all-season operations, including long-range CalCOFI surveys



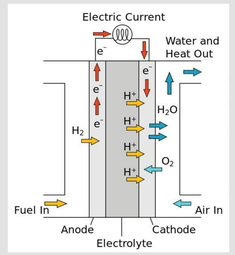
Desire

A) Eliminate criteria pollutant emissions that create smog and impact human health
B) Eliminate the use of fossil fuels and the associated risk of oil spill pollution
C) Eliminate the emission of CO2, which is a greenhouse gas
D) Eliminate our dependence on petroleum fuels in favor of renewable energy

Clean marine power from hydrogen fuel cells

Emissions of criteria pollutants from maritime sources significantly impact air quality and human health on and offshore in California (*Klebanoff et al, 2018*). Carbon dioxide (CO2) is a greenhouse gas (GHG), and is produced in large quantities by ships powered by fossil fuels. Emissions reductions of 80% or more are required to produce results that are robust against growth in the intensity at which technology uses energy (*Keller et al, 2012*). While fossil fuels remain dominant, even the most significant emissions reductions modelled do not result in a downward trend (*IMO, 2014*). **Hydrogen enables a zero-emission energy pathway.**

Proton Exchange Membrane (PEM) Fuel Cells
Efficiently convert hydrogen to electricity without combustion
Faster power response than internal combustion
Zero CO2 emissions, zero criteria pollutants
Quiet (no moving parts), reaction product is pure deionized water for analytical or drinking use
PEM fuel cells are commercially available today



Hydrogen
Liquid (LH2) at 20K (-424°F), evaporates quickly
LH2 spill of 4,000 gal self-resolves in 7 seconds
LH2 can be supplied now in the quantities required
LH2 has been safely produced, transported, stored and used for years

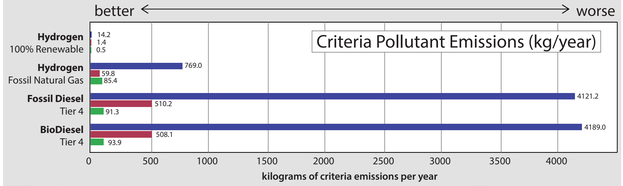
Refueling can use existing infrastrucure
LH2 fueling from trucks is doable at ports of call
Typical two-truck refueling operation can be done in five hours, with trucks pumping in parallel
Fueling would be similiar to LNG bunkering that is already common in USA and worldwide

Emissions: Well-to-waves analysis

By using PEM fuel cells, Zero-V will emit no CO2 or criteria pollutants at the point of use. However, we need to consider overall impact of the technology. *Well-to-waves* (WTW) analysis accounts for all emissions associated with LH2 production and transportation.

Criteria pollutants (CPs)

CPs harm human health, and are produced by the combustion of fossil fuels
Include nitrogen oxides (NOx), hydrocarbons (HC), and particulate matter (PM)

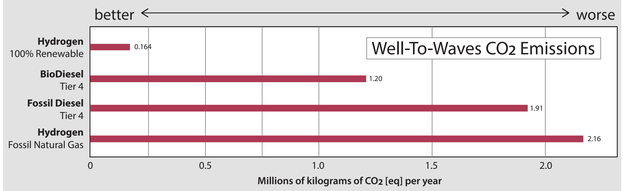


PEM fuel cells involve no combustion, so they cannot produce CPs
All CPs associated with Zero/V are from the production and transportation of LH2
Results of WTW analysis:
1) Fossil diesel and biodiesel produce similar levels of CP
2) LH2 from fossil natural gas reduces NOx 81.3% below an equivalent vessel running on fossil diesel fuel under Tier 4 emission constraints
3) Using 100% renewable electricity, the Zero-V WTW emissions would be reduced 99.6% in NOx, 99.7% in HC and 99.4% in PM vs Tier 4 fossil diesel

If LH2 is delivered by a truck that uses 100% renewable hydrogen instead of diesel fuel, the criteria pollutant emissions could be essentially zero.

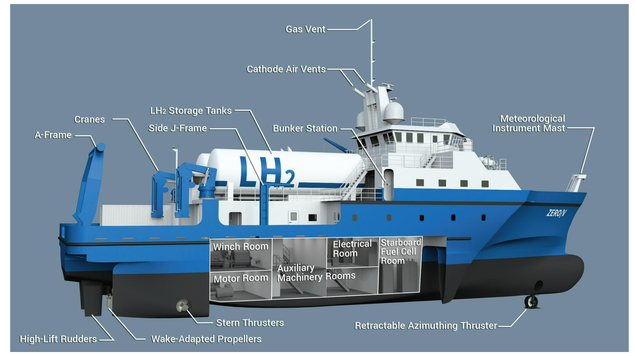
Carbon dioxide emissions

CO2 (eq) emissions are the sum of CO2, CH4 and N2O weighted by radiative trapping - these are greenhouse gasses (GHG).
LH2 can be produced by steam reformation of fossil fuel natural gas (NG), or by electrolysis using renewable low-carbon electricity.
For Zero-V to reduce maritime CO2(eq), need to use LH2 derived from renewable sources, not from fossil NG
Renewable LH2 is commercially available today in quantities needed for Zero-V



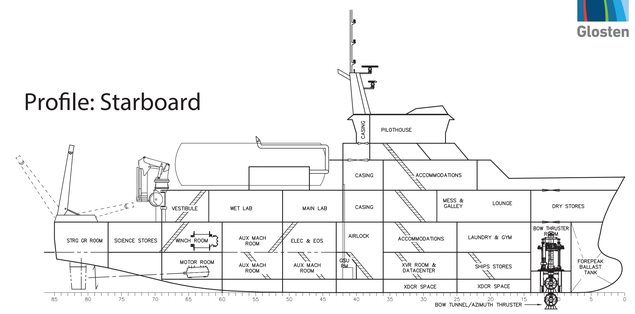
Other benefits of construction and operation of Zero-V

Advances maritime regulations for LH2 vessel technology
Promotes class society capability for examining safe operations of LH2 vessels
Develops fuel-cell technology for maritime applications
Stimulates LH2 production and delivery systems, especially renewable LH2
Promotes domestic production of transportation fuels independent of foreign oil

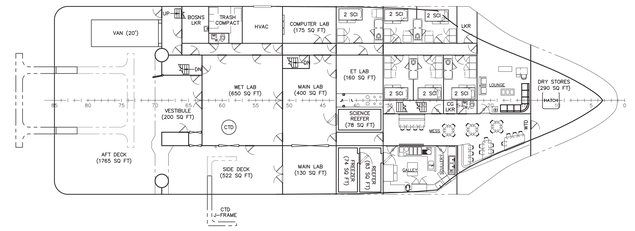


Glosten

Profile: Starboard



Main Deck



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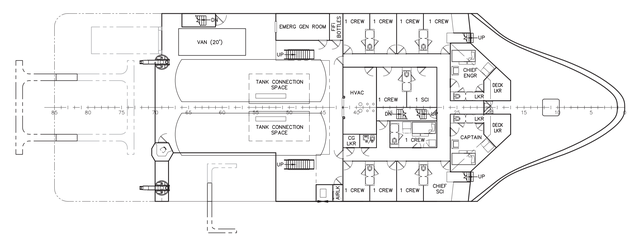

YES: Zero/V is FEASIBLE TODAY
Based on technical - regulatory - economic considerations

Zero/V is a bold, transformative game-changer

Zero emissions: no NOx, SOx, particulates or CO2 **Clean / no GHGs**
Uses clean renewable hydrogen: **No fossil fuels**
Carries no diesel: **No oil spills**
Fuel cell power plant: few moving parts, no internal combustion **Quiet**
Fuel cells produce deionized water for laboratory or potable use **Efficient**
Outstanding scientific instrumentation, range, and habitability **Capable**

Acknowledgements

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