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Vessel Electrification and Future Fuels

Webb Sustainability Conference
Eileen Tausch & Curt Leffers, Crowley Research & Development
November 8, 2022

Agenda

01 Crowley & Sustainability Goals

02 Electrification

03 Future Fuels

Crowley Business Structure

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LOGISTICS

- Ocean, Land and Air Transportation (FCL and LCL)
- Transportation Management
- Supply Chain and Distribution Services (Door to Door)
- Freight Forwarding and Warehousing
- Cargo Risk and Customs Compliance

SHIPPING

- Marine Management: Vessel Technical Management, Crewing Services and Diving Operations
- Marine Assets: Ship Assist and Tanker Escort, U.S. Domestic Petroleum Distribution, Offshore Towing and Heavy-Lift Barges
- Engineering Services: Naval Architecture and Construction Management
- New Energy: Offshore Wind and LNG Distribution and Bunkering

FUELS

- Fuel Supply (Petroleum)
- Fuel Infrastructure (Terminals)
- Energy Solutions (Supply Logistics)

SOLUTIONS

- Maritime Solutions: Ship Management, Engineering and Architecture
- Supply Chain Solutions: Managed Transportation and Advanved Analytics
- Expeditionary Logistics Solutions
- Energy Solutions
- Technology Solutions

Purpose & Values

PURPOSE

–

Bravely advancing what's possible to elevate people and planet

VALUES

–

Integrity

Sustainability

Drive

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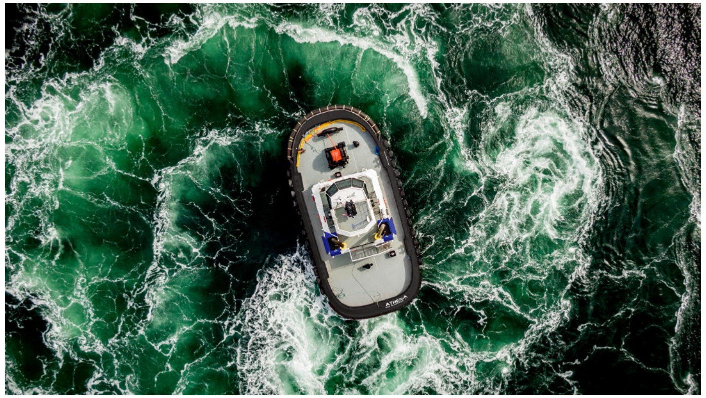
By 2025, Crowley will be the **most sustainable and innovative** maritime and logistics solutions provider in the Americas.

By 2050, Crowley is committed to reach **net-zero emissions across all scopes**.

Path to 2050 – Research and Development



ZERO EMISSION INDUSTRIES

RESEARCH AND DEVELOPMENT

Crowley Shipping has built a team solely focused on **researching, evaluating, and developing new technologies and solutions** to support innovation and decarbonization commitments.

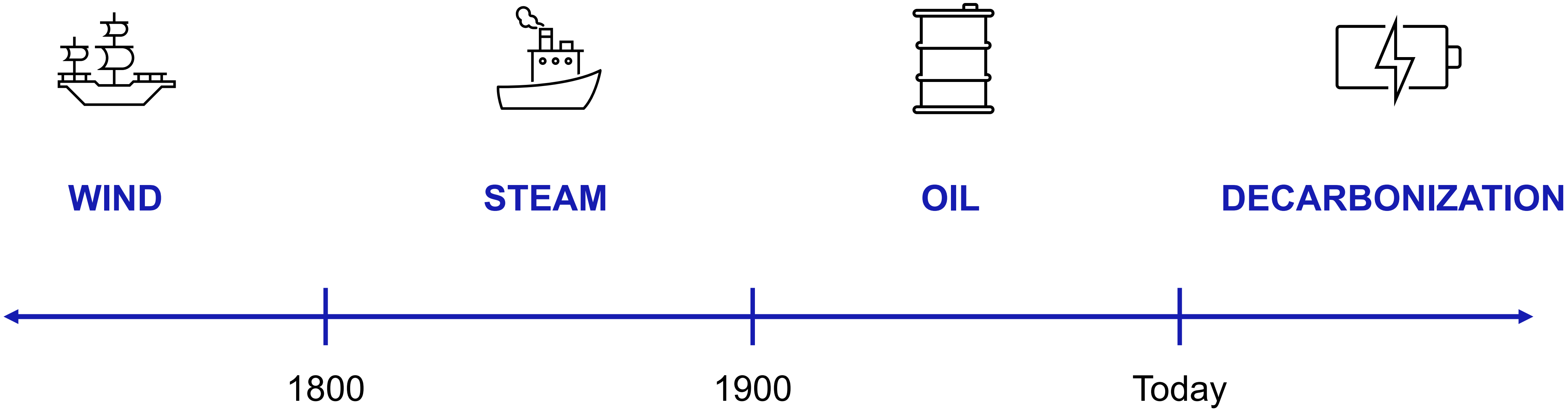
ZERO EMISSIONS INDUSTRIES

Crowley's investment in ZEI enables the accelerated adoption of **hydrogen technologies** across the maritime market to create lower carbon and potentially zero emission power for the industry.

CARBON CAPTURE INVESTMENT

Crowley invested in Carbon Ridge to support development of novel **onboard carbon capture** technology to decarbonize shipping.

Propulsion Revolutions



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Electrification

What is electrification?

The process of replacing technologies that use fossil fuels with technologies that use electricity as a source of energy.

Why do we need electrification?

FUTURE PROOFING AND INCREASED FLEXIBILITY

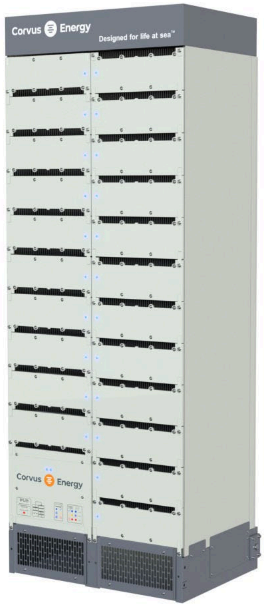
- There is no clear answer for the future of marine propulsion but leading solutions include one common factor: **electrons**
- Allows multiple sources of power to contribute:
  - Generators (whether diesel or an alternative fuel)
  - Batteries
  - Fuel cells
  - Solar

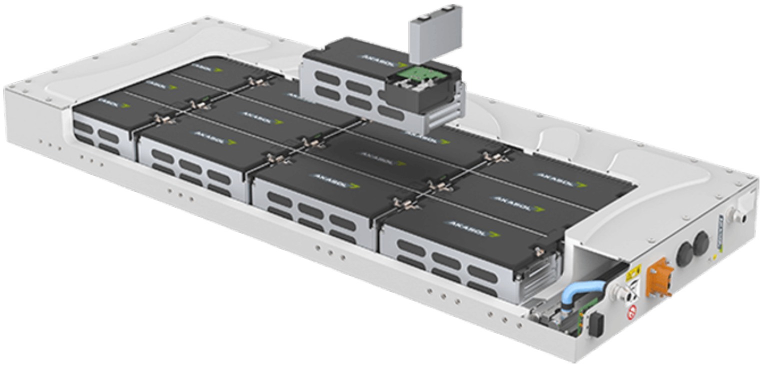
Enabling Technologies – Fuel Cells

FUEL CELLS

- Converts chemical energy of hydrogen (or other hydrogen carrier fuels) to electricity
- Produces DC power
- Output voltage varies with load

Enabling Technologies – Batteries





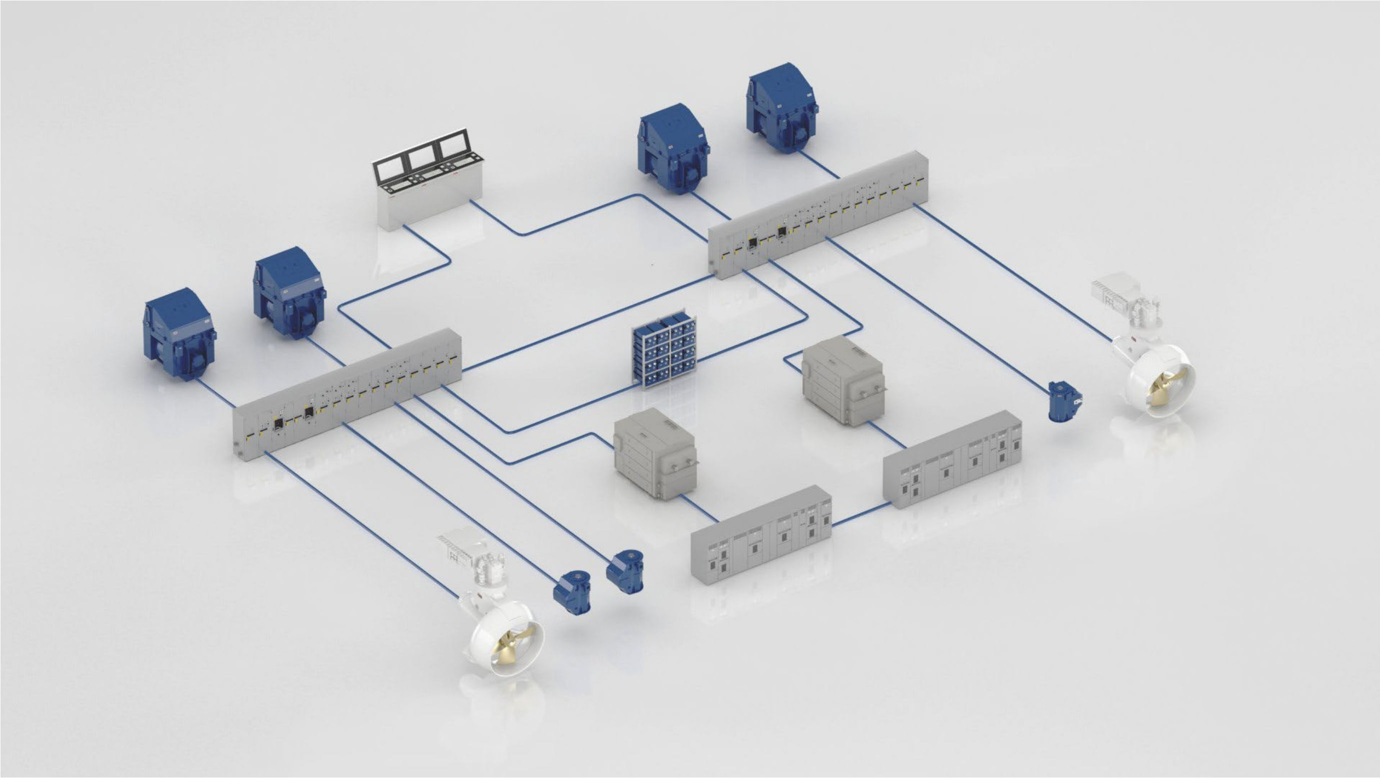
LITHIUM-ION BATTERIES

- Rechargeable energy storage system using lithium ions as a key component of its electrochemistry
- Lithium-ion chemistries are the most popular in the marine industry
  - NMC – Nickel Manganese Cobalt
  - LFP – Lithium Iron Phosphate
  - LTO – Lithium Titanium Oxide
- Produces DC power
- Output voltage varies with battery state of charge

Transition from AC to DC Distribution

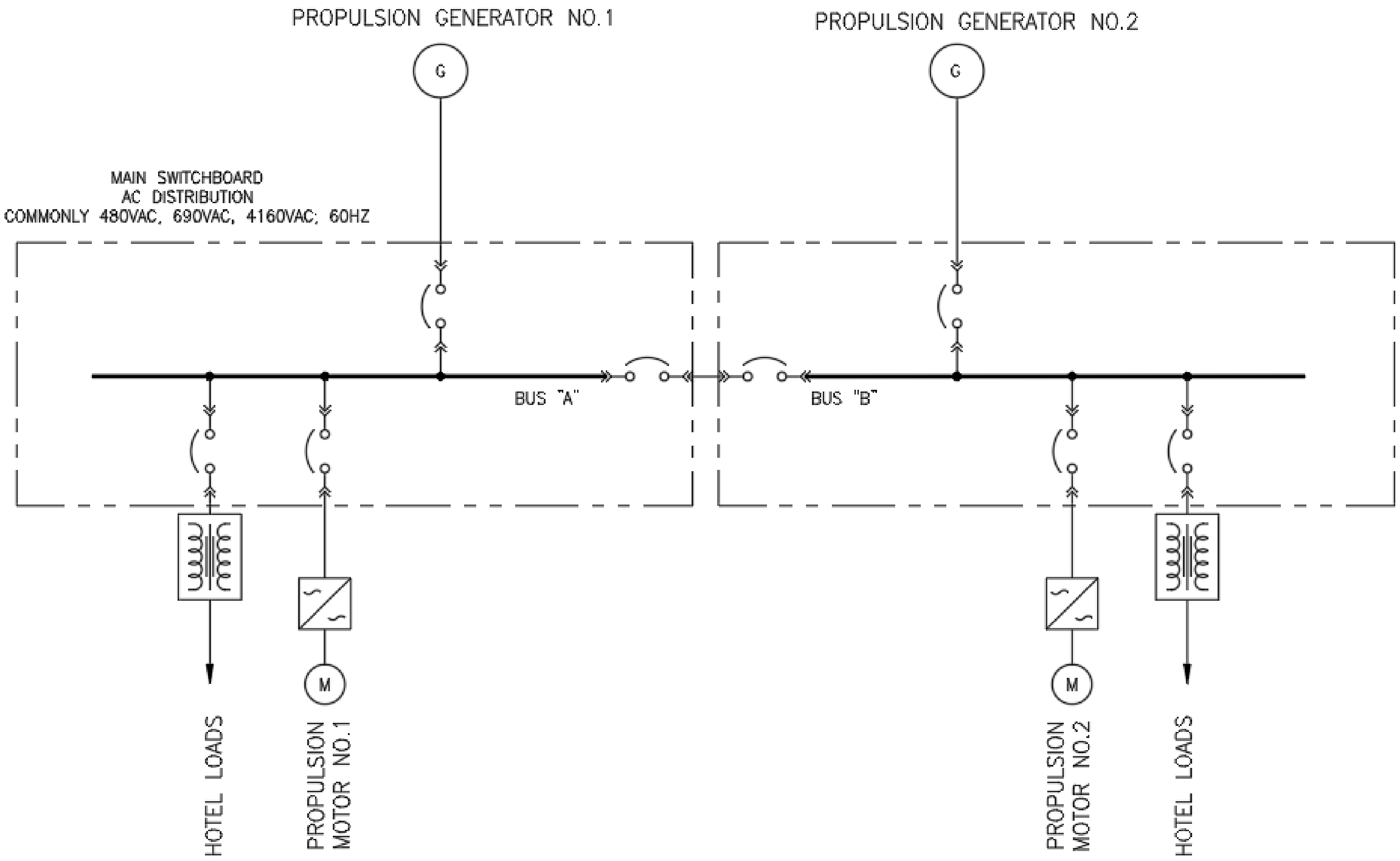
SHIFT TO DC GRID

- With the introduction of new technologies, the main propulsion distribution is shifting from alternating current (AC) to direct current (DC)
- Generators and motors remain AC
- Enabling technologies:
  - DC/DC Converters
  - DC/AC Inverters
  - AC/DC Rectifiers
  - DC Circuit Breakers/Fuses

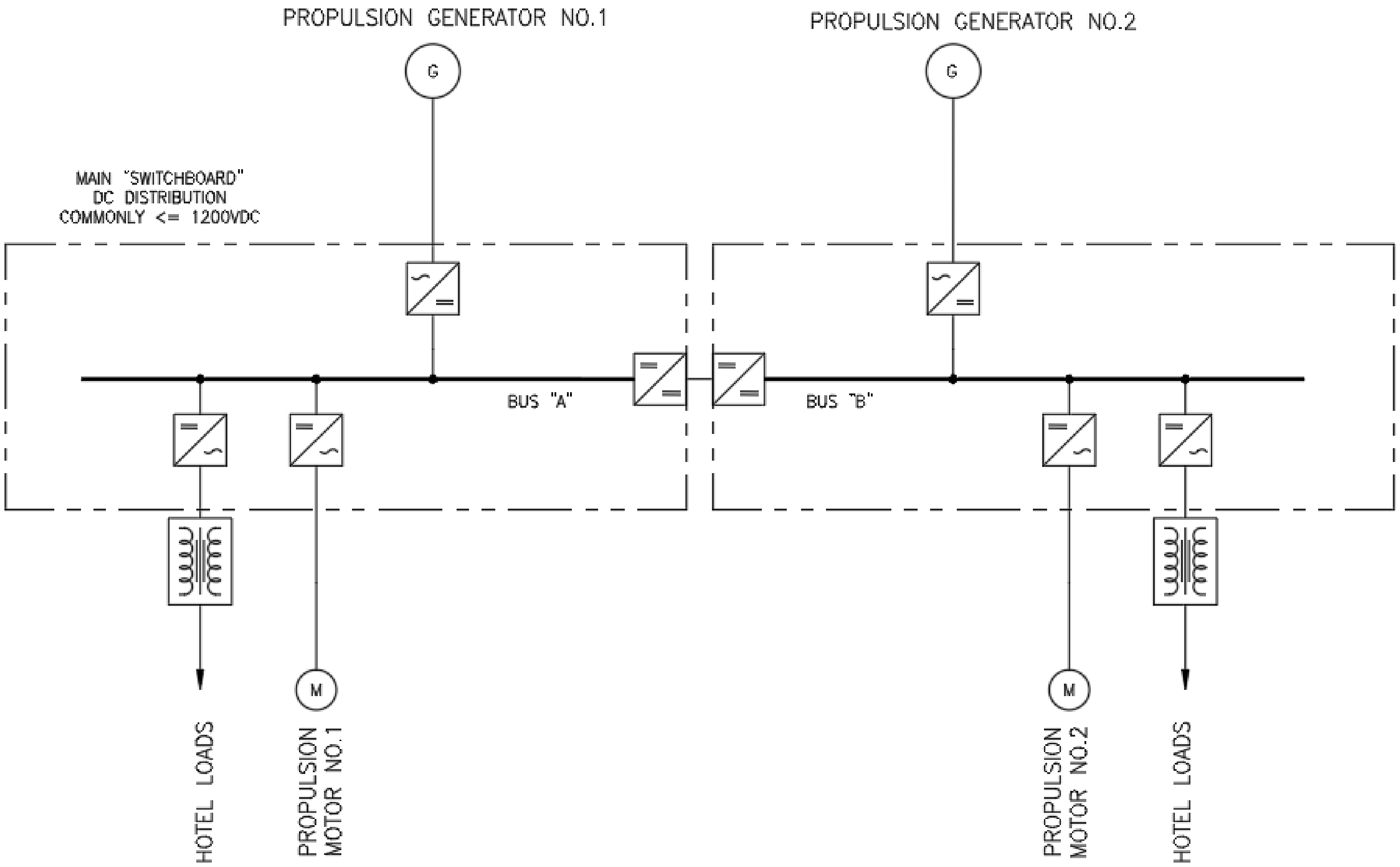


Source: ABB

Sample SLD – AC Bus



Sample SLD – DC Grid



Applications – which technology to use when?

NOT EVERY TECHNOLOGY FITS WITH EVERY APPLICATION

- Vessel size
- Vessel speed
- Route length
- Refueling/charging opportunities
- Route consistency
- Fuel availability

BUT MOST APPLICATIONS CAN BENEFIT FROM ELECTRIFICATION AND ONBOARD ENERGY STORAGE

KONGSBERG

Future fuel vs ship segments

	CRUISE	ROPAX	ROADFERRY	TUG	TRAWLER	OSV	SOV	CONTAINER	BULKER	RIG
PURE BATTERY (shore power)	–	–	√	√	–	–	√	–	–	√
COMPRESSED HYDROGEN	–	–	√	√	√	–	–	–	–	–
LIQUIFIED HYDROGEN	–	–	√	–	√	–	√	–	–	–
AMMONIA	–	–	–	–	–	√	√	√	√	√
SYNTHETIC METHANE	√	√	√	–	–	√	√	√	√	√
METHANOL	√	√	√	√	–	√	√	√	√	√
HVO	√	√	√	√	√	√	√	–	–	√

WORLD CLASS – Through people, technology and dedication

KONGSBERG PROPRIETARY - See Statement of Proprietary information

Source: Kongsberg

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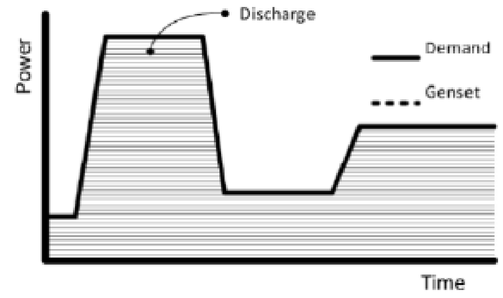
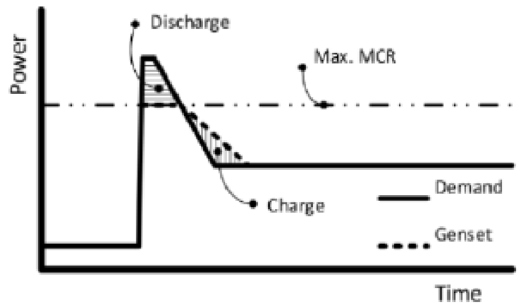
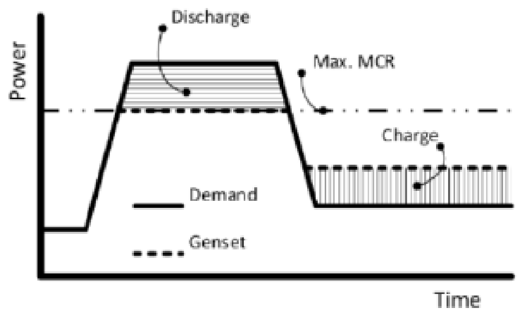
Battery Applications



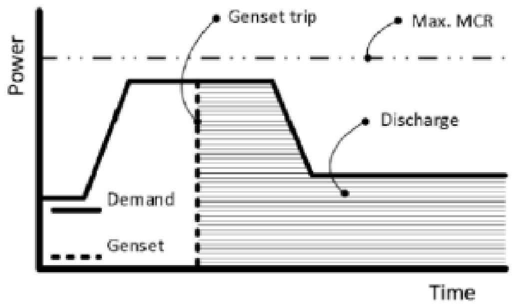
FULL ELECTRIC



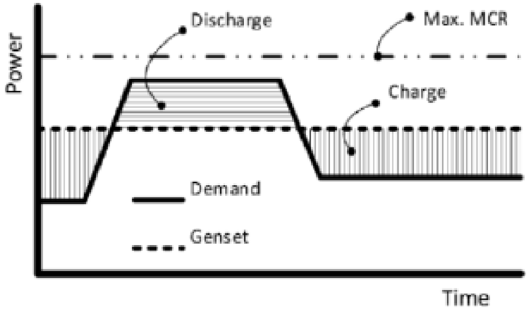
PEAK SHAVING



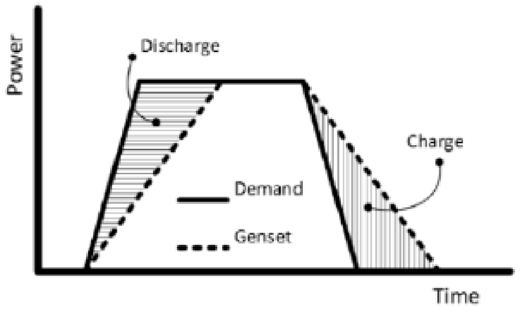
BOOST FUNCTION



SPINNING RESERVE



LOAD LEVELING



RAMP SUPPORT

Shore Charging

SHORE CHARGING

- Shore charging can be instrumental in maximizing carbon emissions reductions

CONSIDERATIONS

- Charging requirements
- Power availability / cost
- Manual vs automatic
- Pier infrastructure
- Standardization

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eWolf Case Study

PROJECT OVERVIEW

- First Jones Act-compliant, all-electric harbor tug
- Vessel delivery expected Q1 2023

eWolf Case Study - Overview

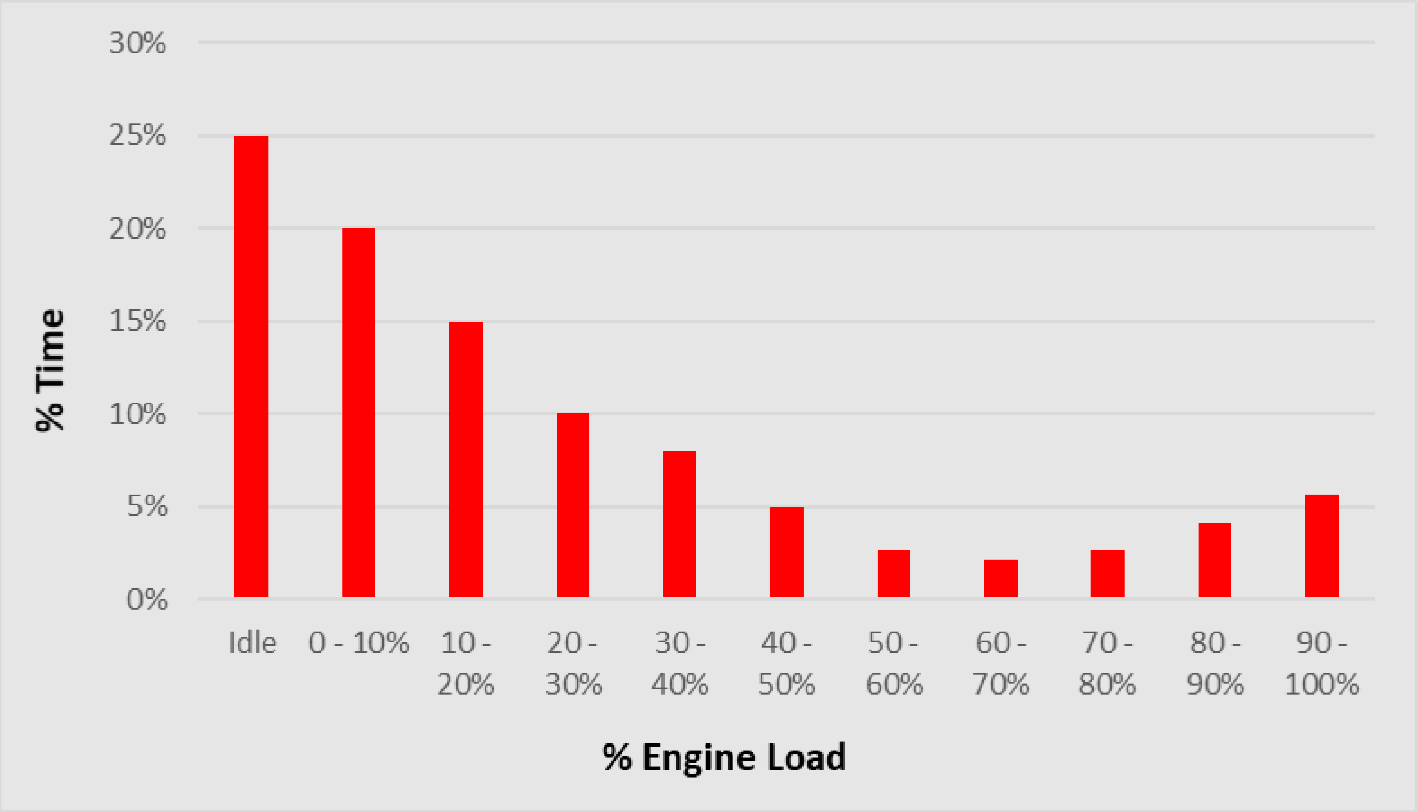
PARTICULARS

Length Overall (over Guards)	82'-0"
Length Molded	78'-4"
Beam Overall (over Guards)	42'-6"
Beam Molded	40'-0"
Depth, Hull to Main Deck Amidships	21'-9"
Draft, Baseline (Max)	17'-5"
Bollard Pull	70 tons

PROPULSION EQUIPMENT

Batteries (50 x 124 kW)	6215 kWh
Range (typical use)	7.1 hrs
L-Drives (2 x 2050 kW)	4100 kW

OPERATIONAL PROFILE



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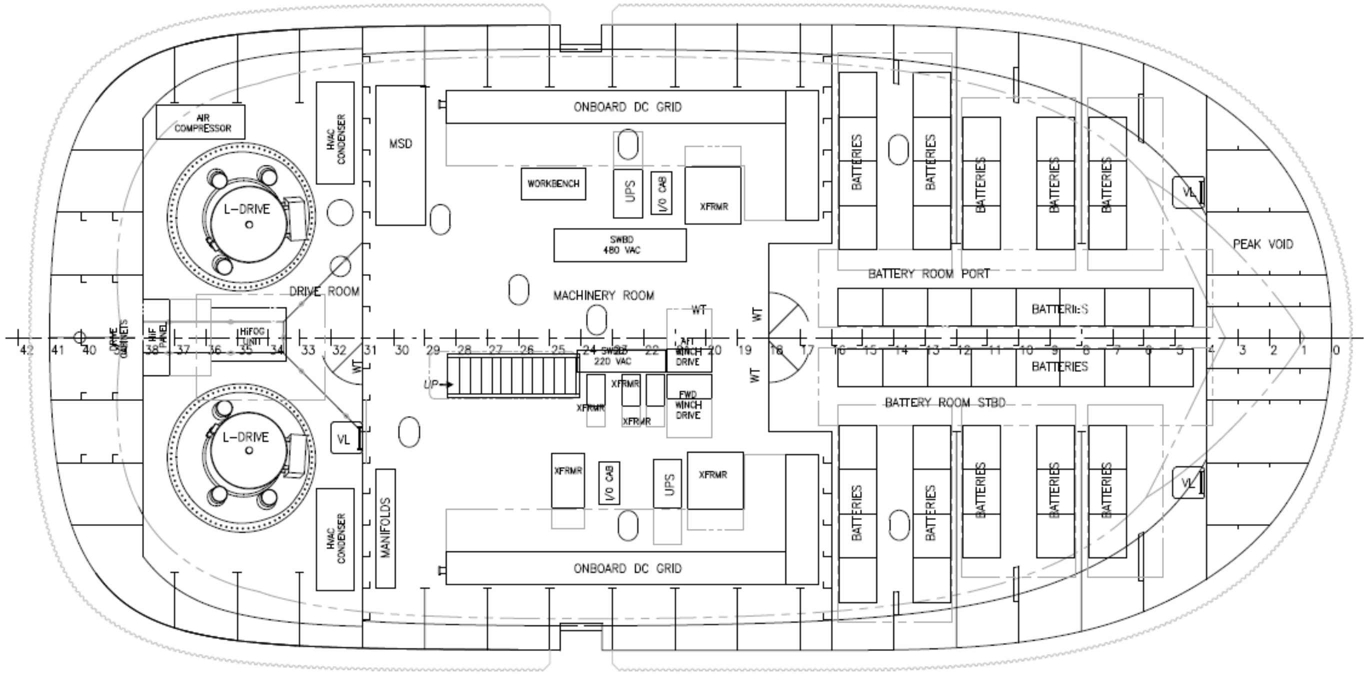
eWolf Case Study – Arrangements

HOLD PLAN



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eWolf Case Study – Shore Charging

CHARGING STATION

- End-to-end shore power from utility to vessel
- Bi-directional connection from existing grid
- Vessel charge rate of 1MW
- Containerized energy storage (3MWh)
- Solar canopy
- Expandable

Future Fuels

Future Fuels – Introduction

KEY POINTS

- The most common future fuels for maritime
- Design considerations for future fuels
- Case study review of a hydrogen fueled tug

Future Fuels – An Overview

WHAT ARE THE MOST VIABLE FUTURE FUELS FOR MARITIME?

- Methane (Natural Gas)
- Methanol
- Hydrogen
- Ammonia

FUTURE FUEL ATTRIBUTES

- Chemical Composition
- Lower Heating Value
- Density
- Boiling Point
- Energy Conversion Equipment

Future Fuels – An Overview

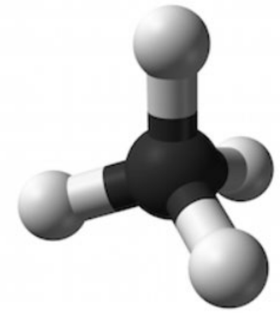
ATTRIBUTES

	ULSD	Liquid Natural Gas	Methanol	Liquid Ammonia	Liquid Hydrogen	Compressed Natural Gas @ 207 bar (3000 psi)	Compressed Hydrogen @ 207 bar (3000 psi)
Lower Heating Value (MJ/kg)	42.60	45.00	20.26	18.90	120.00	45.00	120.00
Density (kg/m^3)	833.56	450.00	801.00	681.90	71.00	184.62	16.5852
Energy Density (MJ/m^3)	35509.66	20250.00	16228.26	12887.91	8520.00	8307.95	1990.22
Boiling Point (Celsius)	154.00	-161.50	64.70	-33.30	-252.90	-161.50	-252.90
Volume Equivalent to Diesel	1.00	1.75	2.19	2.76	4.17	4.27	17.84
Energy Conversion	ICE	ICE, SOFC	ICE, SOFC, Reformer	ICE, SOFC, Reformer	ICE, PEMFC	ICE, SOFC	ICE, PEMFC

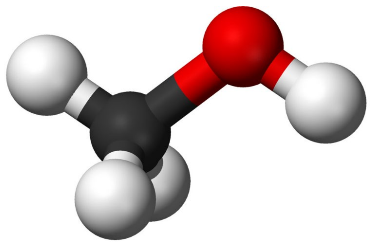
* Internal Combustion Engine (ICE), Solid Oxide Fuel Cell (SOFC), Proton Exchange Membrane Fuel Cell (PEMFC)

CHEMICAL COMPOSITION

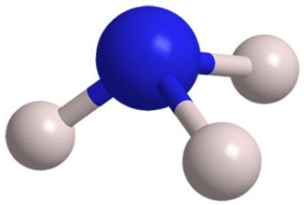
Methane (Natural Gas) - CH_4



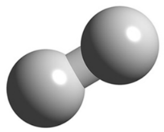
Methanol - CH_3OH



Ammonia - NH_3



Hydrogen - H_2



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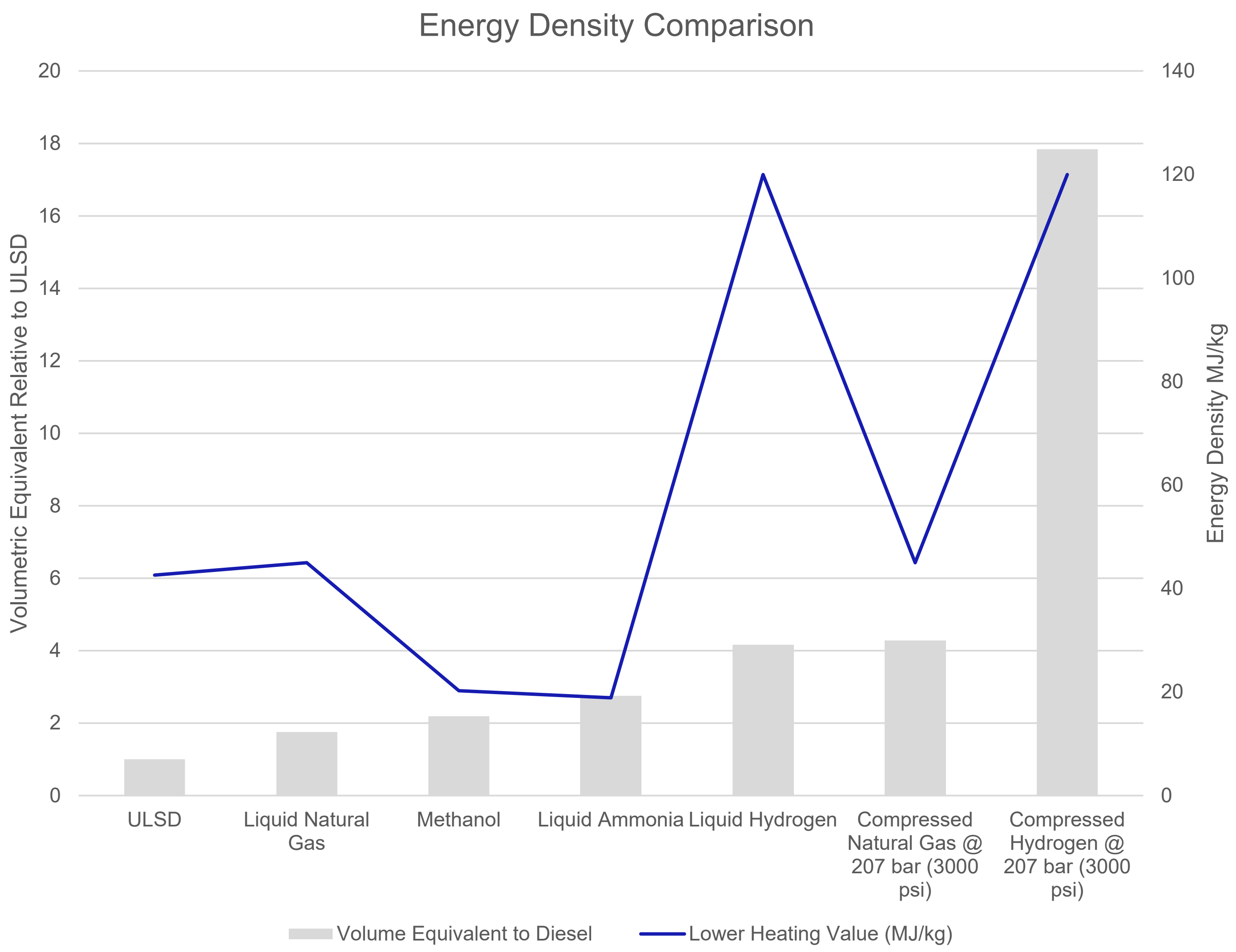
Future Fuels – An Overview



Future Fuels – Design Considerations

Regulatory Compliance Framework

Class | Flag | IMO

CLASSIFICATION SOCIETIES LEVERAGE SEVERAL TOOLS FOR THE APPROVAL OF NOVEL PROJECTS, INCLUDING:

VESSEL APPROVALS

- Leverage Existing Codes
  - IMO: International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF)
  - IMO: International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC)
- Guidance Documents
  - IMO: Interim Guidelines for the Safety of Ships using Methyl/Ethyl Alcohol as Fuel
  - DNV: Guidance on Assessment of Early Phase Design and Novel Concepts and Technology
  - ABS: Guidance Notes on Review and Approval of Novel Concepts
- Design Basis Agreements
  - USCG: Risk-based approval process for system safety

Future Fuels – Design Considerations

Regulatory Maturity

Least Mature

- NH_3

- LH_2
- CH_2
- CH_3OH

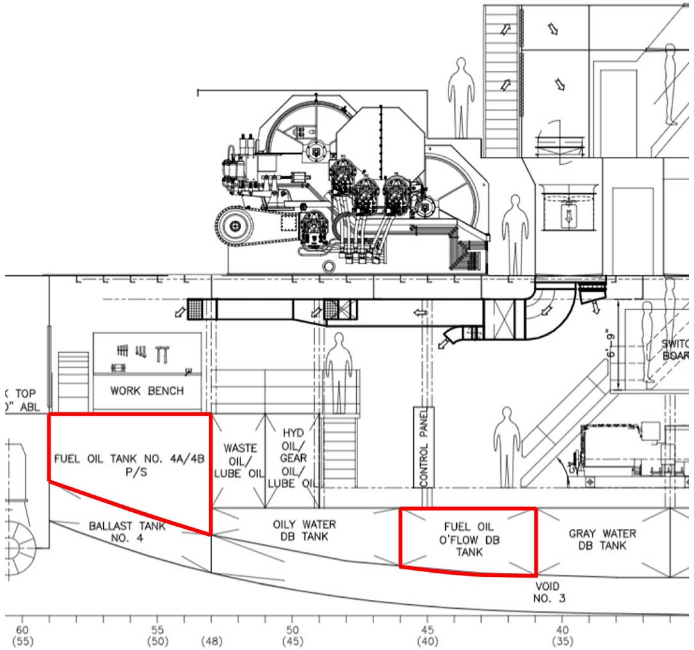
Most Mature

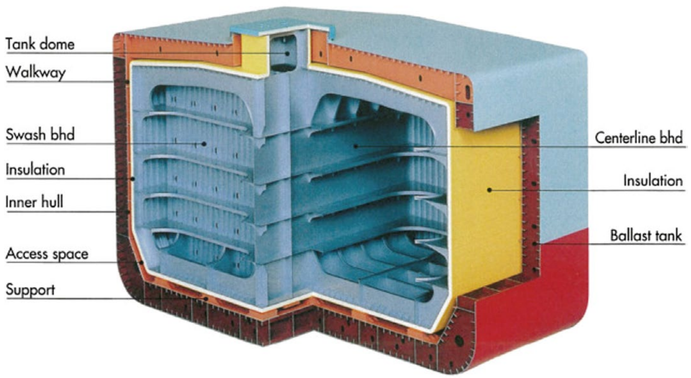
- LNG
- CNG

HyZET
Hydrogen Fuel Cell Concept

El Coquí,
Dual Fuel - LNG ConRo Vessel
DNV Classed, US Flagged
In Operation

Future Fuels – Design Considerations





Source: Handbook of liquefied Natural Gas (2014)

TRADITIONAL HULL TANKS

- Atmospheric pressure
- Integral to vessel hull

TYPE A

- Pressure ≤ 700mBbar
- Full Secondary Barrier (independent tank)
- Prismatic

TYPE C

- Pressure ≥ 2000mBbar
- Cryogenic Pressure Vessels
- No Secondary Barrier (independent tank)
- Cylindrical Bi/Tri-Lobe

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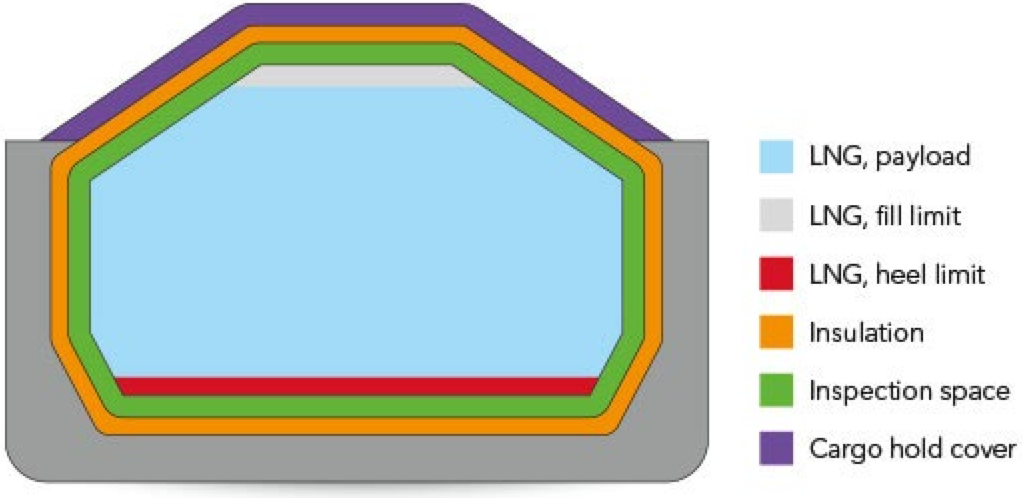
Future Fuels – Design Considerations

LNG and LH2 Tank Volume:

- **Loading Limit**
  - Maximum Loading
  - Based on maximum allowable relief valve setting (MARVS)
  - For LH2, total tank volume maybe be reduced by up 30%
- **Heel**
  - Minimum Loading
  - For LNG, typically around 5%

CH3OH Tank Volume:

- Integral hull tanks can be used, however the additional of cofferdams and limitations on tank adjacencies may reduce available usable volume when compared to ULSD.



Source: DNV, LNG containment systems: Finding the way for Type A

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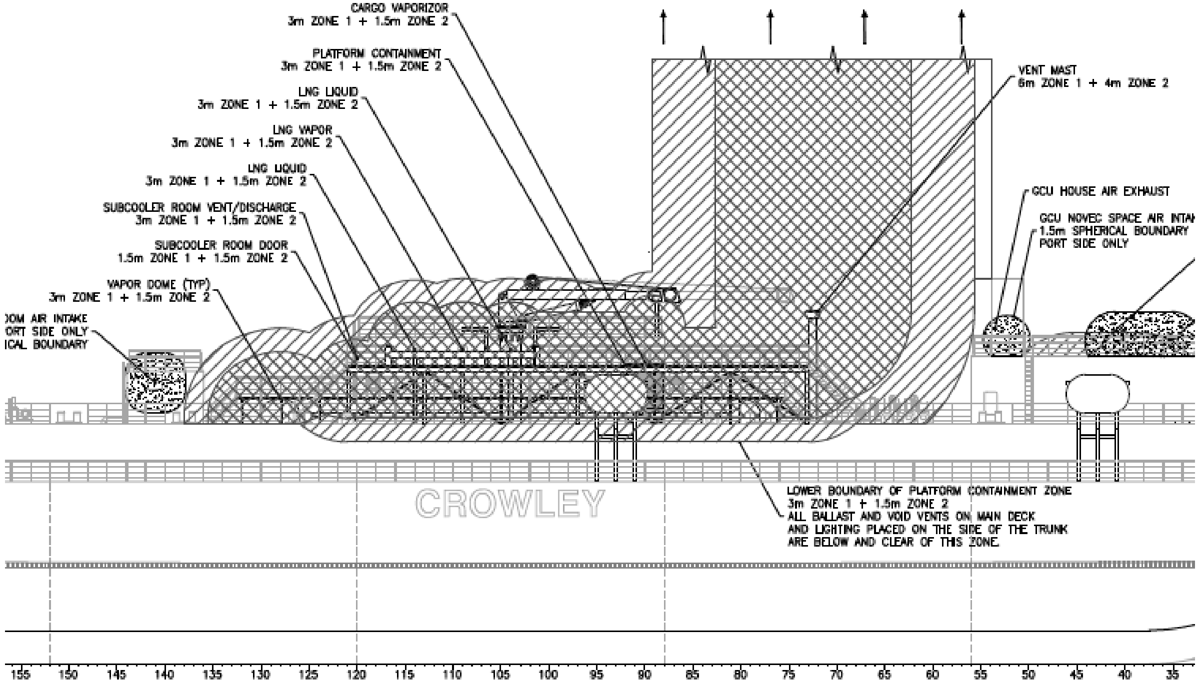
Future Fuels – Design Considerations

HAZARDOUS ZONES

- Openings to gas safe spaces
- Tank vent
- Gas dispersion



Future Fuels – Design Considerations

OTHER KEY FACTORS

- Bunkering strategy
- Emissions requirements (Regulatory, Customer Requirements, Corporate ESG Goals)
- Technological readiness of energy conversion equipment
- Fire fighting
- Fuel supply
- Cost
  - CapEx
  - OpEx
  - TOC

Future Fuels – Case Study

PROJECT OVERVIEW

- Hydrogen Zero Emission Tugboat (HyZET)
- Developed by a consortium of industry leading organizations

PROJECT FOCUS

- Assess feasibility of megawatt scale H2 fuel cell powered harbor craft

PROJECT OUTCOME

- Actionable H2 fuel cell powered tugboat design
- Accelerate decarbonization of marine sector
- Create H2 demand

Future Fuels – Case Study

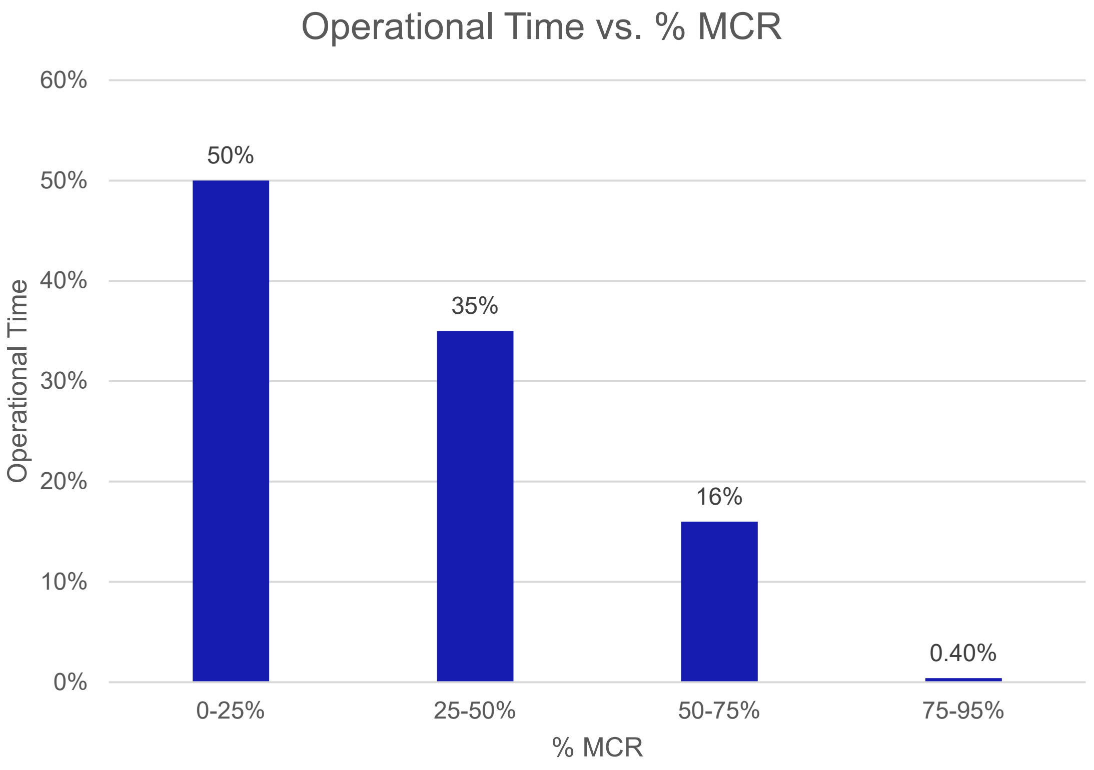
PARTICULARS

Length Overall (over Guards)	105’-0”
Length Molded	102’-0”
Beam Overall (over Guards)	47’-4”
Beam Molded	42’-0”
Depth, Hull to Main Deck Amidships	17’-6”
Draft, Baseline (Design)	18’-8”

PROPULSION EQUIPMENT

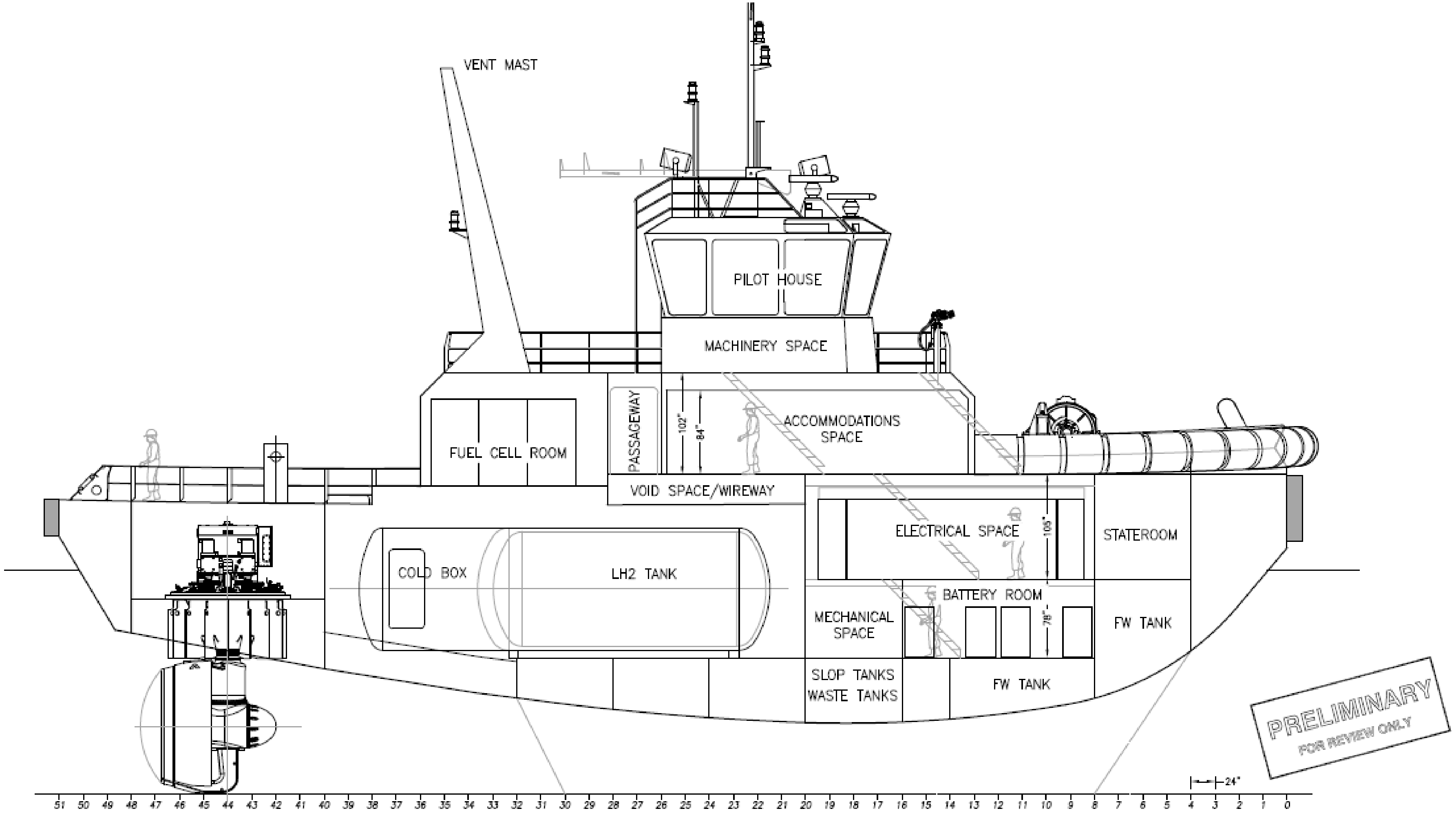
PEM Fuel Cells (12 x 200 kW)	2400 kW
Batteries (14 x 124 kWh)	1740 kWh
L-Drives (2 x 2550 kW)	5100 kW

OPERATIONAL PROFILE



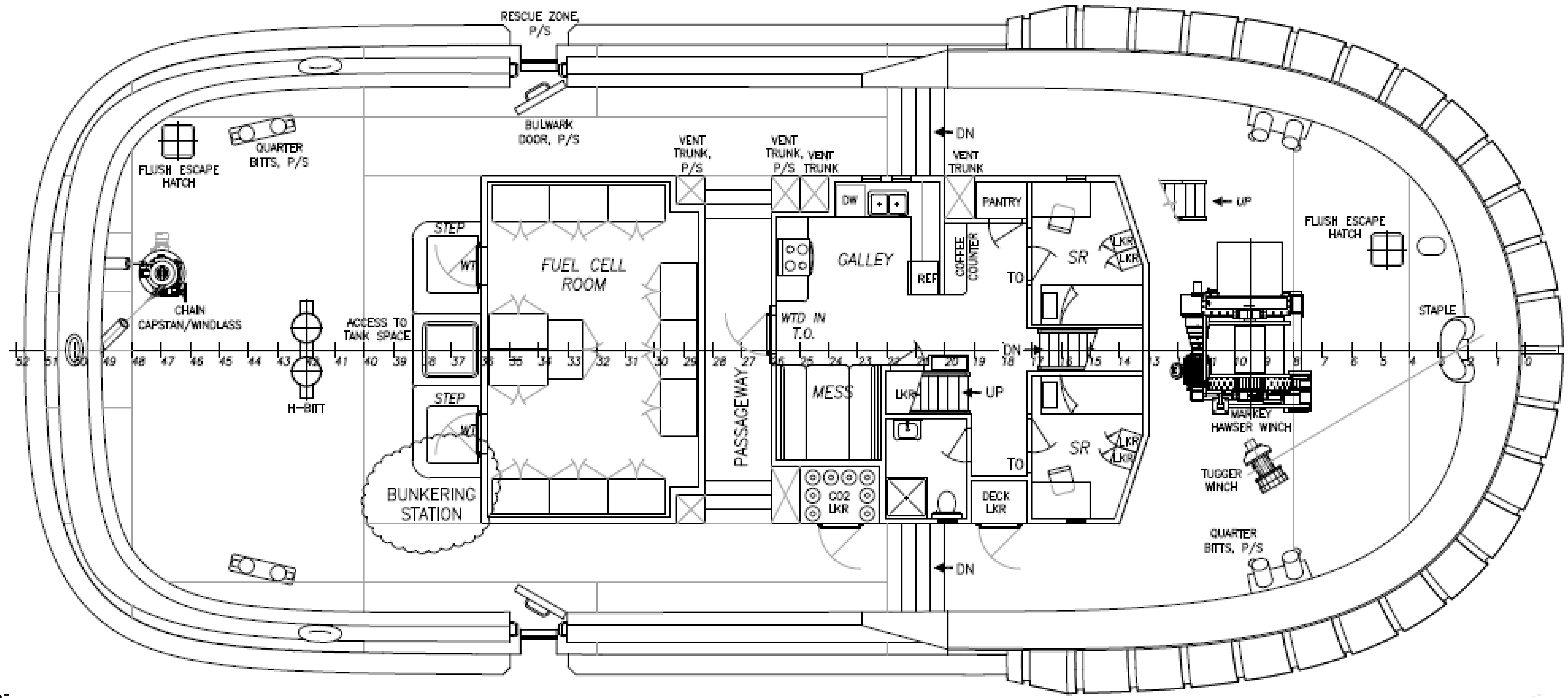
Future Fuels – Case Study

INBOARD PROFILE



Future Fuels – Case Study

MAIN DECK PLAN



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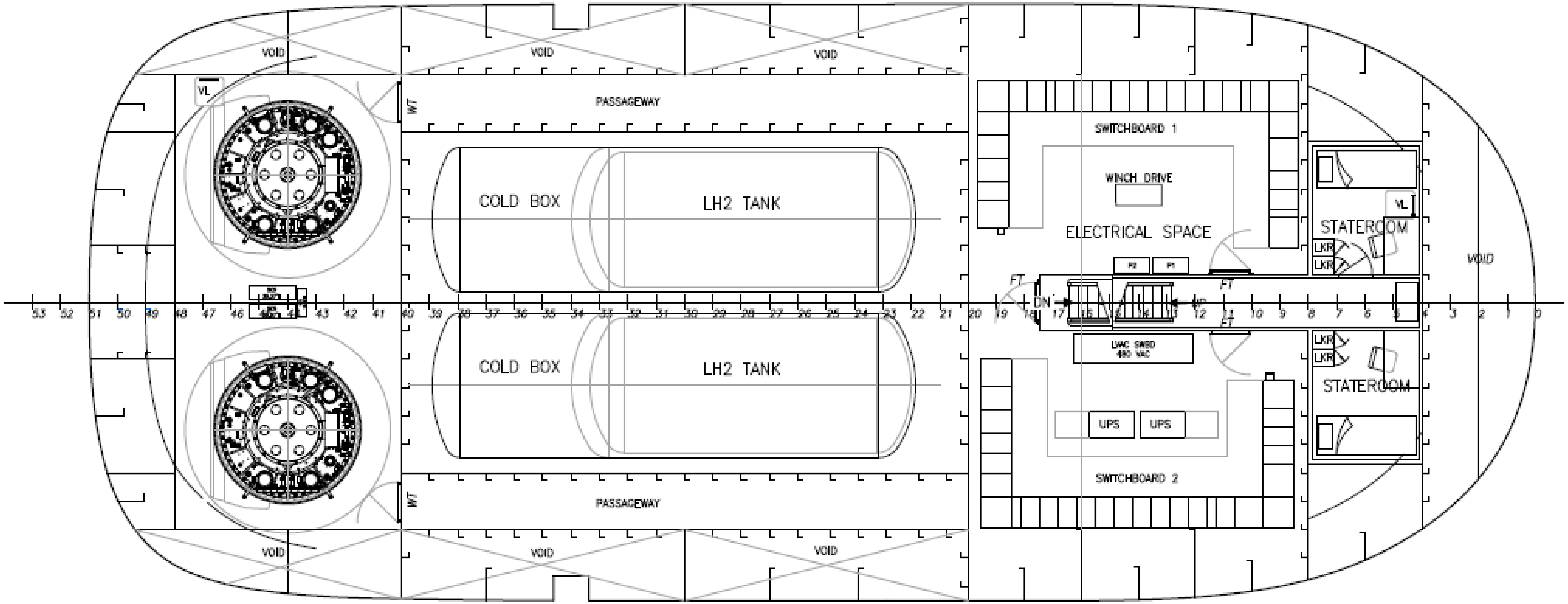
Future Fuels – Case Study

UPPER HOLD PLAN



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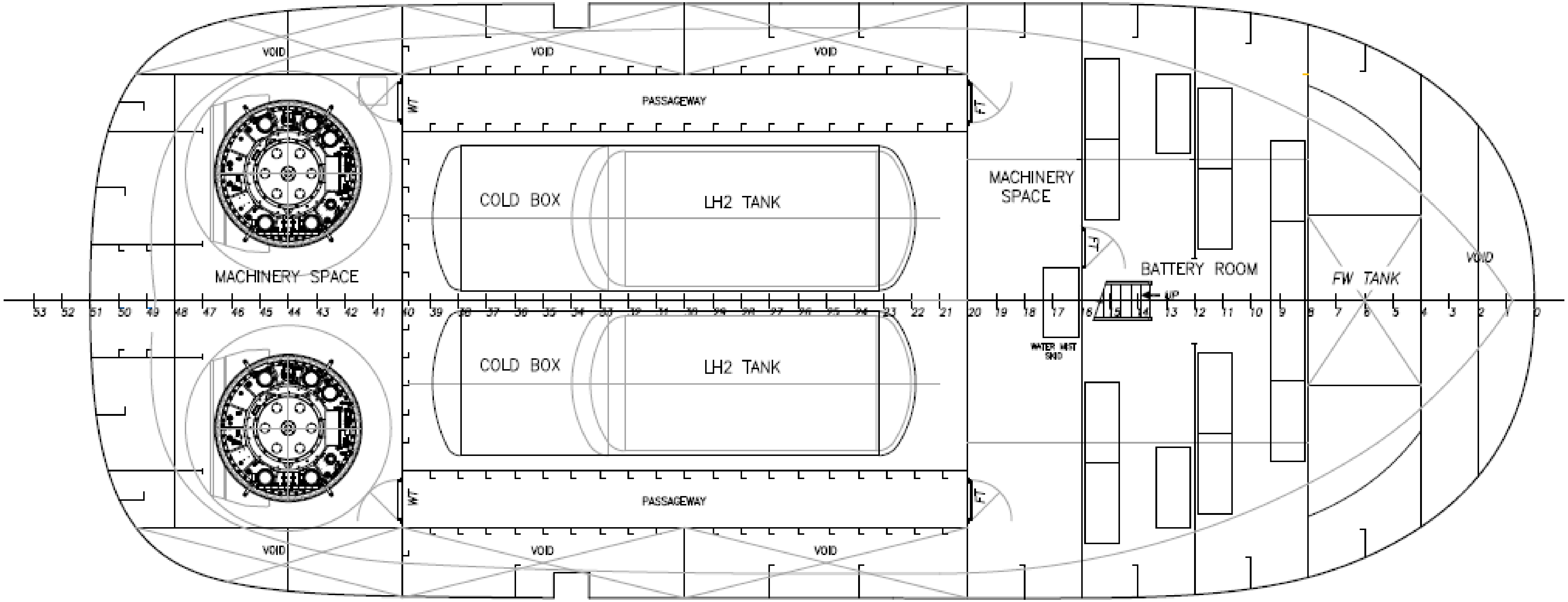
Future Fuels – Case Study

LOWER HOLD PLAN



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Thank you

For questions, contact:

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November 8, 2022