MARAD
Maritime Administration

SCRIPPS INSTITUTION OF OCEANOGRAPHY
UC SAN DIEGO

DNV·GL

Sandia National Laboratories

Glosten

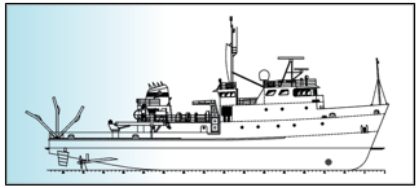
A ZERO-EMISSION HYDROGEN FUEL CELL RESEARCH VESSEL

29 AUGUST 2018

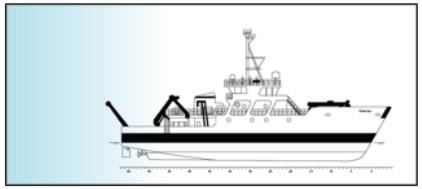
UNOLS GREEN BOATS AND PORTS CONFERENCE 2018

CALIFORNIA-BASED INTERMEDIATE CLASS & SMALLER SHIPS

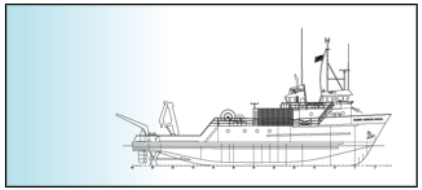
Research vessels able to carry out California's local research and education needs have decreased from 3 to 1, with the last remaining ship approaching the end of its service life. A new vessel is needed.



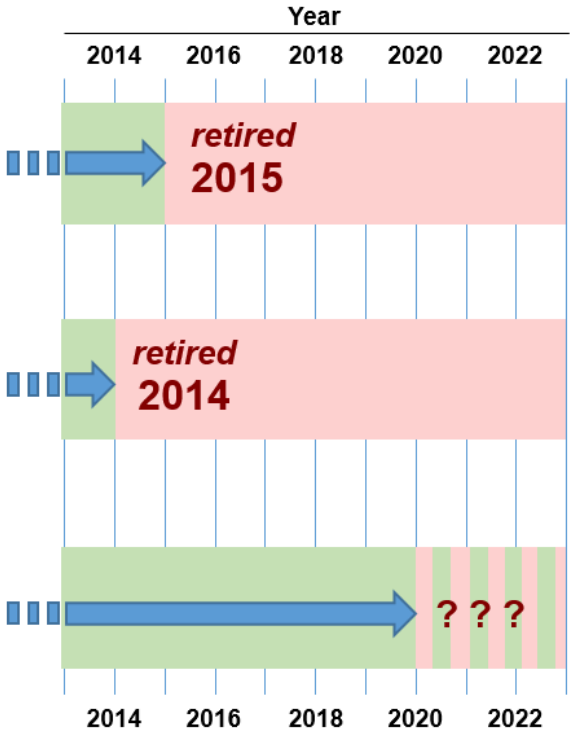
INTERMEDIATE
R/V *New Horizon*
170 feet / 40-day endurance
12 crew / 19 scientists



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



Needed

PROJECT BACKGROUND & GOALS

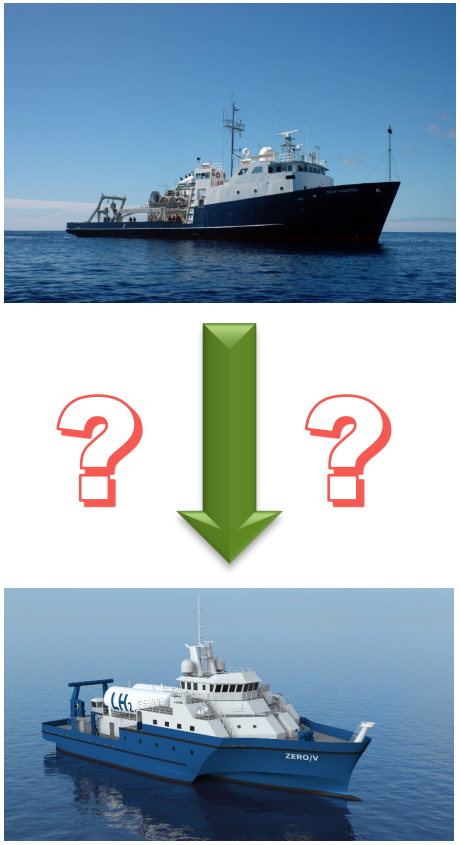
Sandia in collaboration with MARAD has been working to advance marine hydrogen fuel cell applications

Zero-V Project Goals

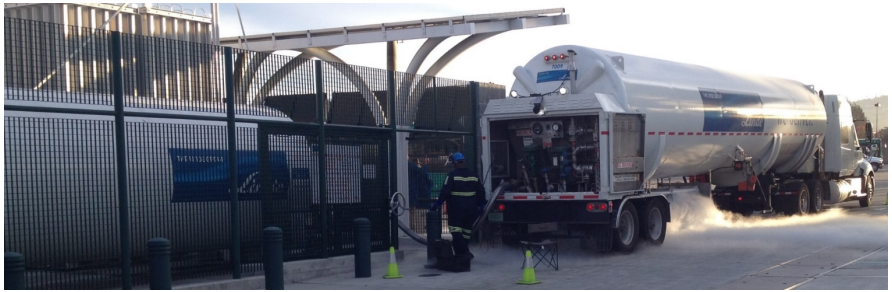
- Assess technical feasibility of H2 fuel cell research vessel
- Establish technology and know-how for marine H2 fuel cells
- Improve the environment

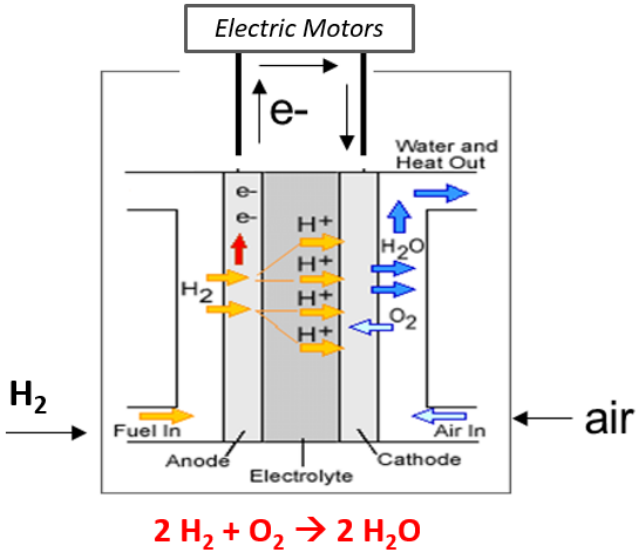
Project Partners

- Sandia National Laboratories
- U.S. Department of Transportation Maritime Administration
- Scripps Institution of Oceanography
- DNV-GL



HYDROGEN (H_2) & FUEL CELLS





$2\ H_2 + O_2 \rightarrow 2\ H_2O$

Hydrogen

- Is a gas at standard conditions
- Liquefies (LH_2) at 20K (-424 °F)
- LH_2 evaporates rapidly
- More buoyant than helium
- H_2 /LH_2 is similar to NG/LNG but there are differences.
- For the same amount of stored energy, LH_2 has 0.38 times the mass of LNG, but has 2.4 times the volume
- LH2 has been delivered over the road by trailers for decades.

PEM Fuel Cells

- Commercially available today
- Zero-emissions power
- Quiet (no moving parts)

ZERO-V SCIENCE MISSION REQUIREMENT

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	18
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

Operational Profiles

- Coastal mooring
- Deep moorings & towed sonar
- Mapping
- Class cruise: biology
- Class cruise: geology
- Class cruise: ROV
- ROV survey
- Geology sampling
- FLIP anchor handling
- UAV flight ops
- AUV ops
- Physical oceanography
- Biogeochemical survey

Primary Ports of Call

VESSEL PARTICULARS – GENERAL

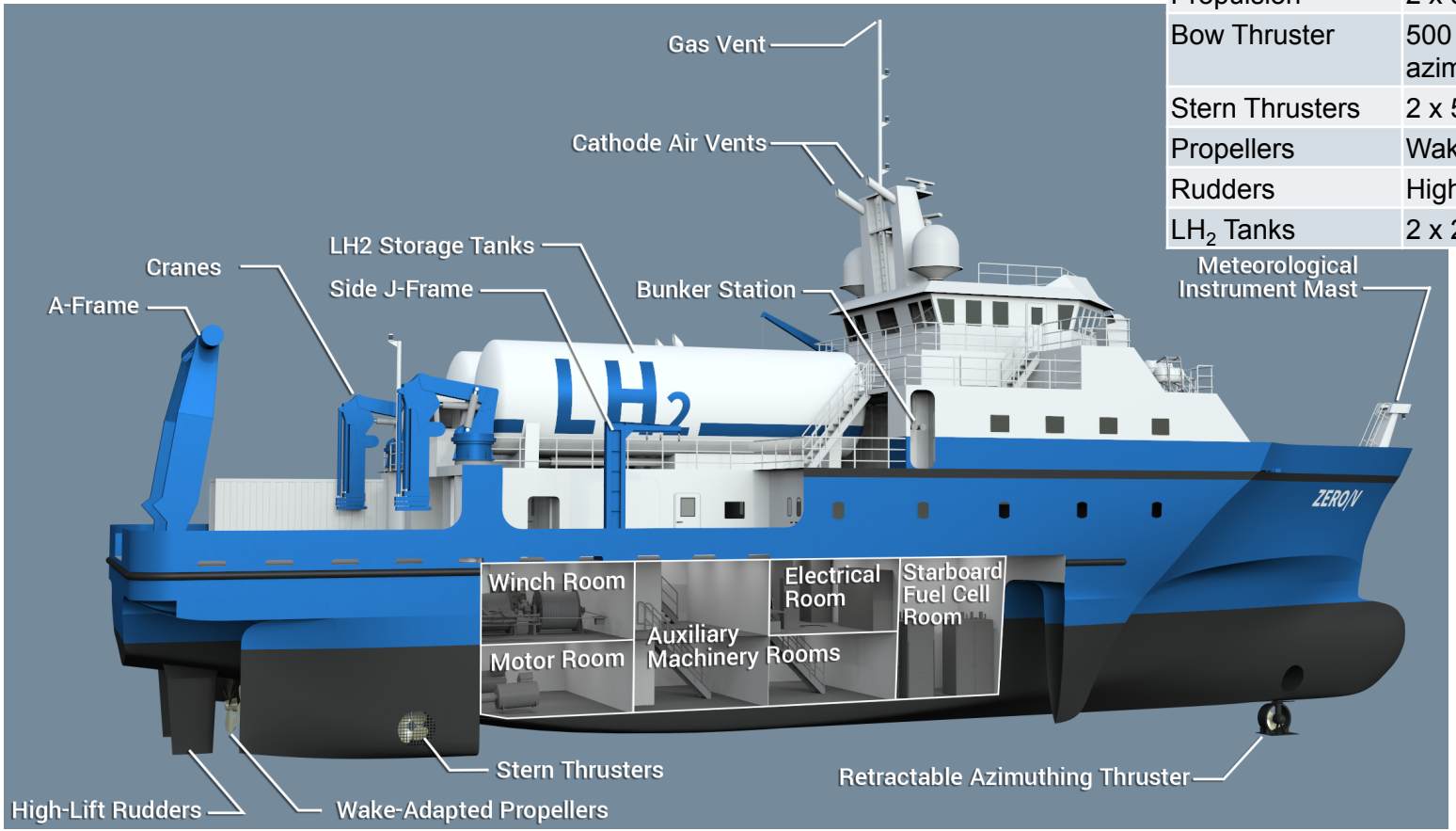
Hull Type	Trimaran
Material	Aluminum
Length	170 ft.
Beam	56 ft.
Draft	12 ft.
Freeboard	9 ft.
Displacement	1,175 LT
Cruise Speed	10 knots
Range	2,400 nm
Endurance	15 days
Station Keeping	Dynamic positioning
Berths	18 Science (8 double, 2 single) 11 Crew (single)
Air Emissions	Water vapor

VESSEL PARTICULARS – SCIENCE

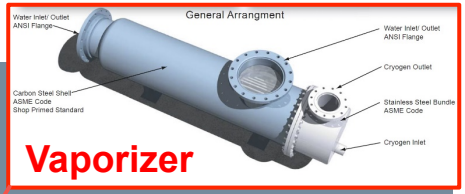
A-Frame	20,000 lbs SWL 20′ vertical clearance 12′ outboard reach
Main Cranes (2)	8,000 lbs SWL over the side
Portable Crane	8,000 lbs SWL
Side Frame	5,000 lbs SWL
Trawl Winch	10,000m 3/8 3x19 wire
Hydro Winch	10,000m 0.322 EM 10,000m ¼″ 3x19 wire
Multi Beam Sonar	Kongsberg EM712
Underwater Noise	ICES 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



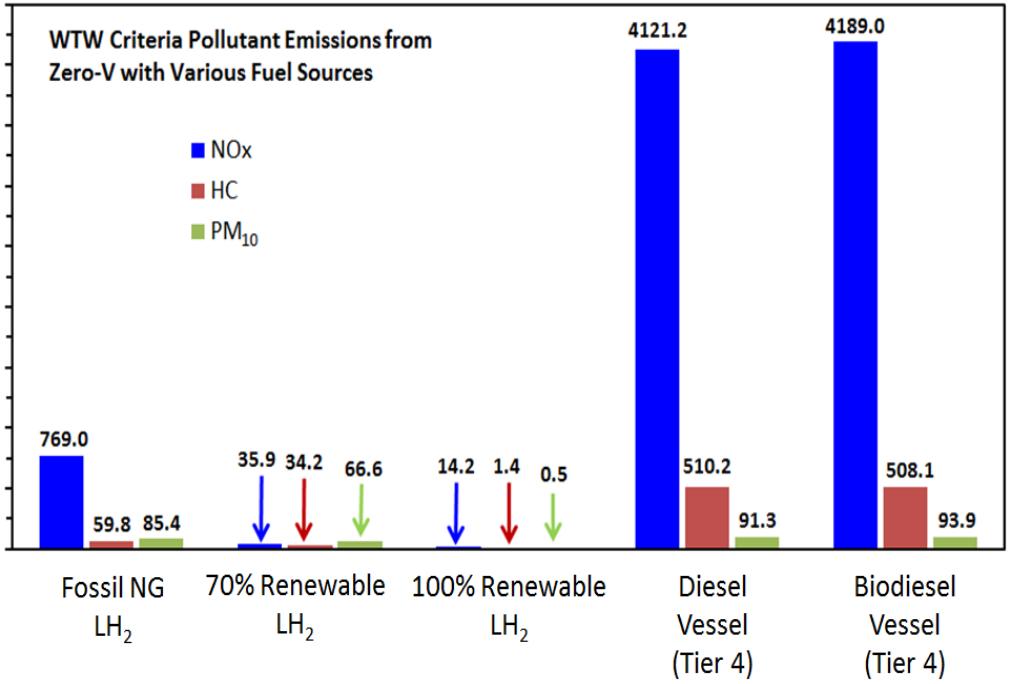
H_2 GAS SYSTEMS



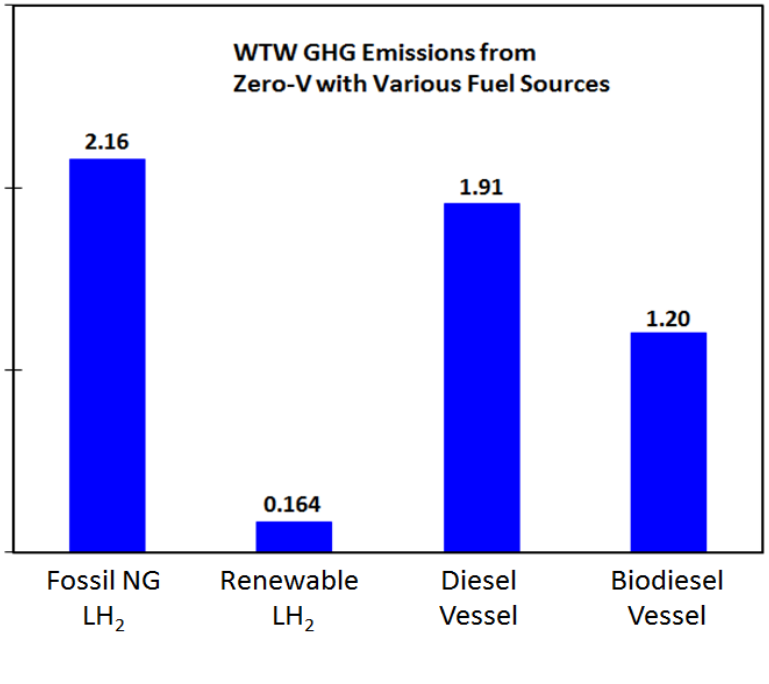
- **(2)** Type C vacuum insulated LH_2 tanks (5,830 kg capacity / tank)
- **(10)** Power racks with 6 Hydrogenics HyPM HD 30 fuel cell modules (180 kW/ rack)
- **(2)** Thermax cryogenic cold water evaporators
- Gas system full redundancy
- Fuel cell room has redundant ventilation and gas detection for each rack and emergency shutdown upon any failure
- Water deluge system protects areas around tank

EMISSIONS (FROM H_2 PRODUCTION)

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



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



Dramatic reductions in GHG and criteria pollutant emissions can be achieved using renewable LH_2. Renewable LH_2 is available from the gas suppliers.

REGULATORY REVIEW

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).*

No show-stopping red flags were identified in the regulatory reviews

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

- The regulatory regime for a hydrogen fuel cell powered vessel is developing
- No current US or international regulations specific to hydrogen fuel cell vessels
- Regulatory basis:
  - Extend the regulations applicable to LNG fueled vessels 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
  - Give consideration to differences hydrogen may present.
- Submitted to the US Coast Guard and DNV GL for review to identify any significant regulatory or safety concerns with the fundamental design.

PATH AHEAD

Pursuit of Class and USCG approval

- Development of gas system details
- Full risk assessment of the gas systems
  - Hazard identification and assessment (HAZID)
  - Failure modes and effects analysis (FMEA) of gas systems, ventilation systems, safety systems
  - Gas dispersion modeling
  - Explosion analysis

Vessel design development

- Refine work from this study
- Computational analysis (seakeeping, resistance, maneuvering, noise)
- Structural design
- Vessel systems design

THANK YOU

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Director of Engineering
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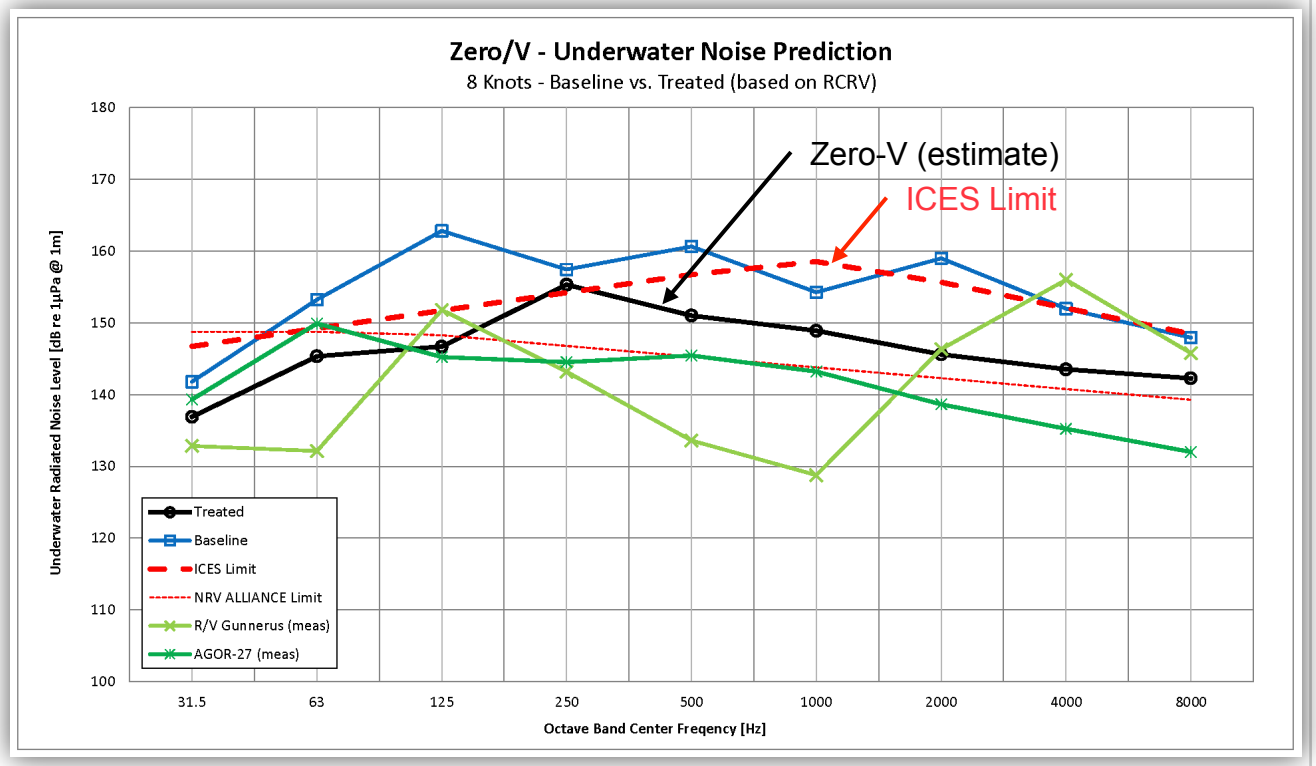
ZERO/V project is funded by the United States Department of Transportation, Maritime Administration (MARAD) Maritime Environmental and Technical Assistance (META) program

CAPABILITIES – UNDERWATER RADIATED NOISE (URN)



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

Initial assessment

- Used Regional Class R/V (monohull) URN analysis and removed noise from Z-drives & diesel engines
- Non-cavitating propellers

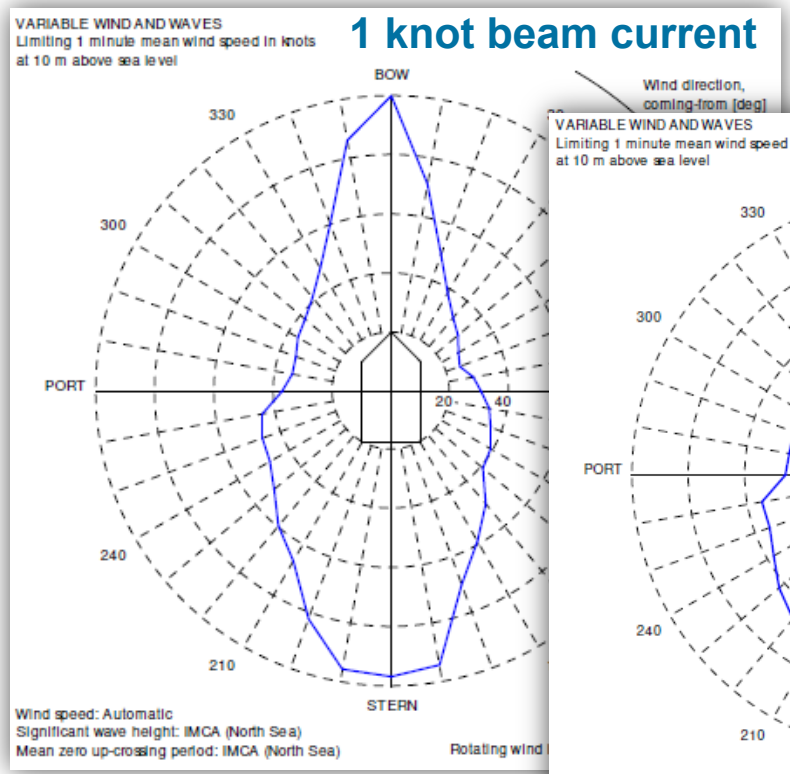
Considerations

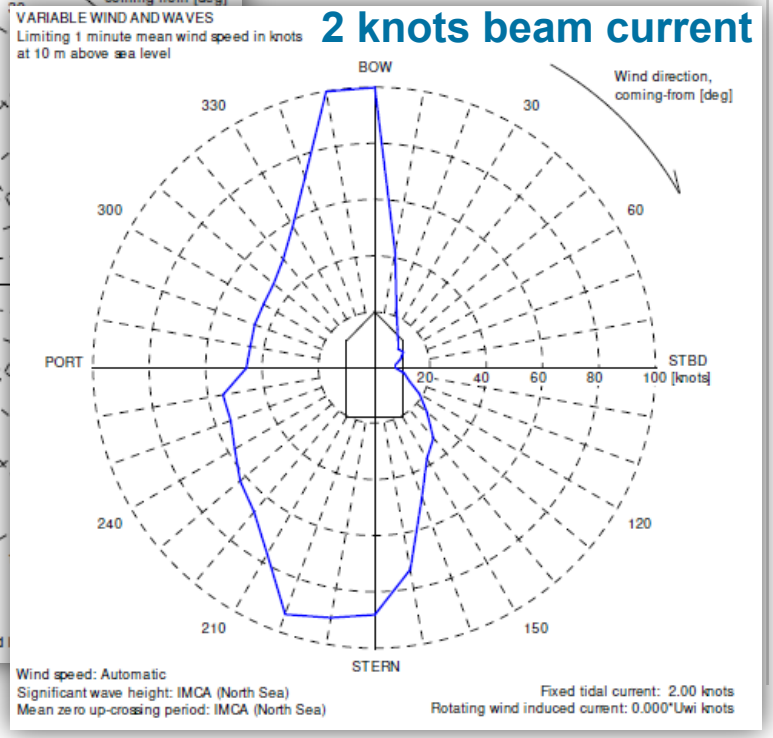
- Trimaran has less noise radiating surface
- Aluminum may require more noise treatment than steel

Computational analysis is required for a more accurate assessment

*International Council for the Exploration of the Sea (ICES) Report 209 is an often used benchmark of R/V URN

CAPABILITIES - POSITION KEEPING





Maintain position with

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

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

Station keeping performance meets science mission requirements

VESSEL COST ESTIMATE

R/V *Sikuliaq* Construction
Credit: *Val Ihde Photography*

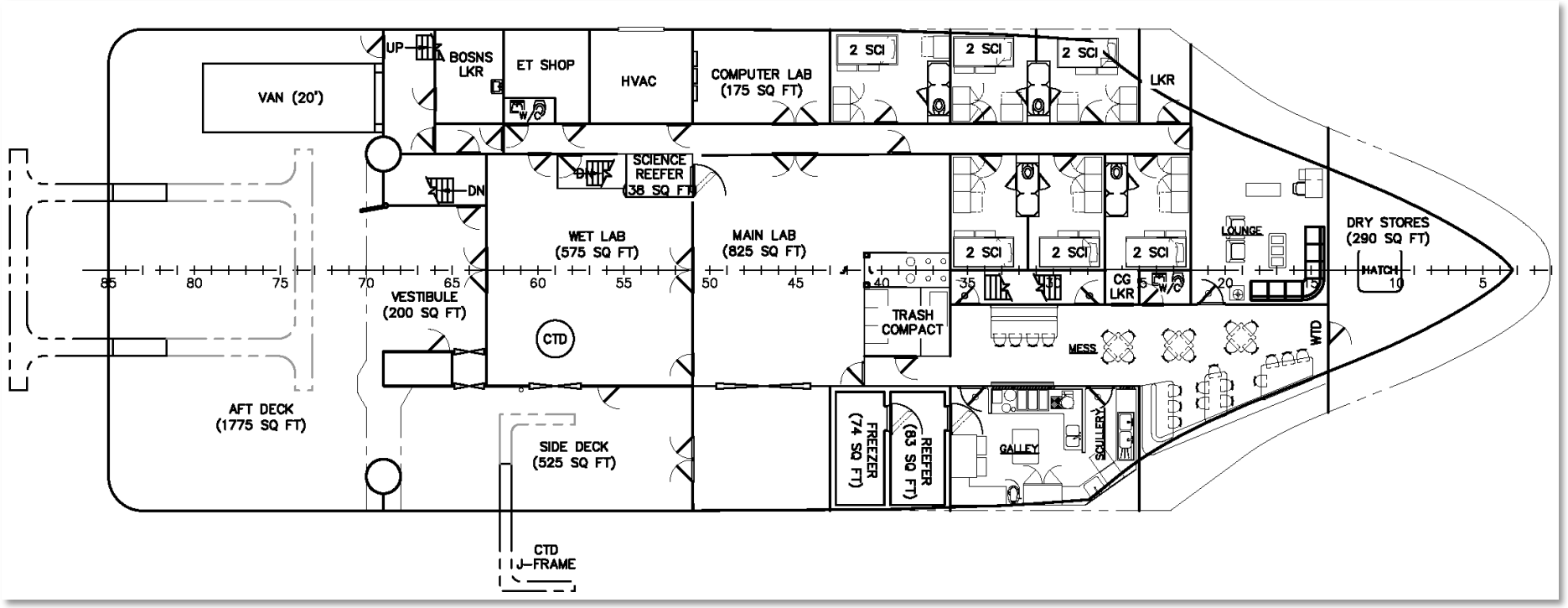
Capital Cost

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

Operating Costs

Using a comparison to annual operating costs for the R/V New Horizon, it is estimated that the Zero-V operating costs would be initially ~20% higher than for an equivalent diesel fueled vessel.

ARRANGEMENTS – MAIN DECK



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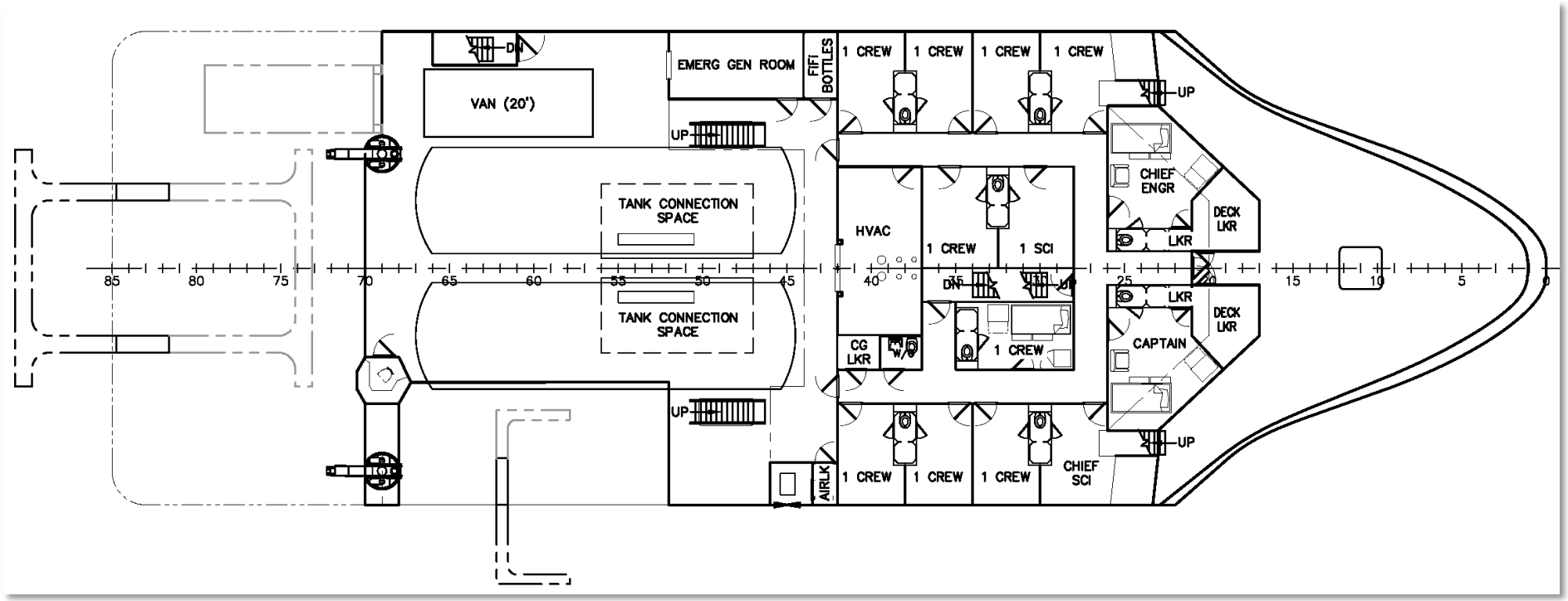
ARRANGEMENTS – 01 LEVEL



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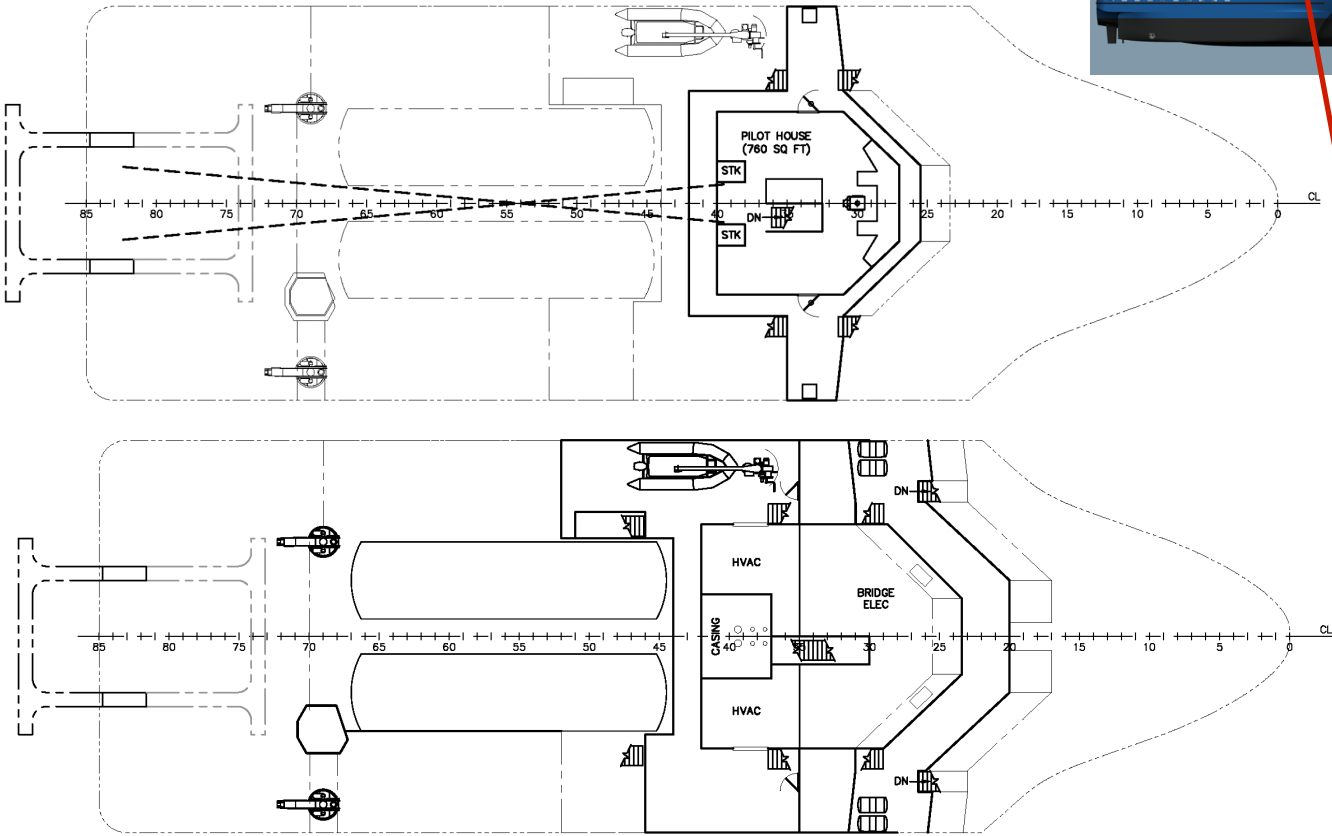
ARRANGEMENTS – 02 & 03 LEVELS



03 Level

02 Level

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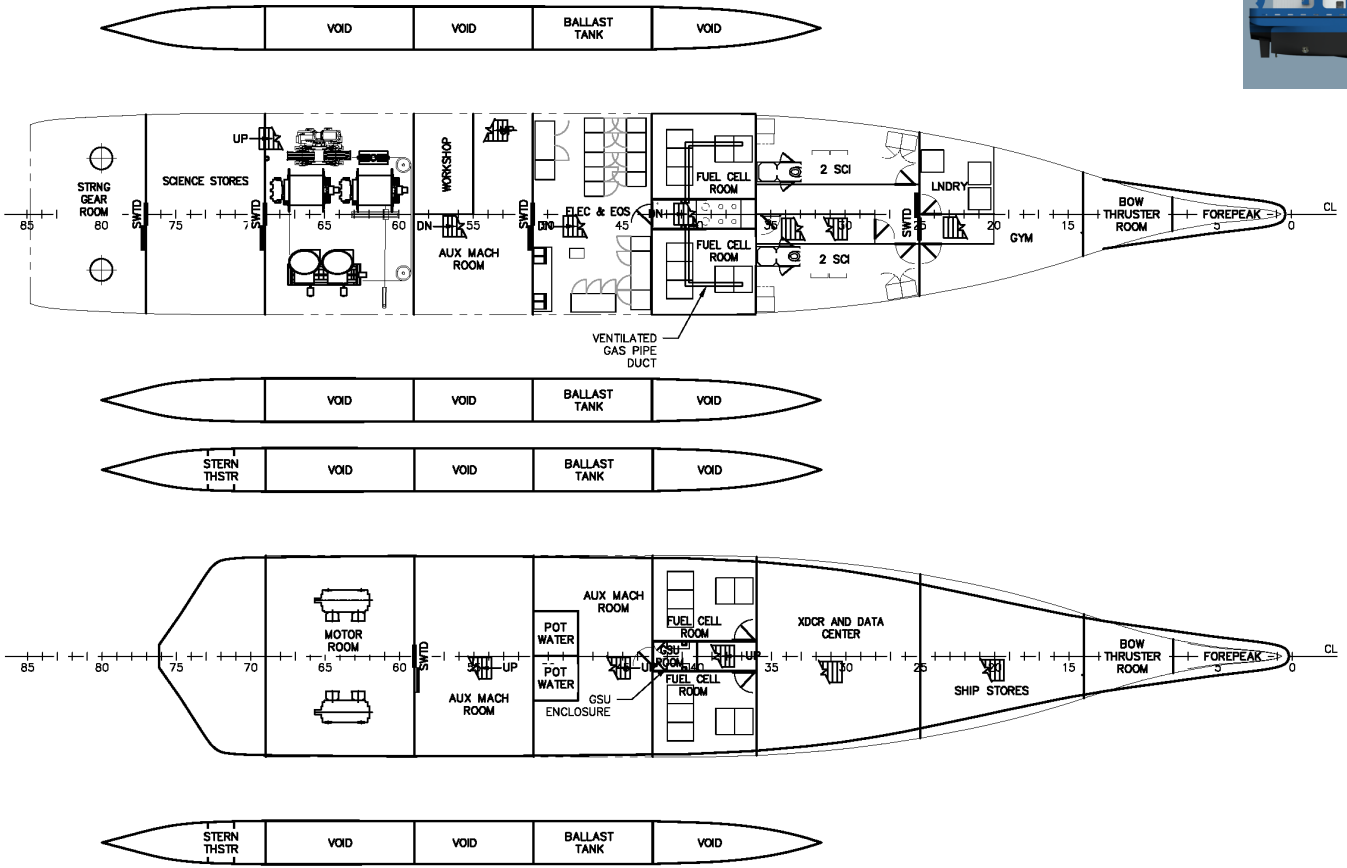
ARRANGEMENTS – TANK TOP & 1ST PLATFORM



1st Platform

Tank Top

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