SF Waterfront Maritime Hydrogen Demonstration Project

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Hornblower Energy, LLC

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DOE Hydrogen Program

2022 Annual Merit Review and Peer Evaluation Meeting

AMR Project ID # TA045

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Partners

HORNBLOWER®

Air Liquide

Sandia National Laboratories

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nel

igx Group, Inc.

Glosten

Project Goals

- To demonstrate the feasibility and viability of hydrogen production, storage, and fueling in a maritime context, establishing robust science-based protocols, procedures, operating parameters, and attendant training materials for the safe and routine generation and storage of electrolyzed hydrogen, and handling of water-to-water and water-land hydrogen and fuel-cell power transfer.

- To catalyze a “green hydrogen ecosystem,” via localized production of renewable hydrogen at the San Francisco Waterfront, encompassing San Francisco and the surrounding Bay Area for both maritime and landside users.

Overview

Timeline

- Project Start Date: October 2021
- Project End Date: June 2025

Budget

• Total Project Budget:	$16 M
• Total DOE Share:	$8 M
• Total Cost Share:	$8 M
• Total DOE Funds Spent*:	$ 34,770
• Total Cost Share Funds Spent*:	$ 45,530

* As of 04/30/2022

Barriers

- Barriers addressed
  - Renewable hydrogen refueling infrastructure
  - Safety Codes & Standards
  - Refueling protocol for vessel to vessel, vessel to land and land to vessel
  - Techno-economic analysis data

Partners

- Hornblower Energy LLC – Lead
- Sandia National Laboratories
- The Port of San Francisco
- Air Liquide
- NEL Hydrogen US
- IGX Group, Inc
- Glosten
- Moffett Nichol

Relevance/Potential Impact

- **Objective**: A hydrogen production and distribution facility onboard a barge at the San Francisco Waterfront will be used for refueling hydrogen (H_2) vessels with renewable hydrogen and recharging the batteries of diesel-electric hybrid vessels. This renewable H_2 infrastructure will also support a land-based H_2 network, creating a hydrogen ecosystem of zero-emission mobility and resiliency. The demonstration will lead to new and improved maritime uses of hydrogen technology.

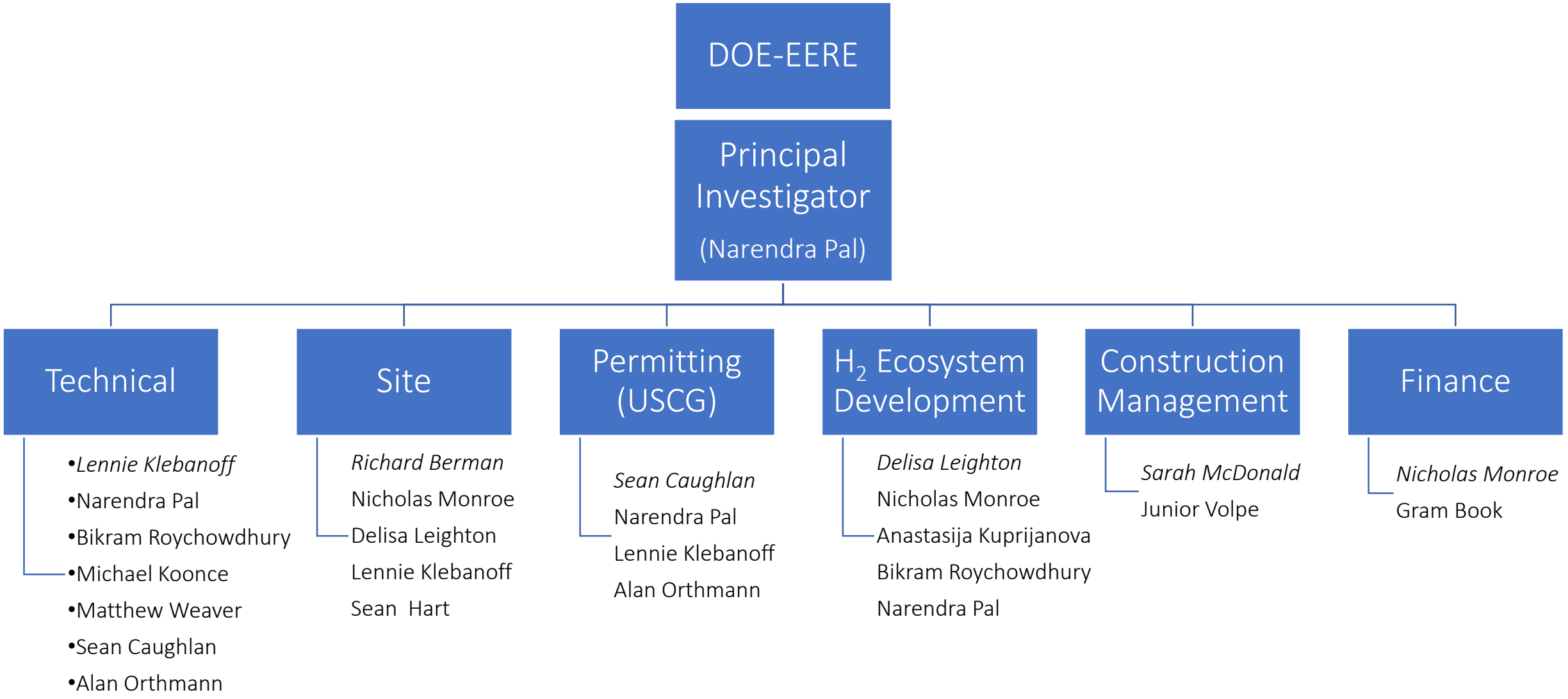
- **Description**: This project will demonstrate a first of its kind Maritime Hydrogen Refueling Infrastructure on water with refueling capabilities of up to ~ 500 kg H_2/day. An integrated system of green hydrogen production via electrolysis and hydrogen power generation via a fuel cell, both mounted on a barge, will bring commercial hydrogen technology to maritime. Performance and efficiency of the integrated hydrogen technology system will be studied, and the project will develop protocols for the safe transfer of hydrogen and power over the water to hydrogen vessels and hybrid electric vessels, respectively. The project will stimulate a renewable maritime hydrogen ecosystem in San Francisco and create a blueprint for safely establishing barge-based renewable power.

- **Impact**: The demonstration will stimulate increased demand for hydrogen, advance the development of safety codes and standards for barge-based hydrogen technology and promote the development of a hydrogen customer base along the San Francisco Waterfront, in the City of San Francisco, and in the greater Bay Area. This project will create a blueprint for optimally designing such a hydrogen barge and how the infrastructure can be replicated at other ports and similar locations across the United States

Approach

- Technical approach:
  - Phase-I: Design finalization and permitting & codes compliance
  - Phase-II: Ordering equipment, developing protocols and integration strategy, constructing H_2 Barge.
  - Phase-II: Demonstration of technology, data collection and analysis
- Milestones:
  - Site finalization, Permitting & Code compliance
  - Hydrogen Barge (HB) and Hydrogen Technology Design finalization
  - Protocol development
  - Assembly and Integration of Hydrogen Technology
  - Final inspection and demonstration of technology
  - Outreach to local business community
  - Technoeconomic and Environmental Analysis
- Go-no-go decision points:
  - Permitting & Code compliance
  - Final inspection by USCG

Project Organization



The Project Participants

HORNBLOWER

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nel

Glosten

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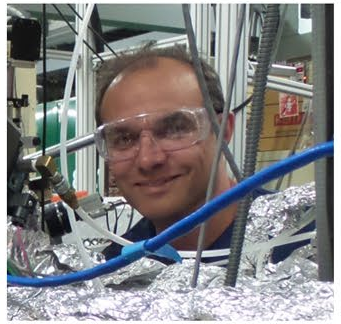
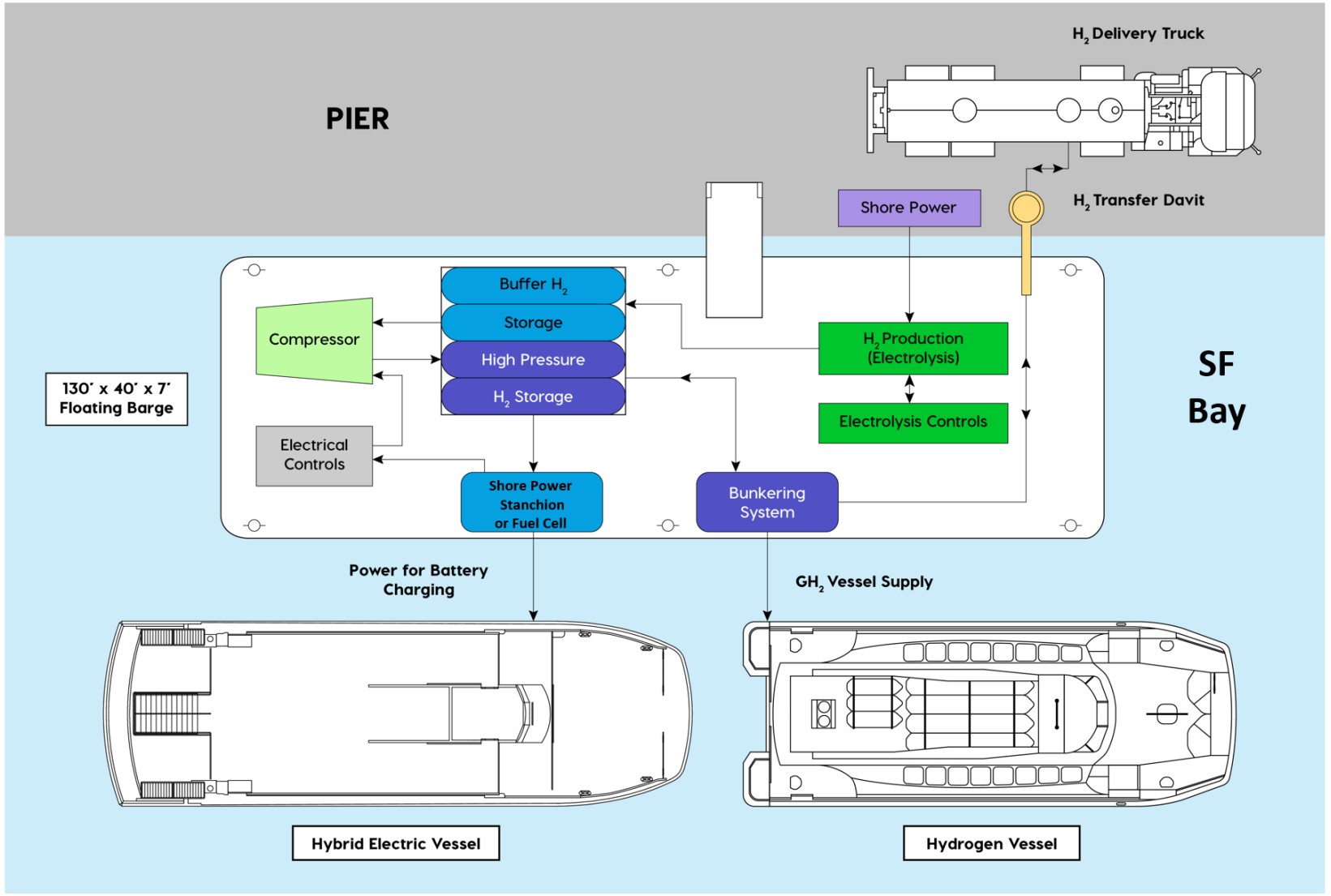


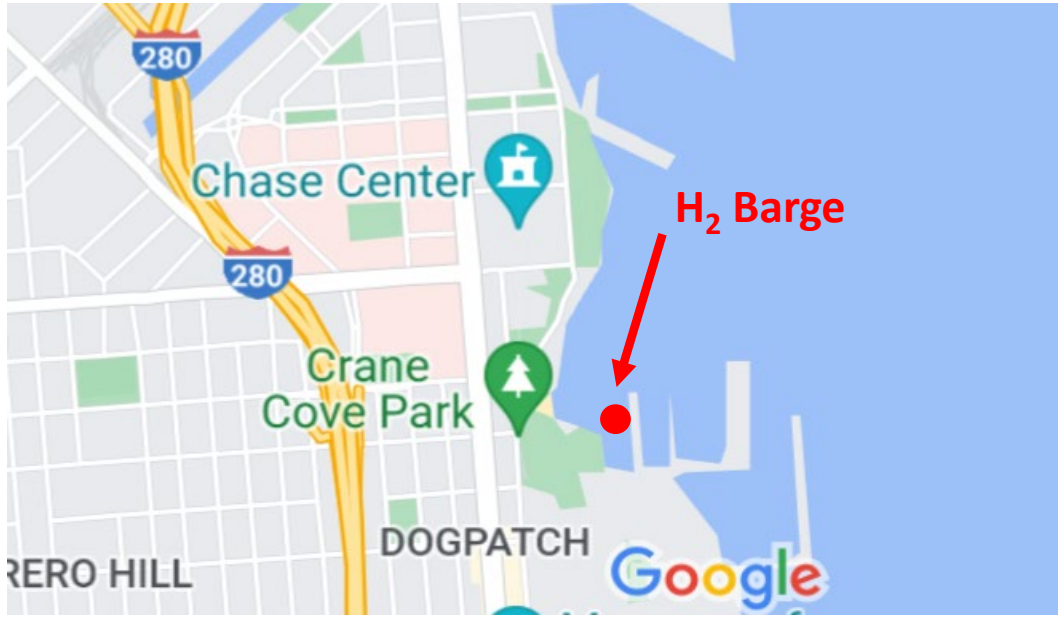
Lennie Klebanoff

Approach: H_2 Barge (HB) Performance Attributes for Phase I Design



- ✓ Produce a total of ~ 500 kg/day renewable hydrogen at 450 bar.
- ✓ 200 kg/day dedicated to hydrogen maritime vessels.
- ✓ 300 kg/day for ecosystem development to support land-based fuel-cell applications (motive and stationary).
- ✓ Renewable electricity for charging the batteries of battery hybrid vessels

Accomplishments: Chose Pier 68 at SF Waterfront for Deployment Site



Attributes of Pier 68, Wharf 3:

- ✓ Sufficient power, water utilities.
- ✓ Protected from strong bay waves.
- ✓ Located away from immediate public (noise concerns reduced).
- ✓ Good freeway access (H_2 trailers).
- ✓ Compatible with H_2 trailer refueling and visits from H_2 vessels, battery-electric vessels.
- ✓ Well-suited for regulatory approvals

Accomplishments: Chose 450 bar Type III Storage Tanks for H_2 Barge

Front View

Front View (Inside)

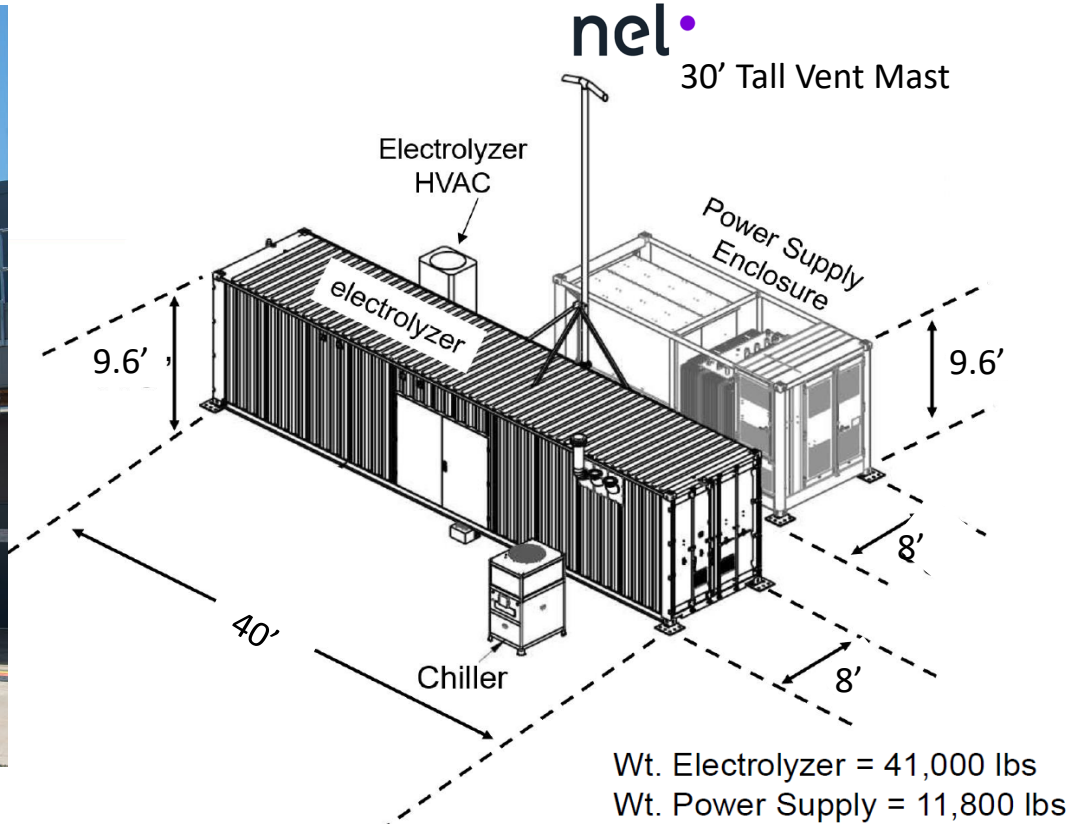
9.5’

Total Weight ~ 24,000 lbs
(2 containers)

9.1’

- HB will have 450 bar Type III H_2 storage tanks due to excellent track record, faster refueling, and there is no weight need to go to Type IV H_2 tanks.
- Use two identical H_2 Storage units to allow good access to hardware, redundancy.
- The HB will be a “450-bar system” since 450-bar hardware is standard, proven, and the equipment will be cheaper and easier to service.
- Enclosures will protect H_2 storage tanks in maritime environment.

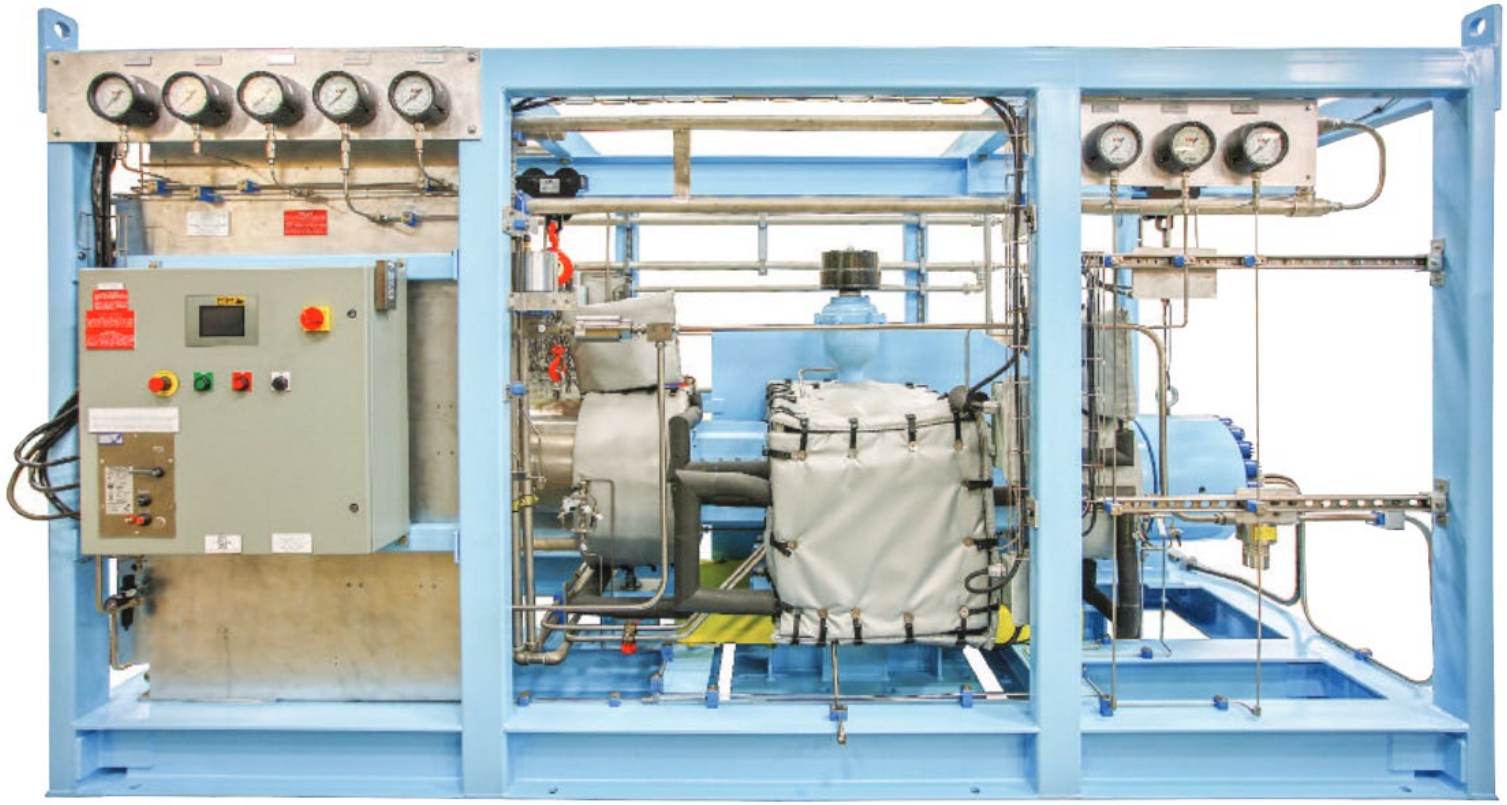
Accomplishments: Chose 1.2 MW NEL Electrolyzer for H_2 Barge



Attributes of the NEL Electrolyzer for H2 Barge:

1. Fully Containerized Standardized Design
2. Reliable Turnkey Solution
3. State-of-the-Art PEM Technology
4. Designed and Built by the Largest Electrolyzer Manufacturer in the World

Accomplishments: Chose PDC-13 2-Stage H_2 Compressor for Project



COMPRESSOR MODEL: PDC-13-1250-7500(100%)	
PROCESS MEDIA	HYDROGEN GAS
SUCTION MAWP	160 PSIG
DISCHARGE MAWP	7500 PSIG
PROCESS FLOW RATE	25 KG/HR (172.5 SCFM)
SUCTION TEMPERATURE	40 - 104 °F
DISCHARGE TEMPERATURE	(APPROX.) 100 °F
NOMINAL SPEED	400 RPM
AREA CLASSIFICATION	CL.I DIV.2 GRP. B,C,D

UTILITY REQUIREMENTS	
COOLANT (CLOSED LOOP)	40GPM / AMBIENT
INSTRUMENT AIR	80 PSIG / 3CFM CLEAN, DRY
COMPRESSOR MOTOR	100HP / 480VAC / 3PH / 60HZ
COOLANT PUMP MOTOR	5HP / 480VAC / 3PH / 60HZ
RADIATOR MOTOR	5HP / 480VAC / 3PH / 60HZ
INSTRUMENTATION	120VAC / 1PH / 60HZ

Attributes of the PDC Compressor for H2 Barge:

1. Compatible with 450 bar HB system pressure
2. Compatible with 500 kg/day H2 production rate.
3. Excellent durability track record.

Accomplishments: HB to Accommodate Renewable Shore Power and MarFC

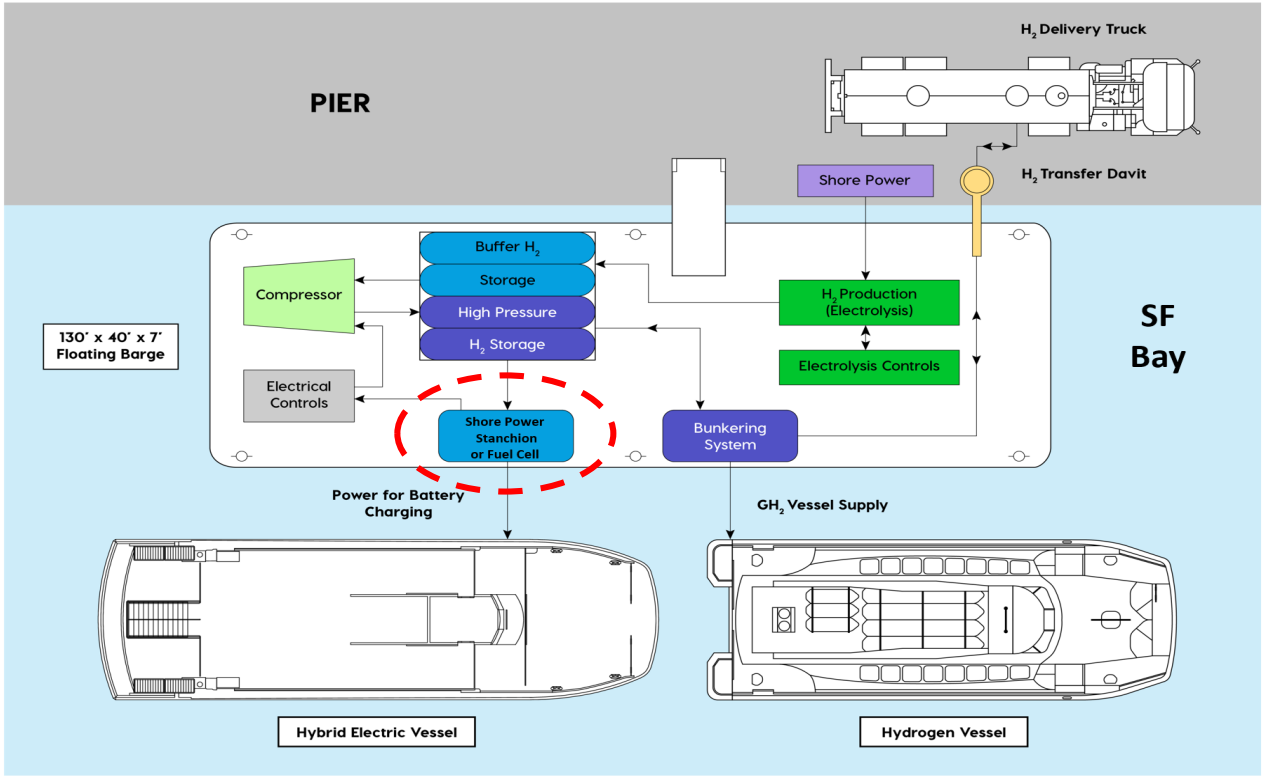
The primary source of electricity for charging the batteries of battery-electric vessels on SF Bay will be a power stanchion that brings renewable 480 VAC Shore Power onto the H_2 Barge.

Power Stanchion

(Source: ESL Power Systems: Item No: 2219-23; Catalog No: E1-R200-480-200-65MEW-SP-221923)

200 A (TBD), 480 VAC stanchion from ESL:

- Indoor or outdoor use, including offshore applications.
- Protection against windblown dust and rain.
- Protection from splashing water and hose-directed water.
- Corrosion-resistant.

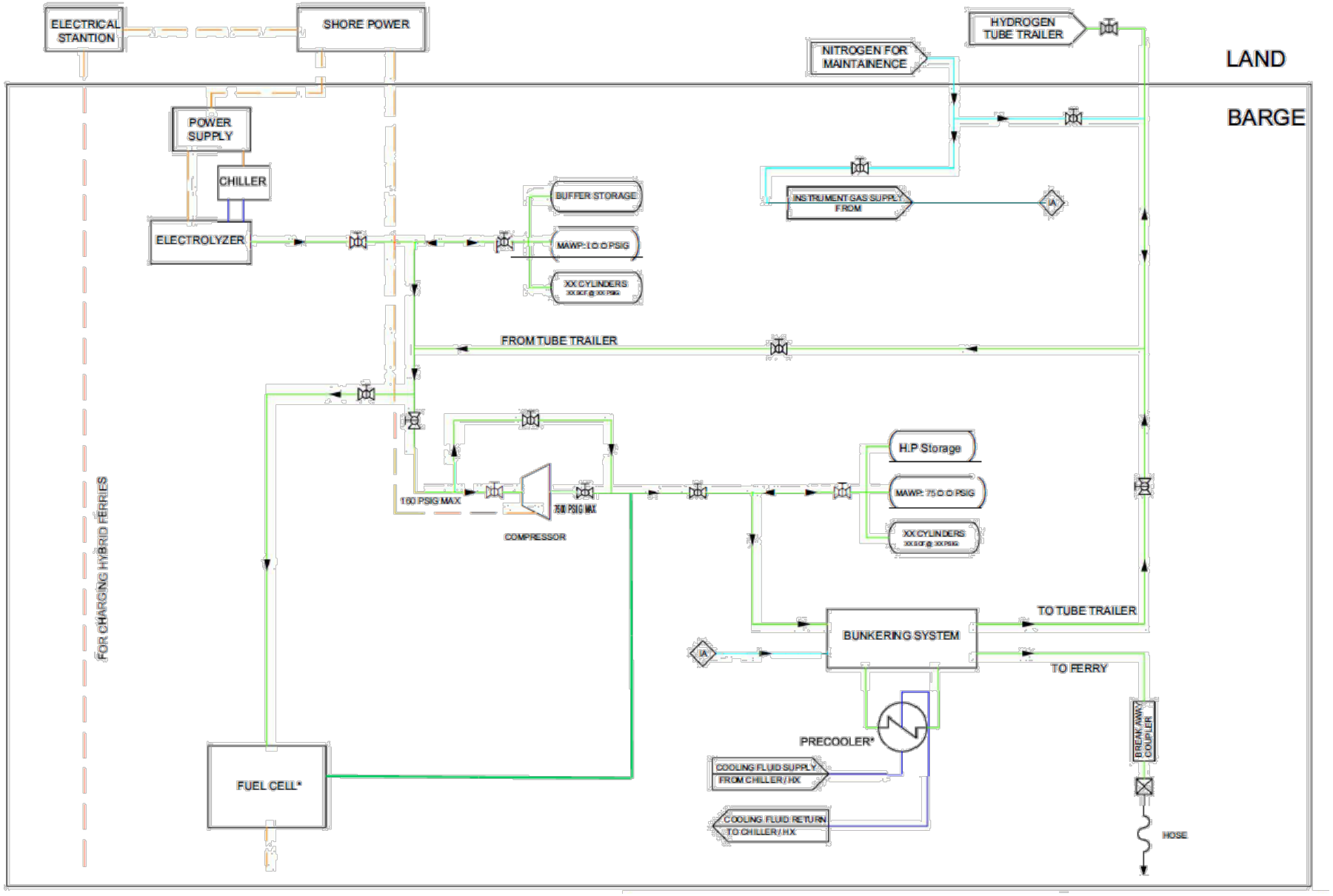


Note: The H_2 Barge is also being designed to accommodate the 100 kW DOE/DOT Maritime Fuel Cell Unit (MarFC), if it is available. We are exploring other fuel-cell alternatives.

Accomplishments: Defined Initial H_2 Barge and Interface Requirements

High-level H_2 Barge Characteristics

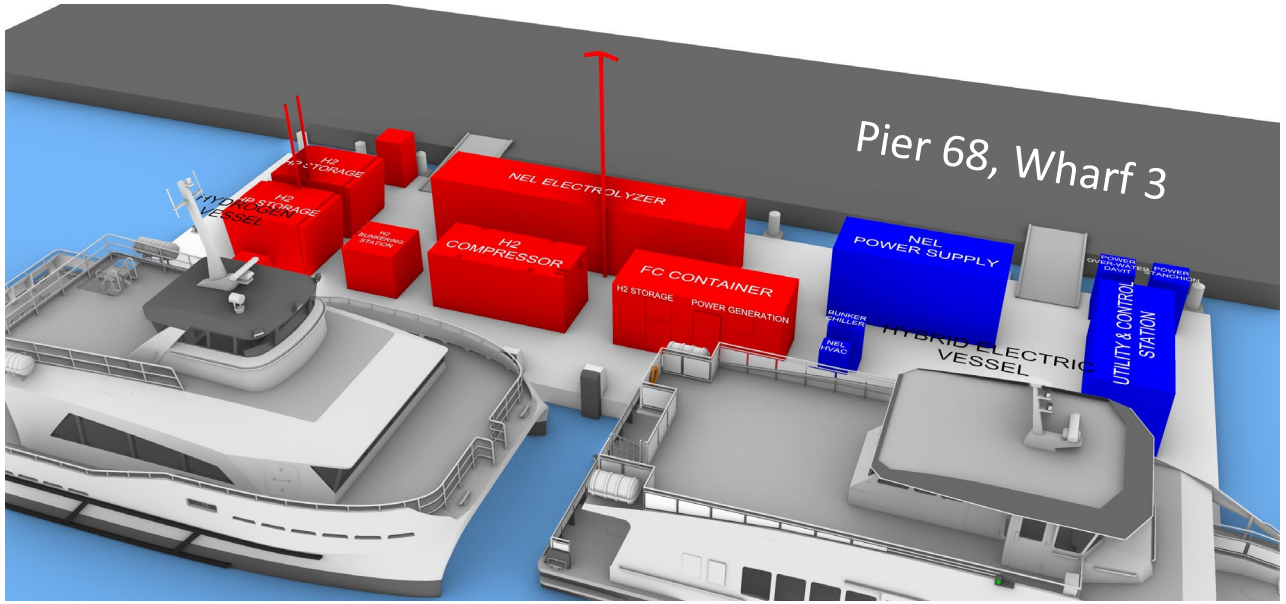
- 130’ x 40' notional footprint
- Permanently secured to pier with connections accommodating tidal variations.
- 12.4kV utility for hydrogen generation
  - H_2 vessel bunkering
  - Transport truck filling
- 480VAC for facility auxiliaries
  - vessel charging
  - support systems
- Central control and monitoring station
- Onboarding cooling systems
  - Process cooling
  - Gas cooling
  - Compressor cooling
  - Bunkering pre-cooling

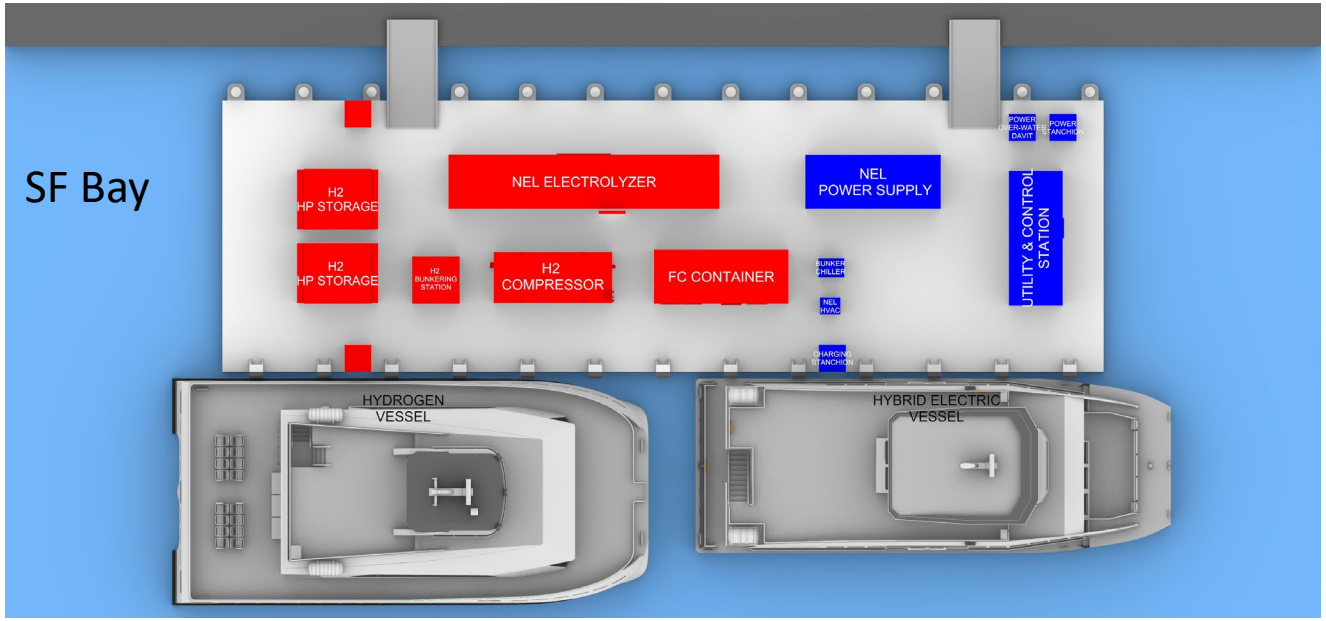


Documenting electrical, mechanical, water interface requirements in progress…

Accomplishments: Completed Initial Layout Design of H_2 Barge

- Separate H_2 Barge into “safe” and “hazardous” areas:
  - Safe: Electrical equipment (blue)
  - Hazardous: H_2 equipment (red)
- Two separate bunkering berths
  - Hydrogen vessel in hazardous area
  - Battery-hybrid vessel in safe area
- Orientation of equipment according to process pressure and defined exposure distances.
- Hydrogen equipment within beam/5 for protection from collision.
- Fixed barge of flexi-float scheme.





Accomplishments: Made Initial Assessment of H_2 Barge Regulatory Basis

The H_2 Barge will have a primary classification as a "designated waterfront facility" as defined in 33 CFR, subchapter L, Part 126 designed for handling, storing, and offloading compressed hydrogen. It would be inspected by the SF Facility Inspection Branch.

The H_2 Barge would *not* be classified as an inspected vessel under 46 CFR.

This proposed regulatory basis to be sent to USCG for review and comment.

Topic	Regulatory Reference
Structure	
Hull Structure	Steel Barge Rules (SBR) Part 3 SBR Part 5, 5-1-1
Stability	
Deck cargo barge stability	46 CFR 174 Subpart B MSC PRG C1-10
Fire Protection and Fire Extinction	
Fire extinguishing equipment	33 CFR 126.15
Fixed fire extinguishing systems	46 CFR 25.30-15
Portable fire extinguishers	33 CFR 126.15
Lifesaving Equipment	
Life preservers	46 CFR 25.25
Hydrogen Systems	
Hydrogen systems	NFPA 2: Hydrogen Technologies Code
Hazardous areas	NFPA 70: National Electrical Code Handbook NFPA 2: Hydrogen Technologies Code
Electrical Systems	
Electrical systems	33 CFR 126.15 NFPA 70, Article 555
Navigation lighting Lighting	33 CFR 83.30 33 CFR 126.15
High Voltage Shore Power, including Grounding	IEC/ISO/IEEE 80005-1
Low Voltage Grounding	NFPA 70, Article 555
Mechanical Systems	
Auxiliary systems	46 CFR Subchapter F
Ventilation	NFPA 2, Chapter 6.18

Accomplishments: Started Modeling for Development of H_2 Refueling Protocols

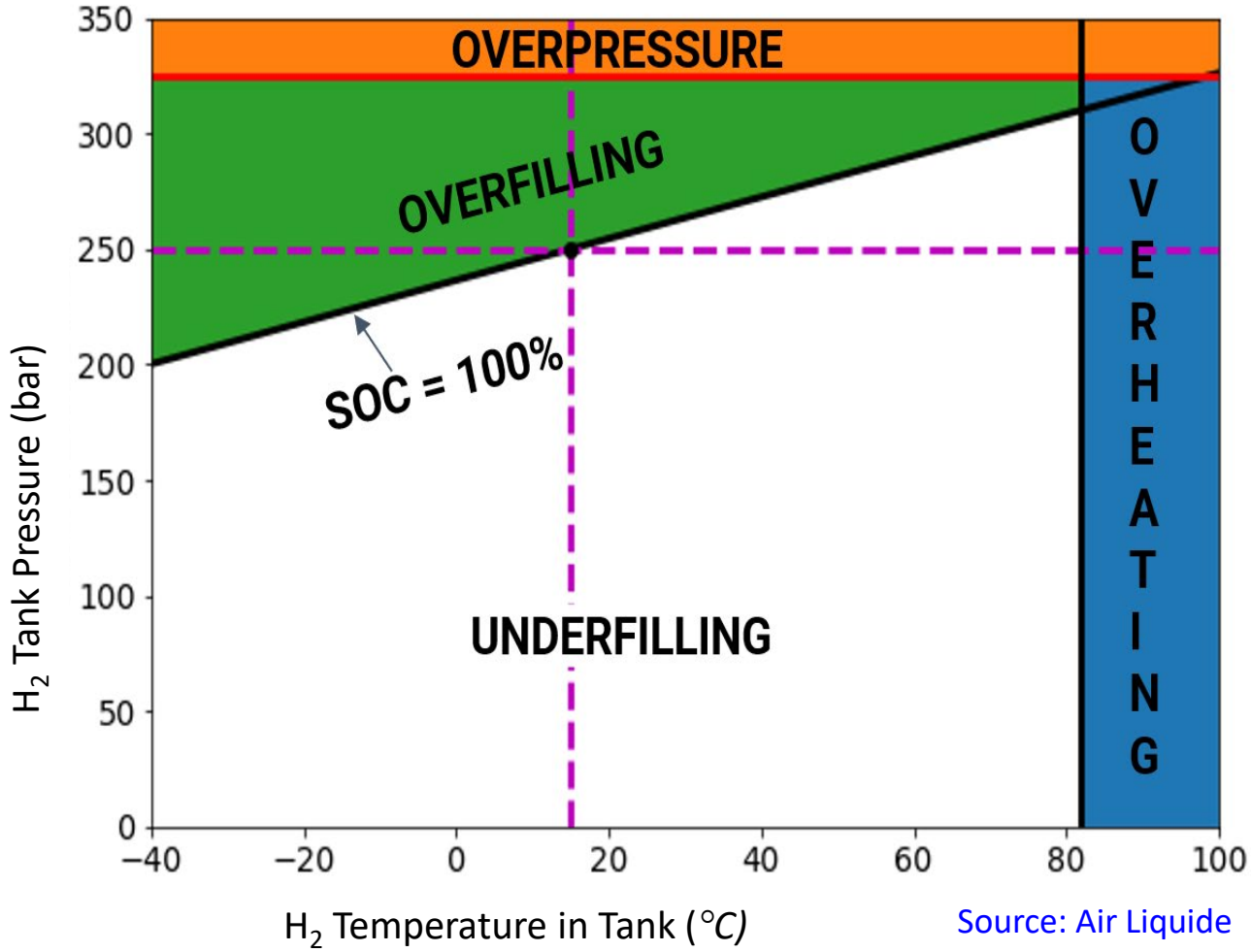
In order to develop safe science-based H_2 tank refueling protocols for land and sea, accurate thermodynamic models are need to predict $T_{end\ of\ fill}$ and thereby, estimate the corresponding $P_{end\ of\ fill}$

Air Liquide has developed a model to examine H_2 fueling heating effects (Joule-Thomson and compression heating, heat conduction through tank walls) for Type IV tanks (250 bar, 28 kg/tank) relevant to the first H_2 vessels (Sea Change, Discover Zero) and applicable to Type III tanks on hydrogen refueling trailers.

The question: how fast can the tanks be filled and not exceed the 82 °C temperature limit set by maritime regulations (American Bureau of Shipping) for vessels, or the 85 °C limit for vehicles?

Type IV H_2 Vessel Fueling Constraints:

- **Nominal Working Pressure: 250 bar**
- **Maximum Allowable pressure: 325 bar**
- **$T_{end\text{-}of\text{-}fill}$(peak) : *82 °C***



Source: Air Liquide

Modeling is in progress to develop fast and safe protocols for filling H_2 vessel hydrogen tanks. Model predictions to be validated by tank-filling experiments at Air Liquide.

Accomplishments: Initiated Ecosystem

More than half of the H_2 output of the H_2 Barge will be for landside uses in order to develop a growing San Francisco Bay Area hydrogen ecosystem. Outreach to existing H_2 users has started.

- Meetings with Stone Edge Farm Microgrid to discuss areas of collaboration (H_2 network links)
- Industry outreach with potential partners: Hyzon, Wiggins Folk Lifts, New Flyer, Stratos Share, Toyota among others
- Hornblower presents H_2 Barge Project to the CARB Sea Change Monthly Meeting
- Prep for Sacramento H_2 Village (April 6th) participation.

Picture Source: IGX

Collaboration and Coordination

- Collaboration and coordination with partners and others counts for 10% of your total project score.
- Project collaborators:

Collaborator	Identity	Relationship	Role
Hornblower Energy, LLC	Industry	Prime	Lead, Compliance, Budget, Design & Demonstration
Sandia National Laboratories	National Lab	Sub	Compliance, Design, Demo
Port of San Francisco	Port	Sub	Compliance, Demo
Air Liquide	Industry	Sub	Refueling Protocol
NEL Hydrogen US	Industry	Sub	Electrolyzer
IGX Group, Inc	Industry	Sub	Hydrogen Storage and Hydrogen Off-take / Supply
Glosten	Industry	Sub	Barge Design, Compliance and Liaisoning with USCG
Moffett Nichol	Industry	Sub	Civil Engineering, Site Preparation

Remaining Challenges and Barriers

Phase-I:	❖ Permitting from Local Agencies ❖ Design Approval from US Coast Guard
Phase-II:	❖ Timely Equipment Procurement ❖ Protocol development ❖ Construction of floating platform (barge)
Phase-III:	❖ Demonstration of technology ❖ Data Collection and analysis
Barriers:	❖ Permitting & Code Compliance ❖ Design Approval from USCG ❖ Final Inspection by USCG

Proposed Future Work

Remainder of FY 2022:

- Finalize Design & Development
- Site Finalization and Permitting from Authorities Having Jurisdiction
- Application submission for Design Basis Letter to USCG.

FY 2023:

- USCG Approval of Design Basis Letter
- Equipment procurement
- H_2 refueling and battery-electric recharging protocol development
- USCG Approval of compliance

Summary

- Organized the project team, defined H_2 Barge performance attributes for Phase I Design
- Identified and selected a barge site that meets key project criteria, including location (accommodating both maritime and land-based users), infrastructure/utilities (availability and condition), and favorable regulatory approval pathway.
- Chose 450 bar Type III storage tanks for H_2 Barge, defined H_2 Barge as a 450-bar hydrogen system.
- Defined initial H_2 Barge interface requirements, completed first-order layout of H_2 Barge systems.
- Made initial assessment of H_2 Barge regulatory basis for discussion with the USCG.
- Established modeling capability and started modeling of H_2 vessel refueling in order to develop fueling protocols.

Thank You…

In case of additional questions, please contact;

Narendra Pal

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Technical Backup and Additional Information

Technology Transfer Activities

Not available: Since during Period 1, our focus is on securing site, permitting, approvals and finalizing the equipment specifications, as of now, there is no technology transfer activity to report.

Special Recognitions and Awards

Not available: Since during Period 1, our focus is on securing site, permitting, approvals and finalizing the equipment specifications, nothing to report.

Publications and Presentations

Not available: Since during Period 1, our focus is on securing site, permitting, approvals and finalizing the equipment specifications, nothing to report.