R/V ZERO-V

A zero-emission hydrogen fuel cell research vessel

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Presentation Overview

- Project motivation and goals
- Pollution from research vessels
- Hydrogen as a fuel
- Science mission requirements
- Vessel particulars
- Capabilities & arrangements
- Hydrogen systems & fueling
- Cost estimates

Sandia National Laboratories

MARAD Maritime Administration

DNV·GL

Glosten

UC San Diego

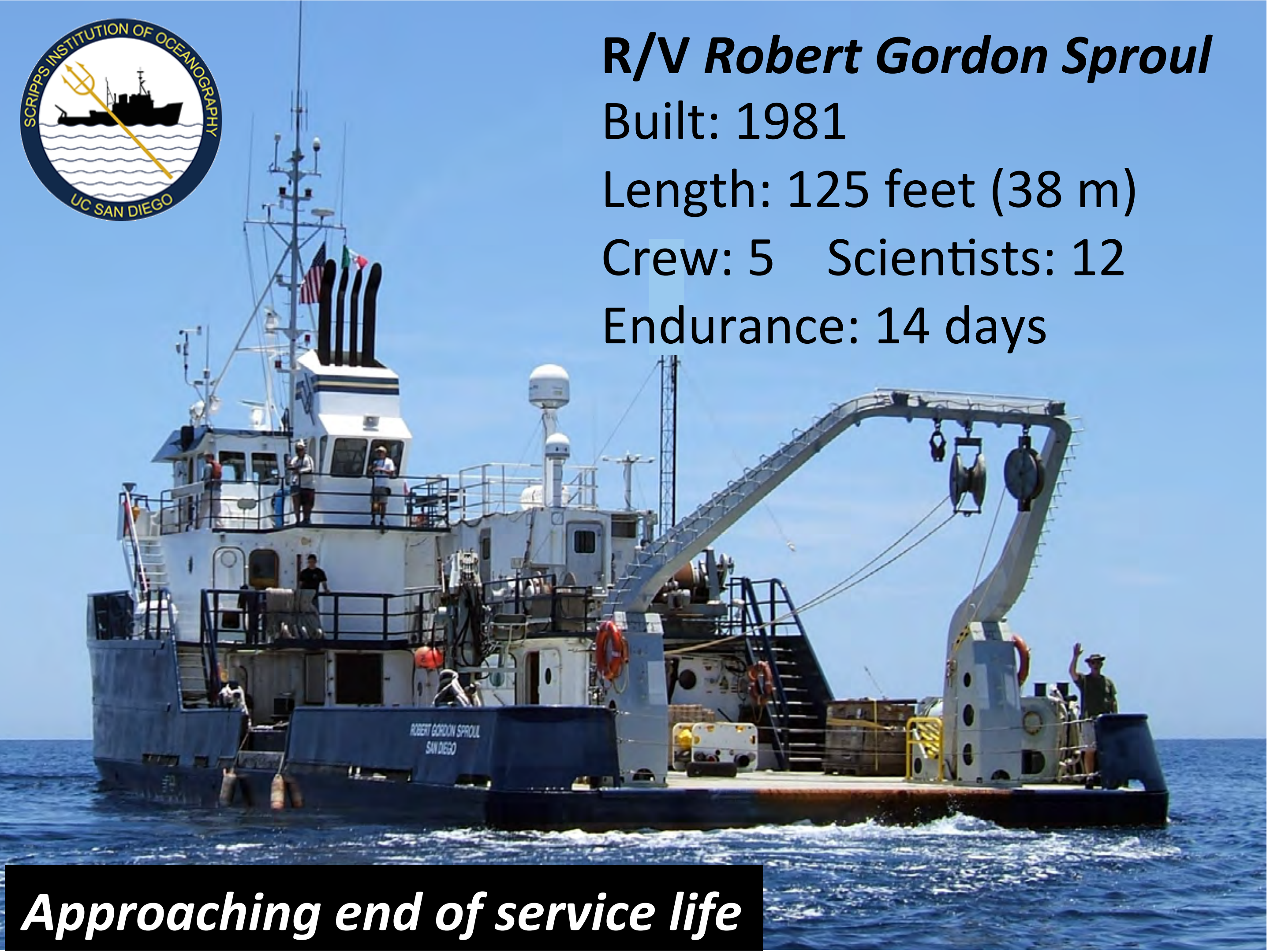
R/V *Robert Gordon Sproul*

Built: 1981

Length: 125 feet (38 m)

Crew: 5 Scientists: 12

Endurance: 14 days



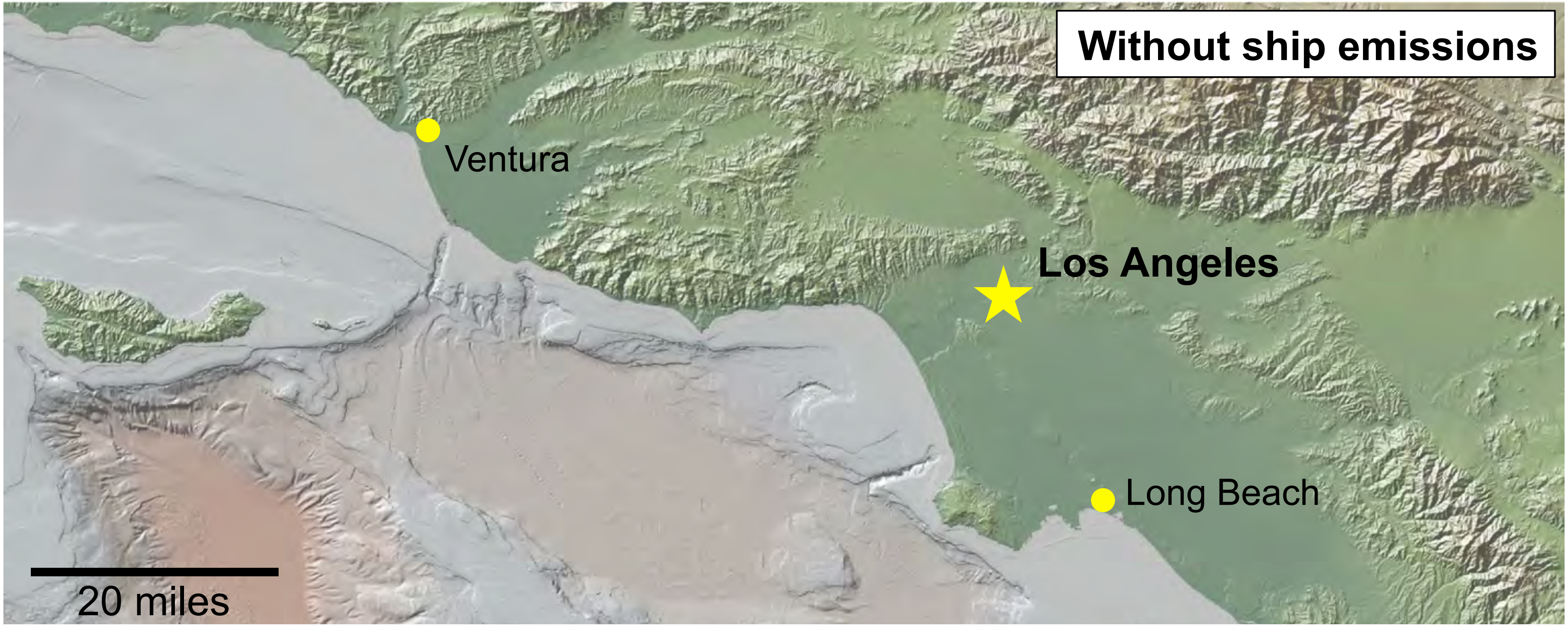
Approaching end of service life


Sally Ride

Roger Revelle


FLIP

Ship emissions pollute all of Southern California



Difference between 24-hour average NO_2 concentration (ppb) for year 2002 in the South Coast air basin of California between cases with and without ship emissions.

Dabdub et al., 2008, Air Quality Impacts of Ship Emissions in the South Coast Air Basin of California

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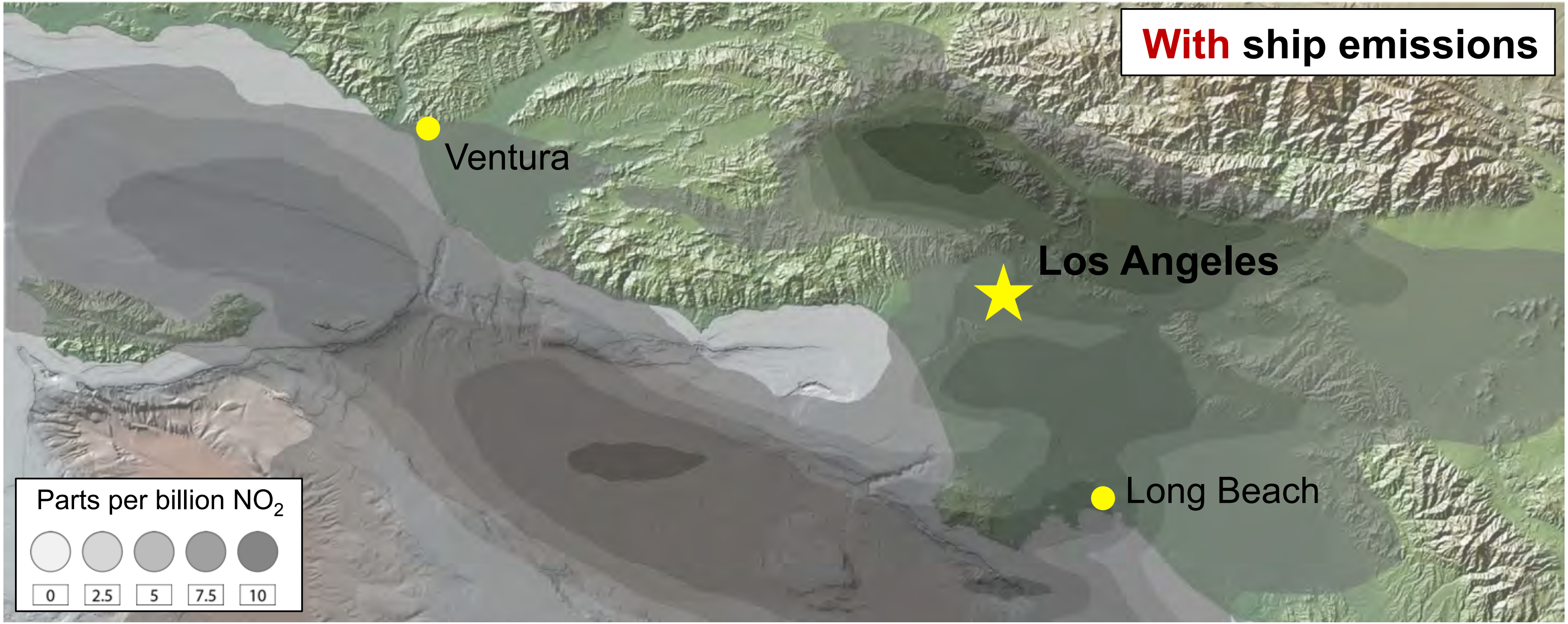

Difference between 24-hour average NO_2 concentration (ppb) for year 2002 in the South Coast air basin of California between cases with and without ship emissions.

Positive values (darker) indicate increased concentration due to ship emissions.

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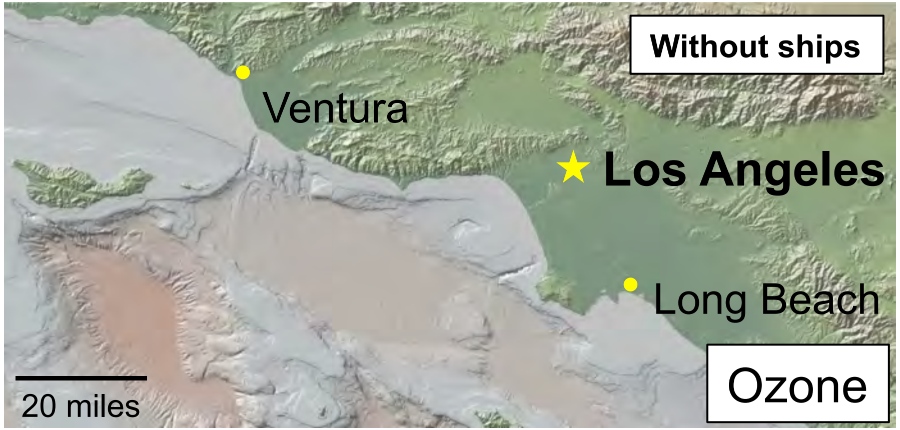

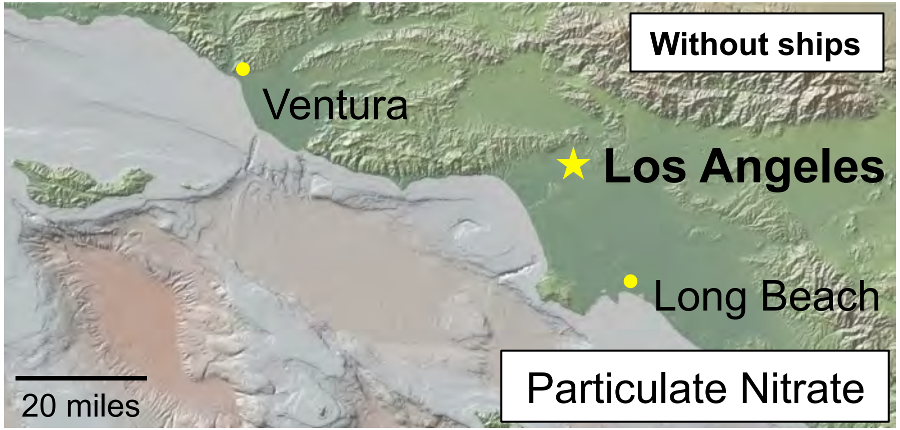

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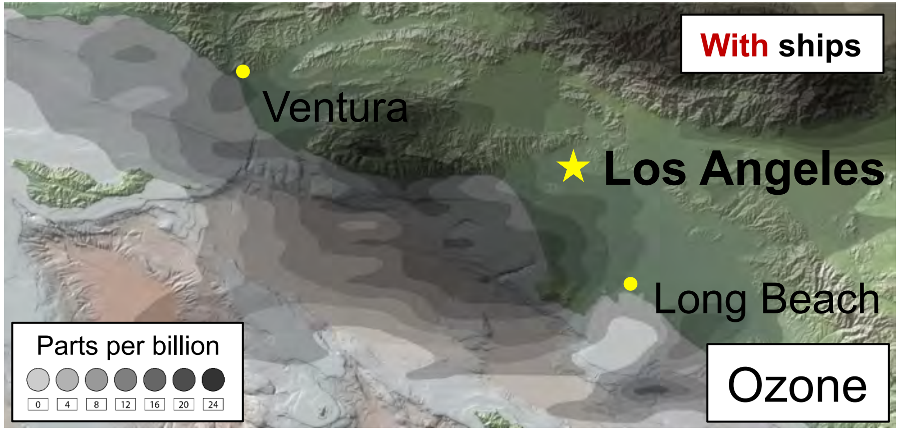

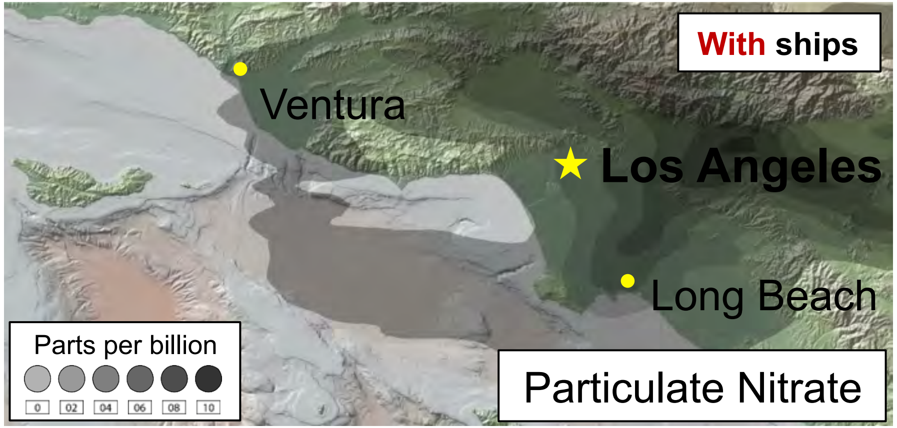

California Air Resources Board identifies diesel particulate matter as a **toxic air contaminant** based on the relationship between diesel exhaust exposure and lung cancer and other adverse health effects

"…diesel exhaust still poses substantial risks to public health and the environment."

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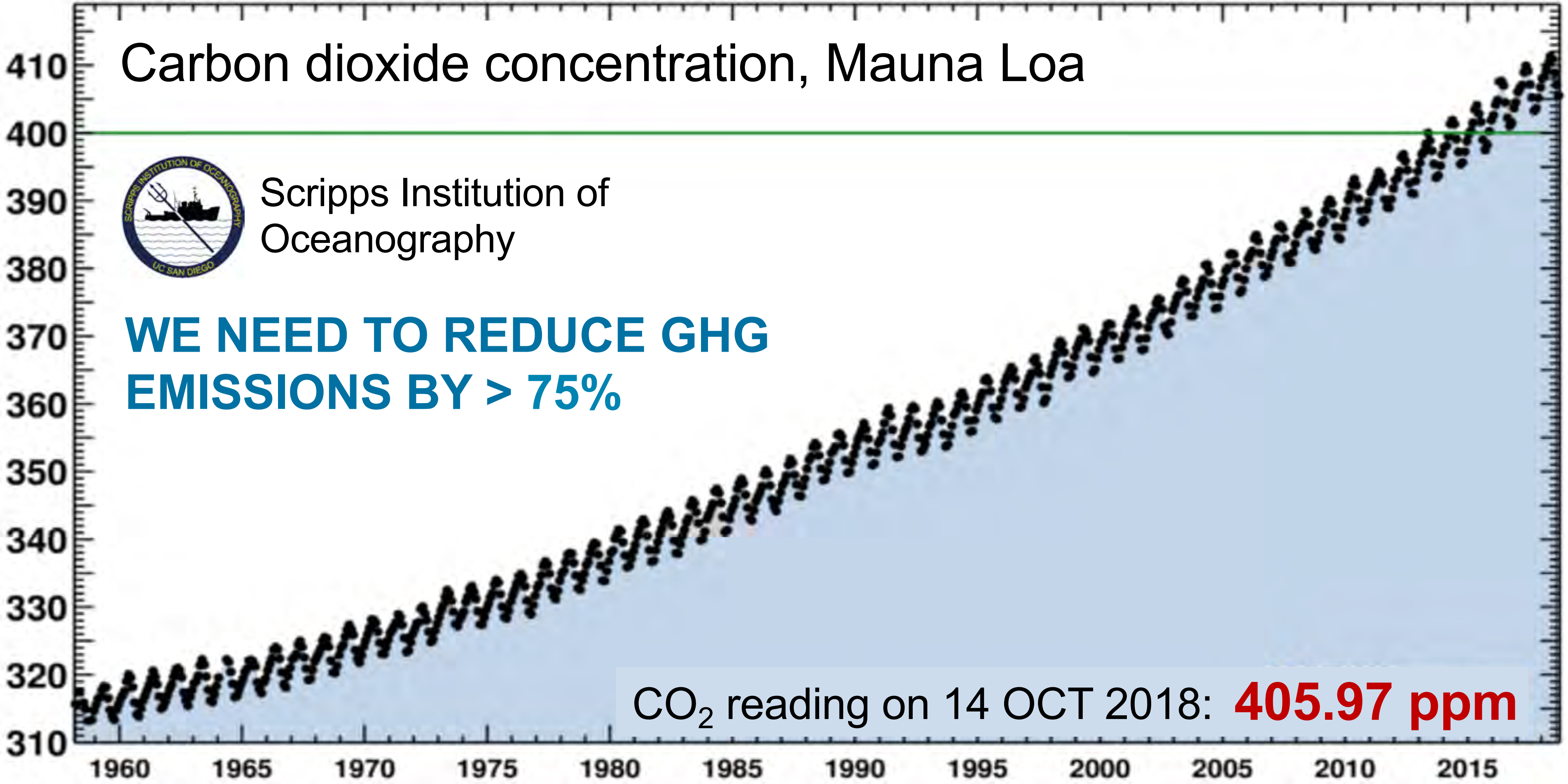
Ships pollute the Earth with CO_2 (a greenhouse gas)



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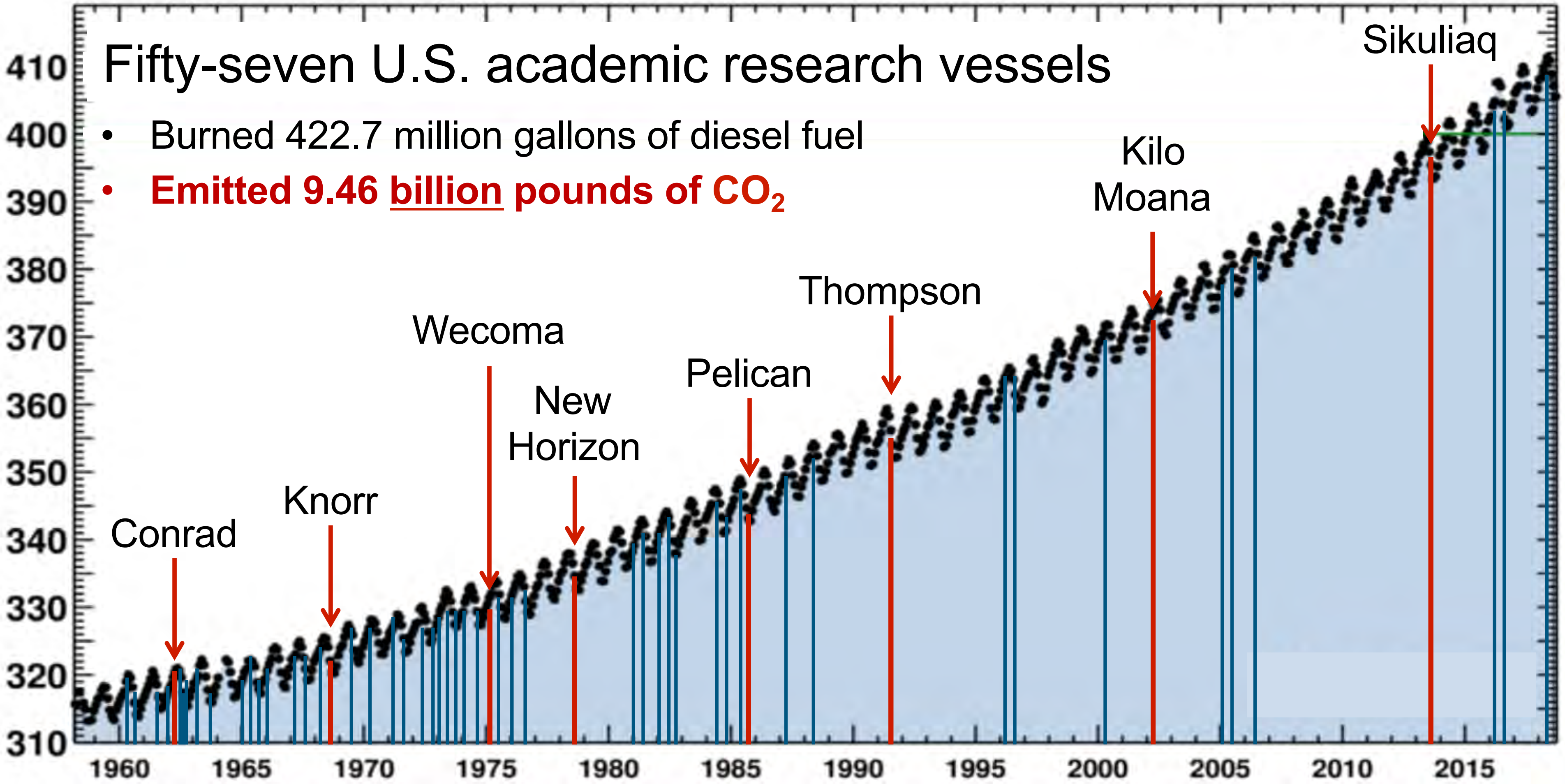


PROJECT MOTIVATION & GOALS

Feasibility study: Is it possible to build a capable non-polluting coastal research vessel that does not use fossil fuels, with existing technology that is available commercially now?

Goals of the study

- Evaluate technical feasibility of marine hydrogen fuel cells
- Design a hydrogen fuel cell research vessel
- Evaluate fuel supply and bunkering feasibility
- Understand the regulatory framework
- Resolve the economics to build & operate
- Assess criteria pollutant and CO2 emissions
- **Answer the question:**

  Can a zero-emission vessel capably fulfill our scientific mission?

Collaborators

Sandia National Laboratories

DNV·GL

MARAD Maritime Administration

Glosten

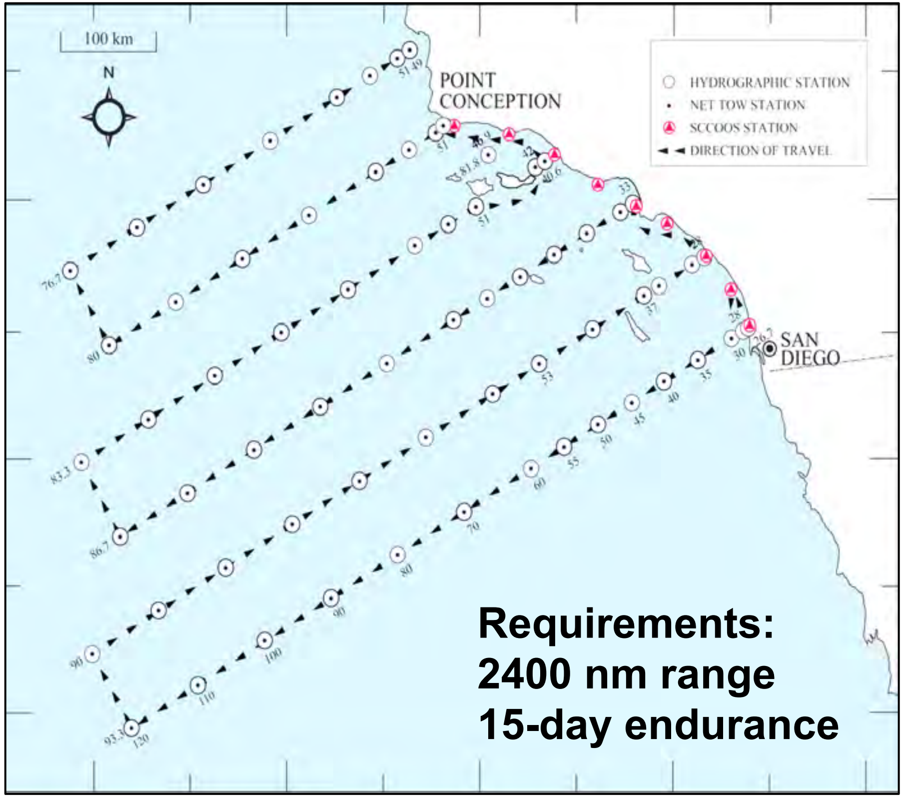
UC San Diego

ZERO-V SCIENCE MISSION REQUIREMENTS

Primary Vessel Requirements

Cruise	10 kts, calm water	Portable Vans	2
Speed	12 kts, calm water (sprint) 9 kts, SS4 7 kts, SS5	Crew Berths	11
Range	2400 nm	Scientist Berths	20
DP	2 kts beam current, 25 kts wind at best heading	A-Frame	12,000 ST SWL
Endurance	15 days	Main Crane	8,000 lbs @ 12’ over the side
Main Lab	800 sq ft	Portable Crane	4,000 lbs SWL
Wet Lab	500 sq ft	Side Frame	5,000 lbs SWL
Computer Lab	120 sq ft	Trawl Winch	10,000m 3/8 3x19
Aft Deck	1200 sq ft	Hydro Winch	10,000m 0.322 EM, 10,000m 1/4 3x19

Benchmark Mission: CalCOFI Survey



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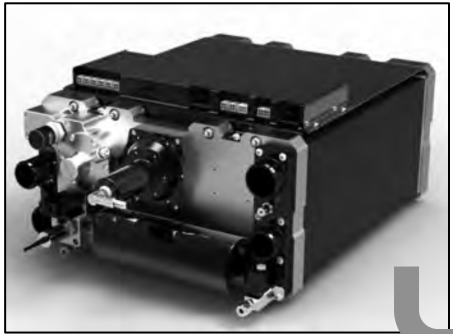
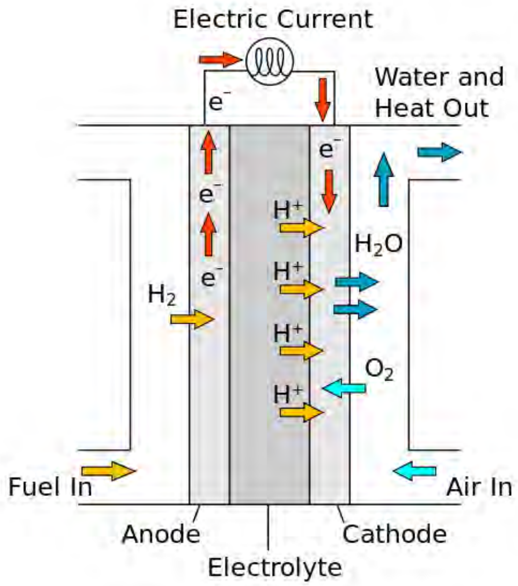
Operational Profiles

- Coastal moorings
- Deep moorings
- Mapping
- Class cruises
- ROV surveys
- Coring & dredging
- CTD profiles
- UAV flight ops
- AUV ops
- Physical oceanography
- Biogeochemistry
- Towed instruments
- FLIP anchor handling

HYDROGEN FUEL CELLS



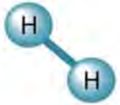


Proton Exchange Membrane (PEM)

- Use a catalyst to combine hydrogen and oxygen to produce electricity and water
- Faster power response than internal combustion engines
- Energizes ship's electric propulsion system
- Quiet: no moving parts, no combustion
- Produces pure deionized water suitable for analytical laboratory use
- Available commercially today

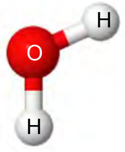
Hydrogenics HY-PM HD30 fuel cell and rack

H_2 molecule



Natural Gas
(90% CH_4)

Water
(H_2O)



Hydrogen is typically made from natural gas, but “renewable H_2” derived from biogas or electrolyzing water (H_2O) with clean power is available. Renewable H_2 is preferred due to low GHG emissions from H_2 production.

HYDROGEN (H_2)

- **Gas at standard conditions (room T, atmospheric pressure)**
- **Liquefies (LH_2) at 20K (-424 °F, -253 °C)**
- **Liquid hydrogen (LH_2) evaporates rapidly (seconds)**
- **More buoyant than helium**

H_2 /LH_2 is similar to NG/LNG but there are differences

	Liquid Hydrogen	Liquid Natural Gas
Greenhouse Gas	No	Yes, potent
Ignitable	yes, given right mixture	yes, given right mixture
Lower Heating Value	120 MJ/kg	45 MJ/kg
Approach to Safety	Avoid leaks and ignition sources	Avoid leaks and ignition sources
Boiling point (liquid)	20K (-253 °C).	111K (-162 °C)
Density (liquid)	71 g/L	422 g/L

For the same amount of stored energy, LH2 has 0.38 times the mass of LNG, but has 2.4 times the volume

VESSEL PARTICULARS: GENERAL

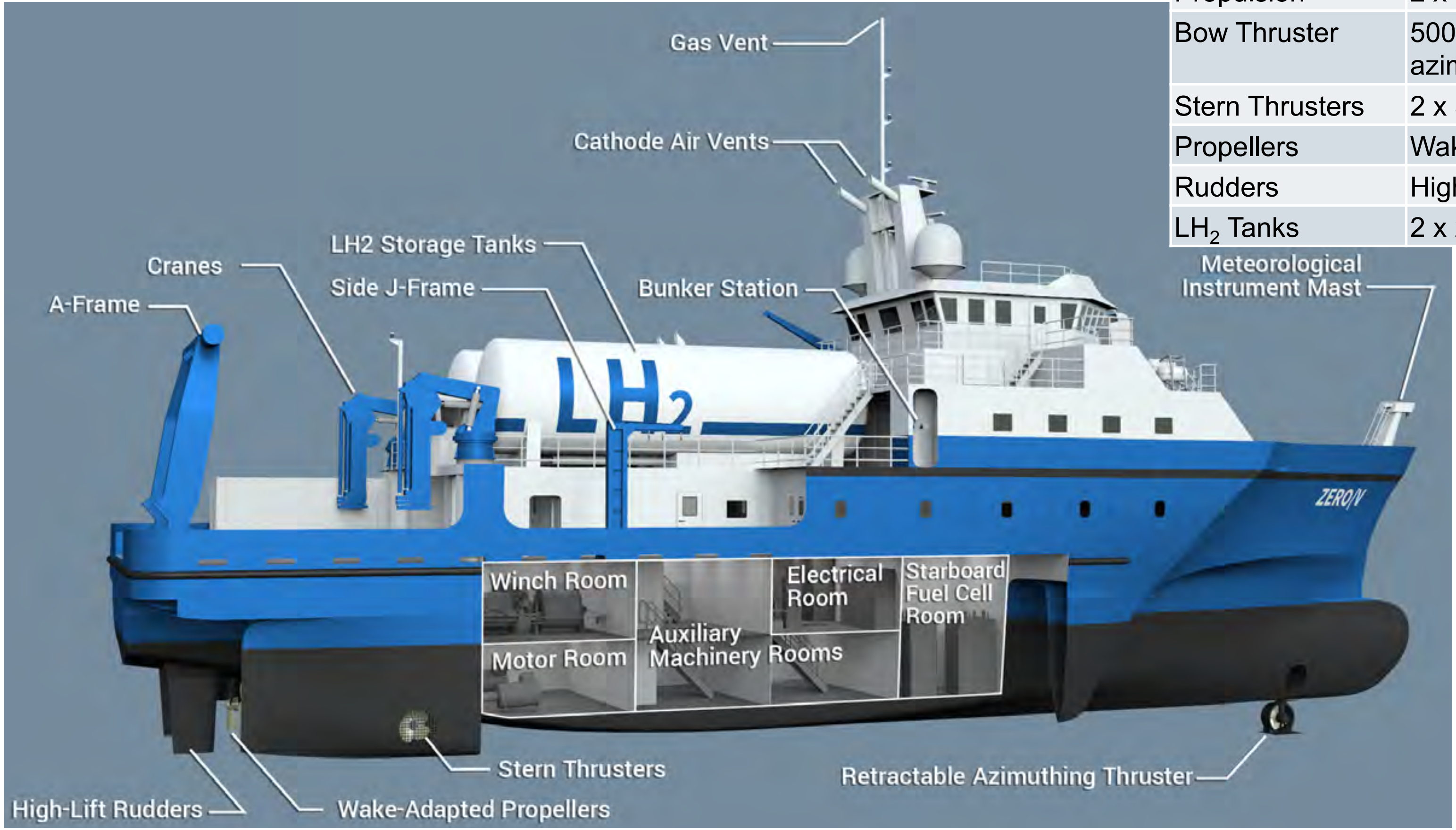
Hull Type	Trimaran
Material	Aluminum
Length	170 ft.
Beam	56 ft.
Draft	12 ft.
Freeboard	9 ft.
Displacement	1,175 LT
Cruise Speed	10 knots
Range	2,400 nm
Endurance	15 days
Station Keeping	Dynamic positioning
Berths	20 Science (double) 11 Crew (single)
Air Emissions	Water vapor

VESSEL PARTICULARS: SCIENCE

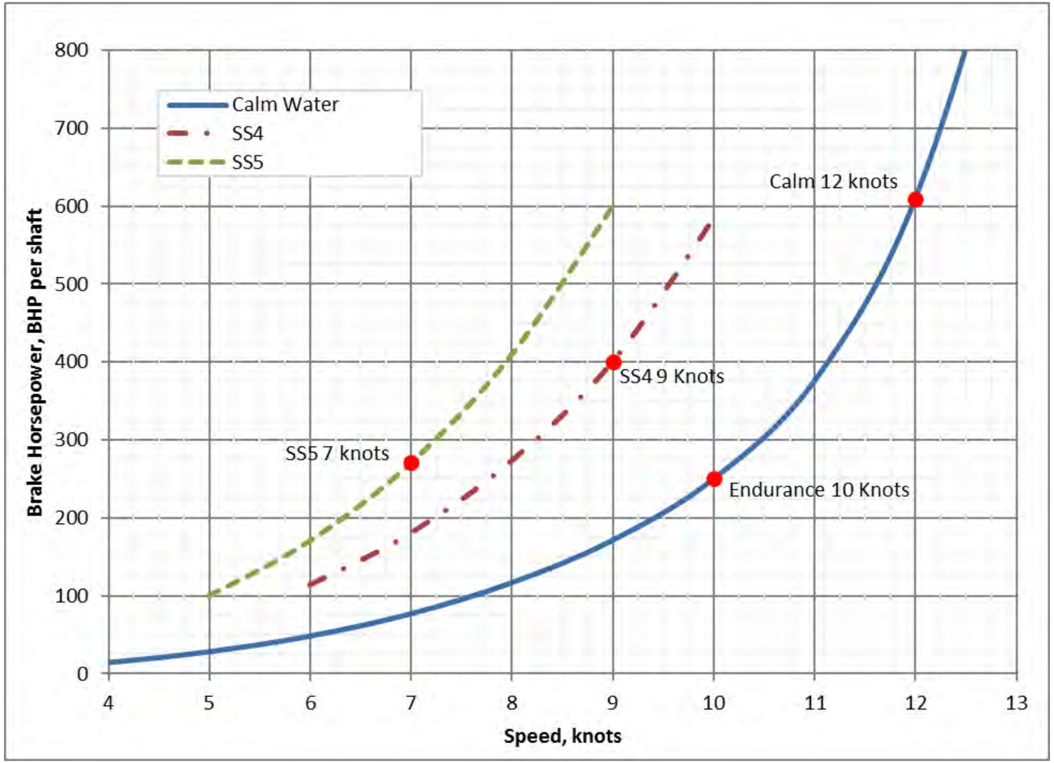
A-Frame	20,000 lbs SWL 20′ vertical clearance 12′ outboard reach
Main Cranes (2)	8,000 lbs SWL over the side
Portable Crane	8,000 lbs SWL
Side Frame	5,000 lbs SWL
Trawl Winch	10,000m 3/8 3x19 wire
Hydro Winch	10,000m 0.322 EM 10,000m ¼″ 3x19 wire
Multi Beam Sonar	Kongsberg EM712
Underwater Noise	ICES up 8 knots
Main Lab	825 ft^2
Wet Lab	575 ft^2
Computer Lab	175 ft^2
Aft Deck	1,775 ft^2
Side Deck	525 ft^2
Van Spaces	2
Science Payload	50 LT

VESSEL PARTICULARS: PROPULSION

Power	10 x 180 kW hydrogen fuel cell racks
Propulsion	2 x 500 kW PM motors
Bow Thruster	500 kW, retractable azimuthing
Stern Thrusters	2 x 500 kW tunnel
Propellers	Wake-adapted fixed pitch
Rudders	High-lift
LH_2 Tanks	2 x 28,800 gal type C



CAPABILITIES: SPEED AND POWERING

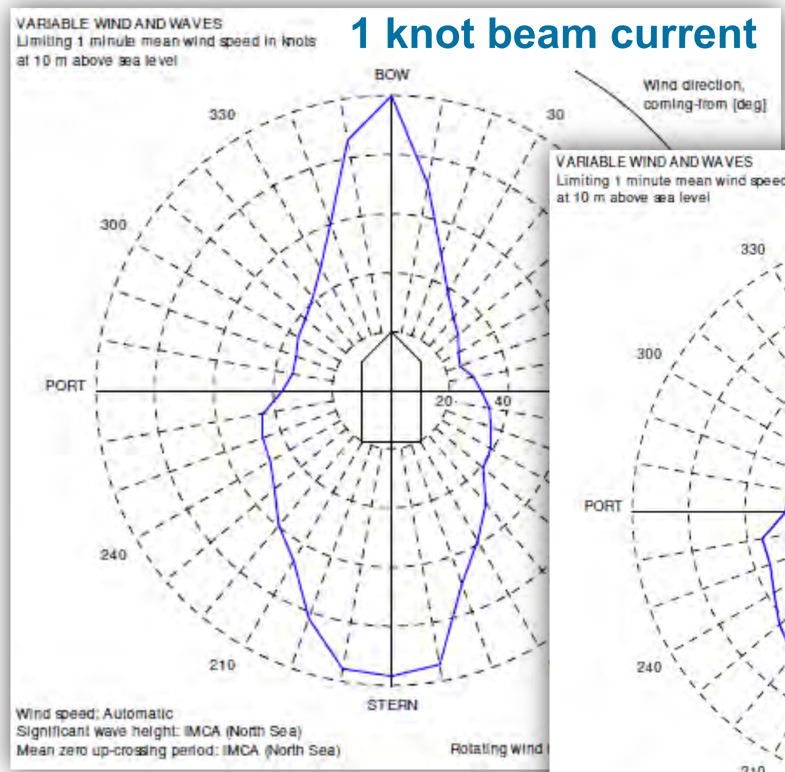


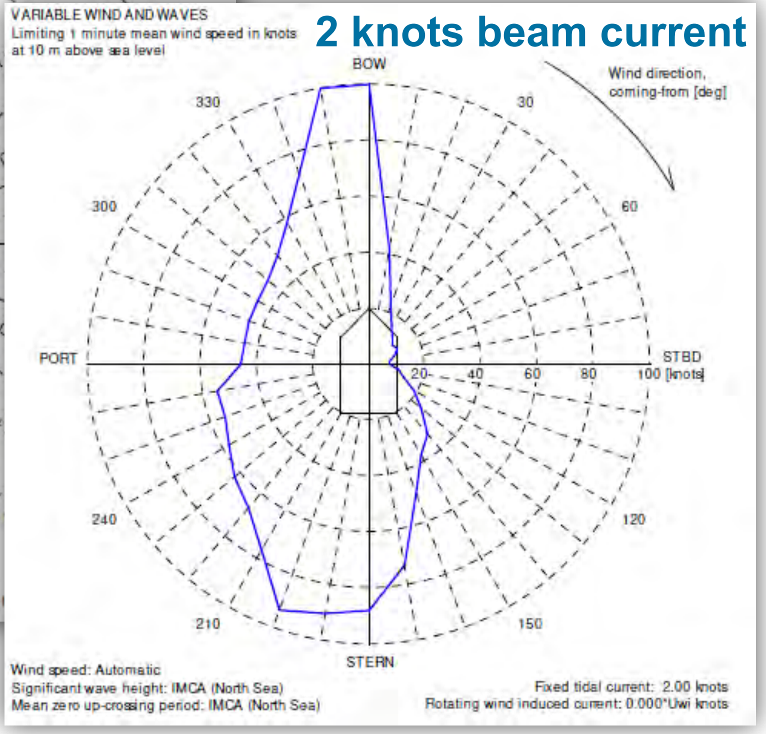
Zero-V achieves required 10 knot cruise speed

Methodology

- Parametric regression methods not available for low speed trimarans
- Calculated Resistance with ITTC Method
  - Resistance calculated for each hull separately
  - Frictional + residuary + appendage + air
- Speed in seaways extrapolated from calm water using added resistance from waves

CAPABILITIES: POSITION KEEPING





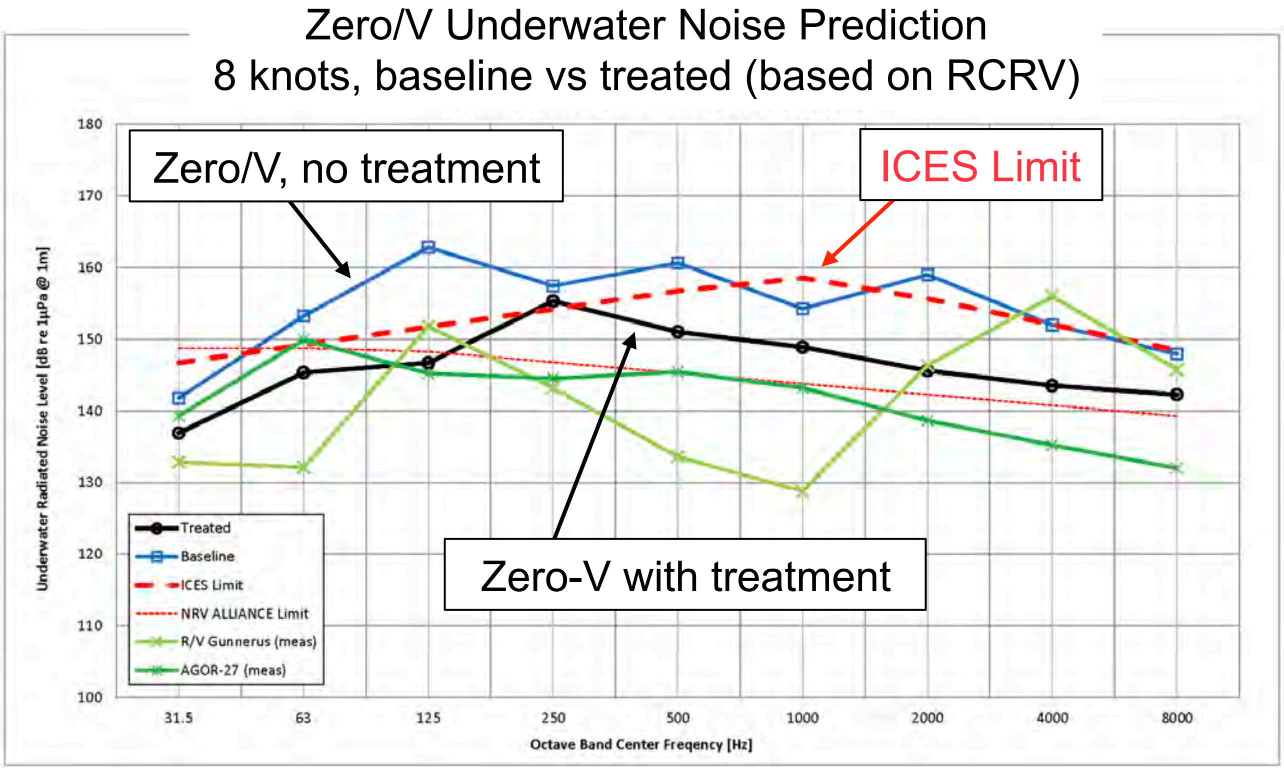
Zero/V can maintain position in challenging wind & wave conditions

- 1 kt beam current
- 25 kt wind and waves from any direction

- 2 kts beam current
- 25 knots wind and waves at best heading (15 deg bow quarter, 45 deg stern quarter)

Station keeping performance meets science mission requirements

CAPABILITIES: UNDERWATER RADIATED NOISE (URN)



* ICES: International Council for the Exploration of the Sea Report 209 is a measure of underwater radiated noise

Initial assessment

- Used RCRV URN analysis and removed noise from Z-drives & diesel engines
- Non-cavitating propellers

Considerations

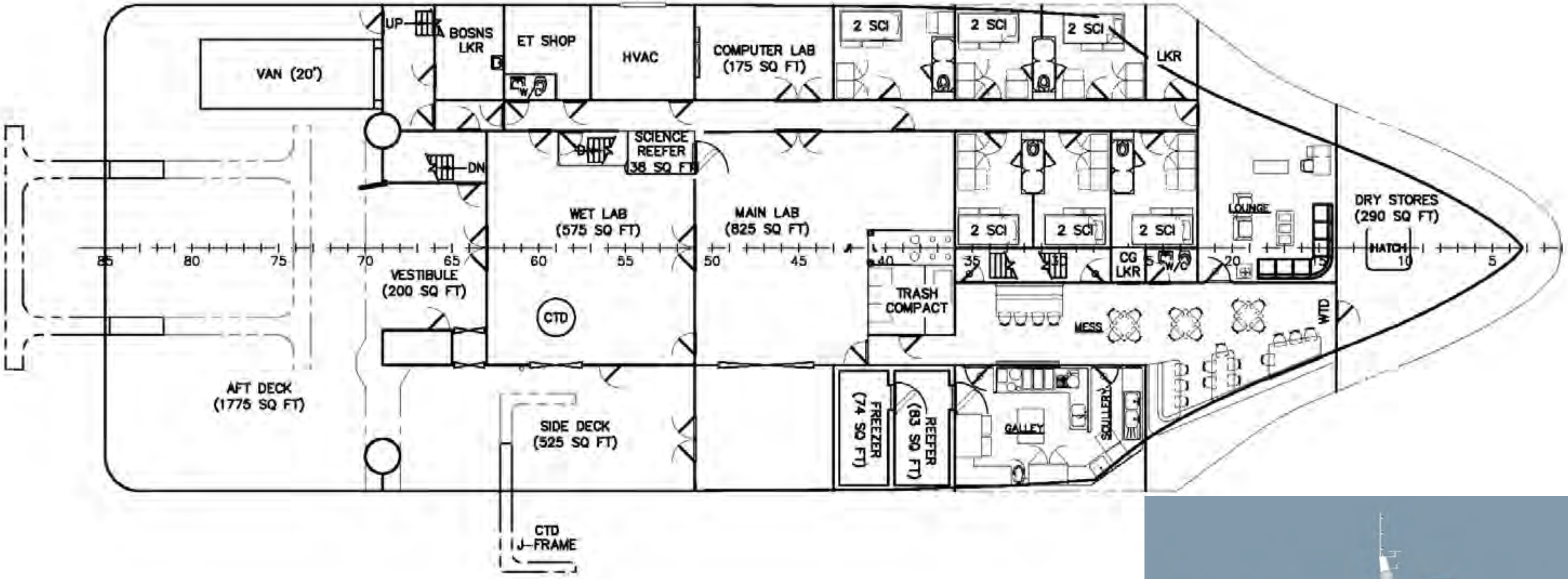
- Trimaran has less noise radiating surface
- Aluminum may require more noise treatment than steel

Computational analysis is required for full assessment

Expectation is Zero/V can meet ICES* limit at 8 knots

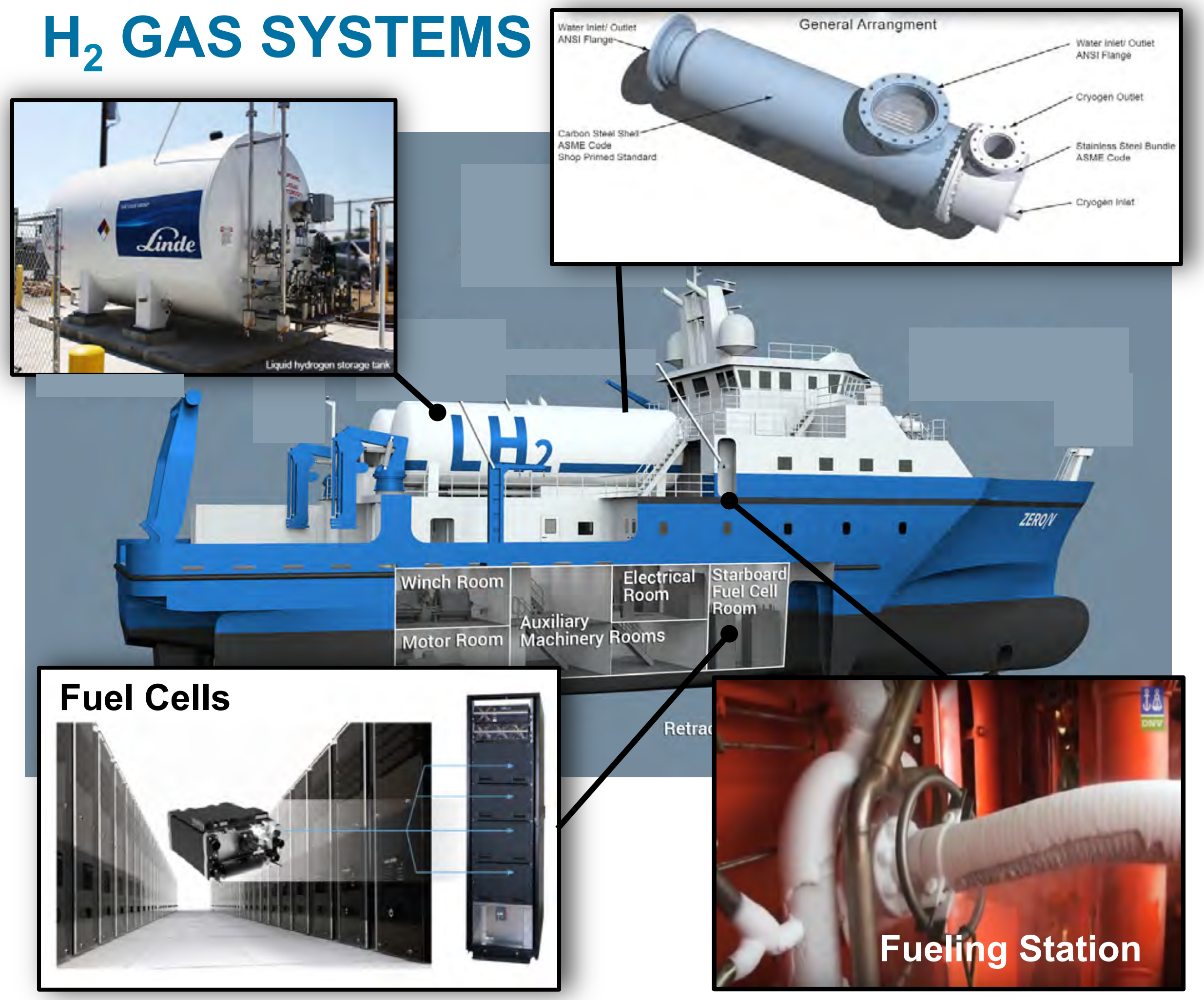
ARRANGEMENTS: MAIN DECK

Lots of laboratory space -- plenty of working deck



Main deck →

H_2 GAS SYSTEMS



- Two Type C vacuum insulated LH_2 tanks (5,830 kg / tank)
- Ten power racks with six Hydrogenics HyPM HD 30 fuel cell modules (180 kW/rack)
- Two Thermax cryogenic cold water evaporators
- Fully redundant gas system
- Fuel cell room has redundant ventilation and gas detection for each rack and emergency shutdown upon any failure
- Fire risk mitigated with water deluge and NOVEC systems around tanks & in fuel cell rooms
- Bunker on 01 deck starboard
- Bunker piping is doubled walled vacuum insulated stainless steel
- Provides secondary containment and minimize heat ingress into the LH_2 during bunkering.

FUELING LIQUID HYDROGEN

Existing methods of delivery and transfer can be easily adopted

- Based on safe, proven practices
- No shore infrastructure
- Currently used for filling LH_2 storage tanks across the USA
- Fueling procedures were informed by commercial vendors

- Each trailer provides 4,000 kg of LH_2
- Typical bunkering will require 1-2 trailers
- Full trailer deliver take < 4 hours
- Simultaneous & independent bunkering of each fuel tank, so two trailers can be used simultaneously
- Cryogenic fuel transfer to vessels is well known, and can be applied to Zero/V with no new R&D needed

Existing technology can be used

No new shoreside infrastructure is needed

REGULATORY REVIEW

No US or international regulations specific to hydrogen fuel cell vessels exist

- The regulatory regime for a hydrogen fuel cell powered vessel is currently under development
- Regulatory basis:
- Extend LNG regulations to hydrogen fuel
  - DNV GL Rules for Classification: Ships
  - IGF Code: International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuel
  - 46 CFR Subchapter U: Oceanographic Research Vessel

Submitted to the US Coast Guard and DNV GL for review to identify any significant regulatory or safety concerns with the fundamental design.

No show-stopping red flags were identified.

DNV·GL

STATEMENT OF CONDITIONAL APPROVAL IN PRINCIPLE

Glosten/Sandia National Laboratories
Zero-V Hydrogen Research Vessel

This is to certify that Zero-V Hydrogen Research Vessel is granted *Conditional Approval in Principle (CAIP).*

Received a Conditional Approval In Principle (CAIP) from DNV GL.

VESSEL COST ESTIMATE

Capital Cost

Contract Design Engineering	$2.5M
Vessel Construction	$76M to $82M
Program Costs	$4M to $8M (5-10% of construction cost)

Total: $82.5M to $92.5M

Operating Costs

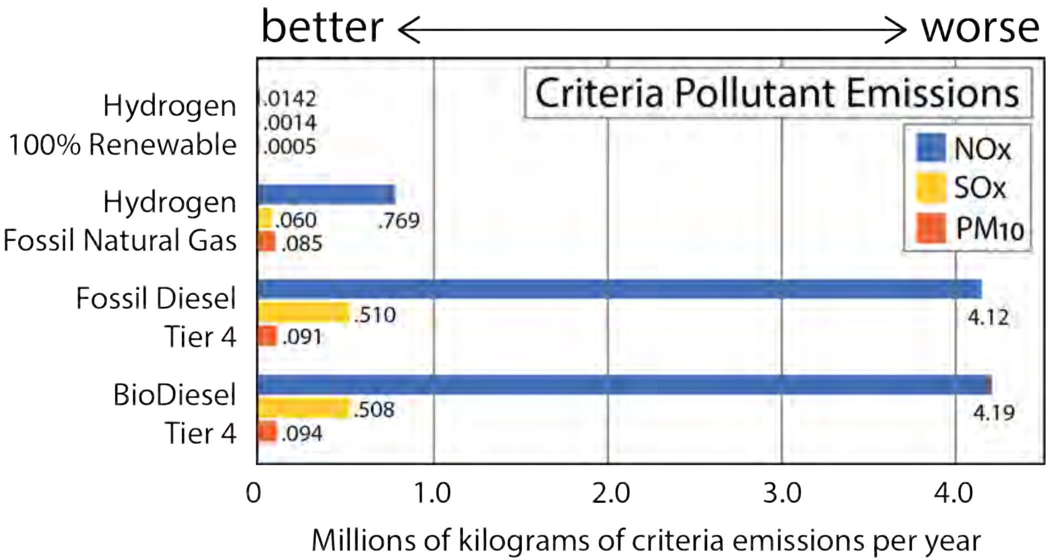
Baseline: R/V *New Horizon*

- Similar size and complement
- No maintenance related to diesel generators
- Fuel costs (diesel vs LH2)

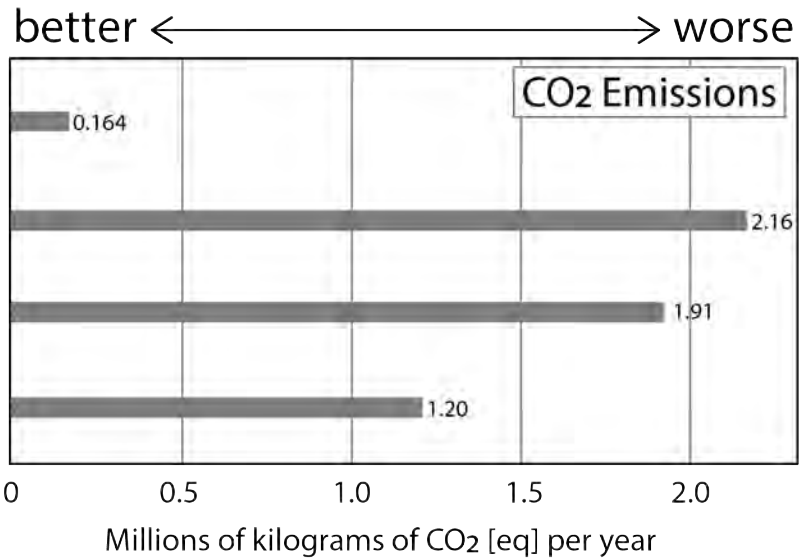
ZeroV ~7.7% higher, based on 2018 prices

EMISSIONS (FROM H_2 PRODUCTION)

Well-To-Waves Criteria Emissions (1,000 MT / year)



Well-to-Waves Greenhouse Gas Emissions (1,000 MT CO_2 equivalent / year)



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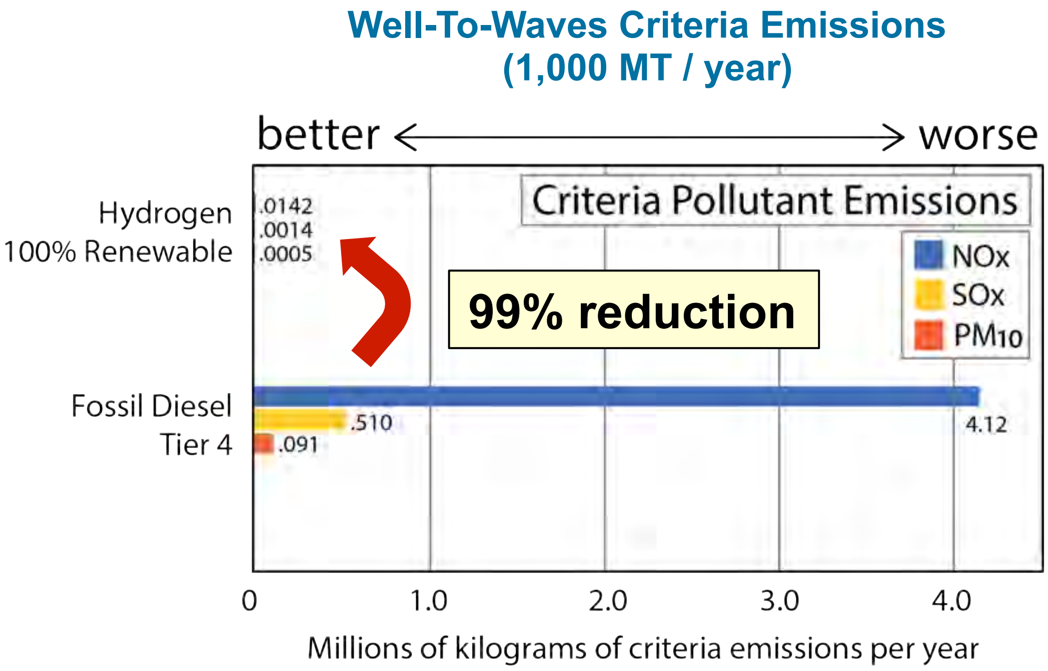

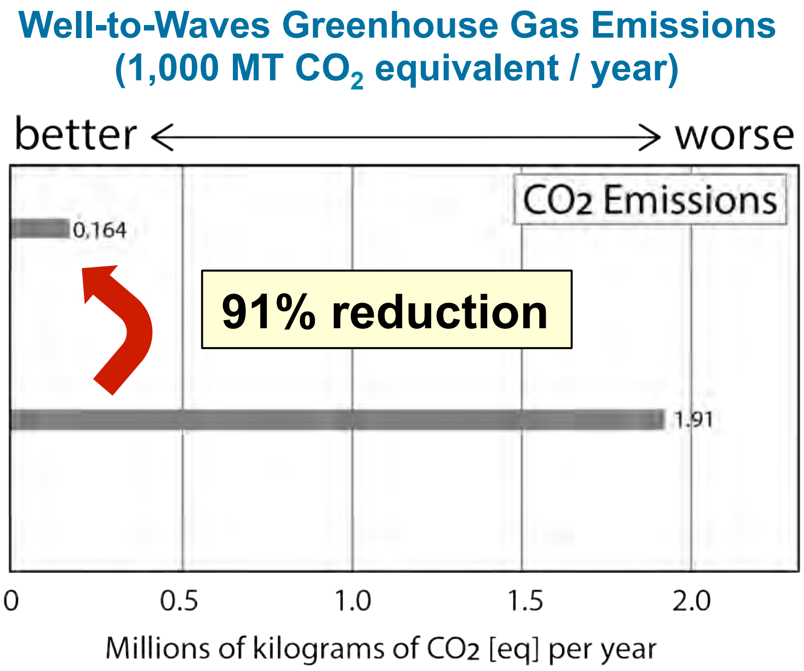

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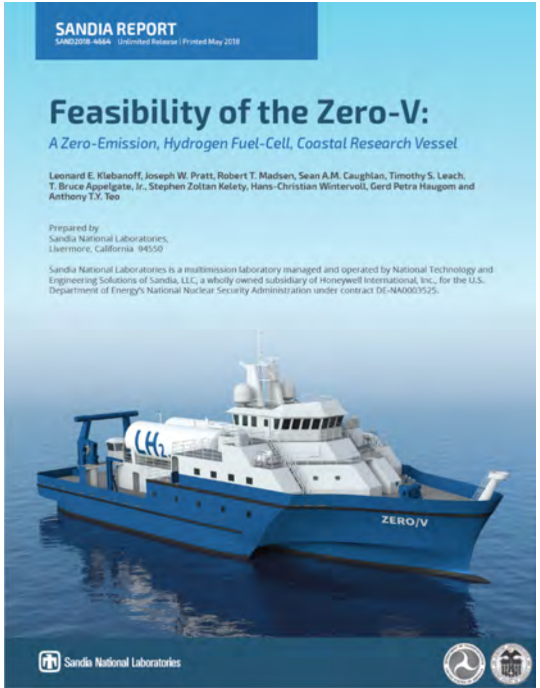

Yes

Download the full report:
energy.sandia.gov/transportation-energy/hydrogen/market-transformation/maritime-fuel-cells/

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