Current Commercial Operational Readiness and Barriers to ZEAT Commercial Harbor Craft

ADVANCED POWER & ENERGY PROGRAM
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ZEAT Regulations and Vessel Definition

- **CARB regulations related to ZEAT**
  - Short run ferries with a single voyage of less than three nautical miles will be required to be fully-zero-emission by the end of 2025
  - New and newly acquired excursion vessels after Dec. 31, 2024 are required to be able to operate with a minimum of 30% zero emission

- **ZEAT Definitions**
  - **Zero-Emission –** propulsion or auxiliary system that generates no tailpipe emissions other than water vapor or diatomic nitrogen
  - **Zero-Emission Capable Hybrid Vessel –** CHC with two or more onboard power sources, one or more of which is approved by CARB to be capable of providing a minimum of 30% of vessel power required for main propulsion and auxiliary power with zero emissions when averaged over a calendar year
  - **Zero-emission and Advanced Technology –** Collectively refers zero-emission capable hybrid and zero emission vessels
  - **Zero-emission Infrastructure –** Installed dockside infrastructure necessary to support operation of a ZEAT vessel including charging systems for propulsion system batteries, on-dock hydrogen storage tanks and fueling infrastructure

- **For this work, ZEAT includes plug-in battery electric hybrids, full battery electric, and hydrogen fuel cell electric vessels**
  - Diesel-electric tugs (not using shore power) have been in use in California for many years but are not considered ZEAT

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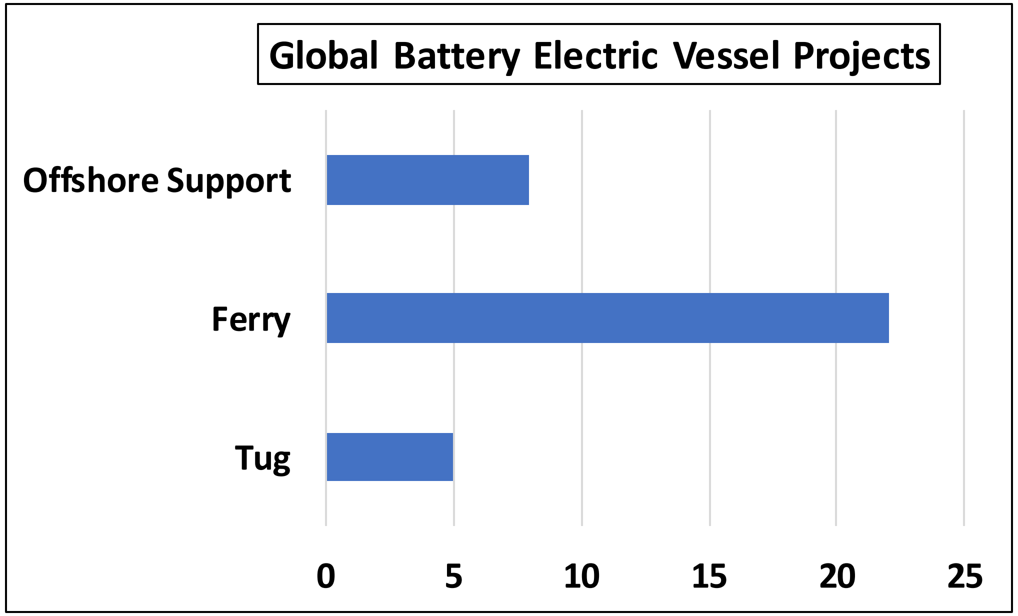
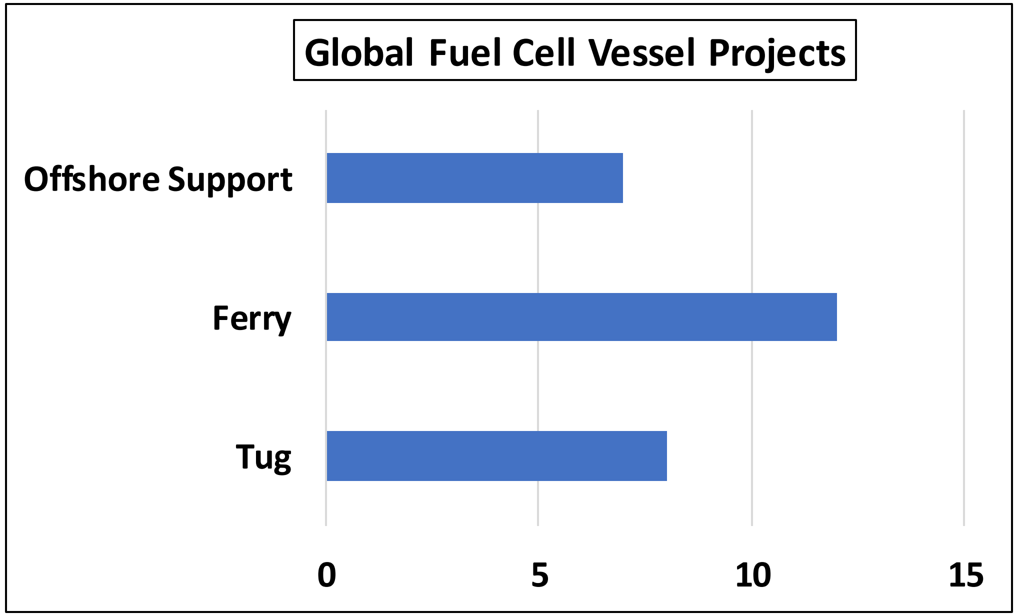
ZEAT Vessels

- **Globally there is momentum for ZEAT vessels with the largest markets in Europe and Asia**
  - Ferries, tugs, and offshore support vessels are the most common applications
  - Battery electric vessels more commercially advanced than fuel cell vessels





Source: IMO NextGEN database

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Near-ZEAT and ZEAT Fuels

Fuel	Advantages	Disadvantages
Batteries and Electricity	• More technologically mature and commercially available • Less safety concerns • Some existing infrastructure and efforts to further develop in place at many ports • High energy efficient compared to other fuels • Generally lower costs for batteries than fuel cells	• Competition with other sectors that are electrifying • Range limitations and charging times • Weight challenges that impact vessel design • Lack of widespread fast charging systems • Impacts on the local electrical grid
Hydrogen	• Can be stored as compressed gas, cryogenic liquid, or bonded with other chemicals (methanol, NH_3) • Fast response and high power output • Potentially longer ranges and quicker refueling times • Strong momentum for renewable H_2, e.g., ARCHES • Lower weight, better cold weather performance	• Highly combustible • Compression/liquefaction energy intensive and expensive • Lack of current infrastructure • Fuel cost uncertainty • Immaturity of safety regulations and protocols
Methanol	• Easier to store and handle than H_2 and NH_3 • Can be used for ICE and fuel cell engines • Safety protocols already established (IGC and IGF) • Bunkering available at some ports (Port of Houston)	• Conventional has higher GHG emissions than diesel • Lower energy density than conventional • Fuel cost uncertainty • Less efficient than using H_2 directly • Corrosive, toxic, flammable
Ammonia	• Low flammability risk • Stored and transported as a liquid • High level of maturity for storage and transport • Can be used directly in high temperature fuel cells or cracked to H_2 for others	• Toxic, corrosive • Lack of safety regulations • Large storage volume • High costs from fuel and infrastructure • Limited supply and bunker infrastructure • Less efficient than using H_2 directly

Fuel Cells

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California ZEAT Vessels

ZEAT Short Run Ferries

- **Operate on shorter, fixed routes, which are favorable for ZEAT**

- **Angel Island Tiburon Ferry plans convert to two short run ferries to ZEAT and one excursion vessel to near-ZEAT**
  - 59’ 400-passenger short-run *Angel Island* Ferry will be retrofitted to an all-electric propulsion system first
    - Barge type vessel which is a good candidate for electrification because increased weight not a concern
    - Infrastructure being developed with assistance from PG&E

Angel Island short run ferry

- **Balboa Island Ferry plans to convert to comply with regulatory deadline**
  - Has received grant funding from CARB

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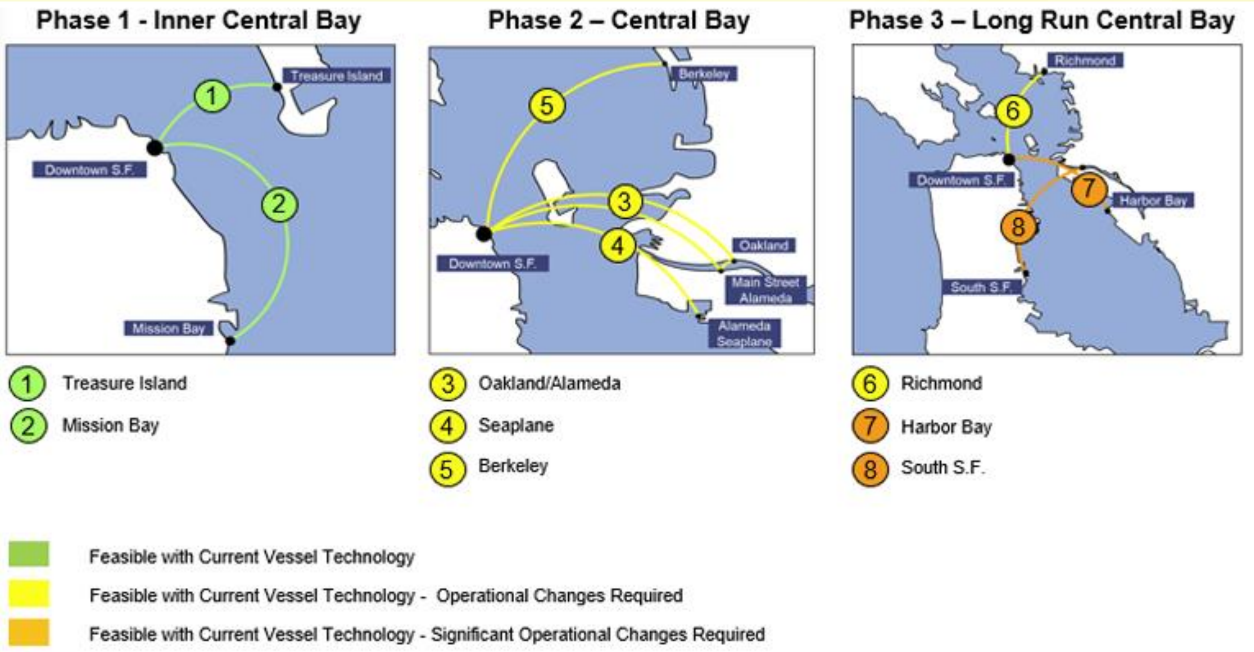
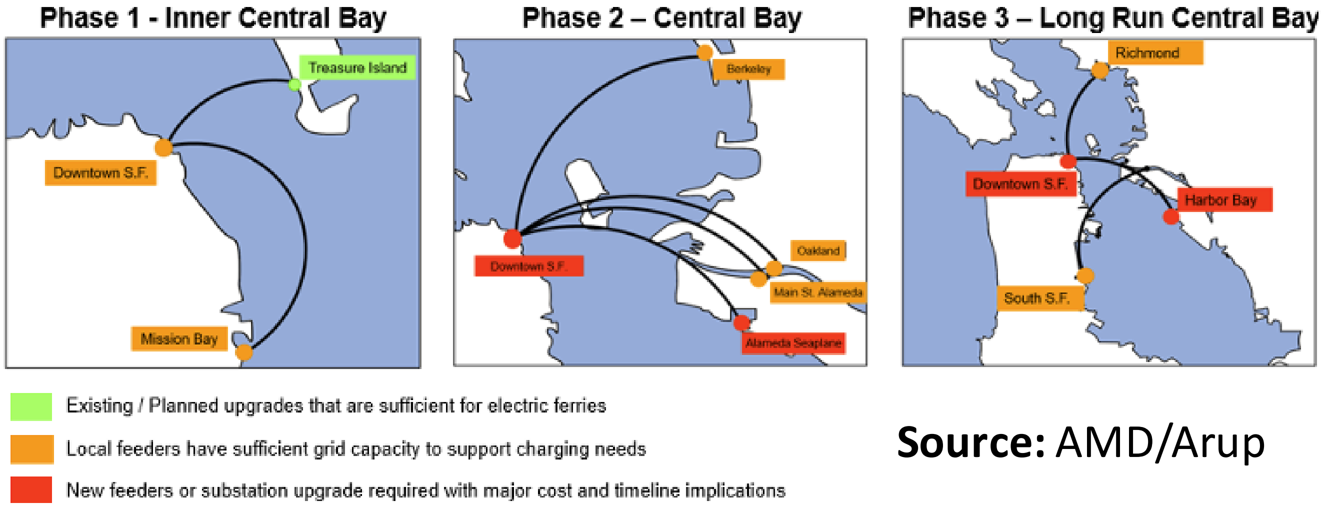
ZEAT High-speed Ferries

- **WETA has developed a phased approach to electrifying 50% of ferry fleet by 2035**
  - Phase 1-3 for short- to medium-routes
  - Phase 4 routes will require technological advancement due to large power requirements
- **Partnered with Wartsila to develop 5 battery electric fast ferries for the first phase**
  - 150 passenger (x3) and 300 passenger (x2)
- **Charging requirements include DC fast charging ranging from 1 to 5 MW**
  - Battery energy storage important
  - Some terminals require minimal upgrades while others require substantial work





Source: AMD/Arup

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ZEAT Catamaran Ferries

- **Sea Change conducting sea trials for WETA with Blue and Gold Fleet**
  - 70' aluminum catamaran with a top speed of 15-knots and 75 passenger capacity

- **Designed as a technology demonstration and not intended to have the same operational capability of a larger diesel-powered fast ferry**

- **Current hydrogen refueling occurs from gaseous trailer truck delivery**
  - Requires a strict set of protocols

***Sea Change* fuel cell ferry**

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ZEAT Tugboats

- **Crowley designed battery electric *eWolf* ship assist tug operating at the Port of San Diego**
  - 82’ with 70-ton bollard pull capable of 12 knots
    - Activity pattern is advantageous to battery electric due to dormancy during the middle of the day and night
      - Low power usage with occasional large increases in power
  - Charging infrastructure has been a major challenge
    - Currently charging using 480-amp AC (slow)
  - Planned DC solar battery microgrid facility to support charging
    - Reduce peak loads and enhance renewable electricity use

Crowley *eWolf* ship assist tug

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ZEAT Tugboats

- **Planned plug-in hybrid electric ship assist tug at the Port of Los Angeles (POLA)**
  - 82’ with 70-ton bollard pull battery capable of 12 knots
  - With 3 strategic charging stations and careful operation could be 90% all-electric

- **Planned Bay Area Zero-Emissions Tug (BAZE ElectRA Tug) at the Port of Oakland**
  - Supported by microgrid power system (Cat® battery system and associated switchgear) for fast charging during daily operation and lower power charging while docked

- **HyZET project established a design for a H_2 fuel cell electric ship assist tug at POLA**
  - 90’ with 90-ton bollard pull and powered by around six 200 kW Ballard fuel cells
  - Able to operate for a minimum of one week in between refueling

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ZEAT Excursion Vessels

- **Red and White Fleet's *Enhydra* provides harbor cruises in the S.F. Bay**
    - 128' plug-in diesel electric hybrid aluminum 600-passenger battery/diesel-electric excursion vessel capable of 12 knots
    - Lack of shoreside infrastructure prevents operation in zero emissions mode more frequently
        - Currently charging using 480-amp AC (slow) overnight

***Enhyrda* Excursion Vessel**

- **Planned Projects**
    - Port of LA awarded funding for the design, construction, and demonstration of two battery electric hybrid excursion vessels
    - Monterey Air Resources Board, Monterey Bay Eco Tours and Left Coast Composites will build the first ZEAT plug-in electric hybrid whale watching vessel based out of Moss Landing

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ZEAT Fishing Vessels

- **ZEAT commercial fishing vessels are challenging**
  - Power/endurance requirements, vessel design challenges, irregular operating patterns
  - Larger vessels including those operating for significant distances offshore will likely require technology advancement and proof of concept demonstration prior to commercialization

- **Zero Emission Projects**
  - Battery electric likely limited to small vessels (<32') with lower power and energy needs
  - Hydrogen fuel cell vessels may have increased feasibility, but no current projects identified

- **Plug-in hybrid projects**
  - Funding for the conversion/electrification of the commercial fishing Gold Rush in S.F. Bay

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ZEAT Dredges

- **Sandpiper all-electric cutterhead suction dredge**
  - Operated by Pacific Dredge and Construction and used to maintain Santa Barbara Harbor and channels year-round
  - 74’ x 26’ 14,000-foot dredge discharge pipeline with 65’ SPUD length and production of up to 28,000 cubic yards per 24 hours
  - Power provided from shore by 13,800 volt trailing electrical cable

- **Curtin Maritime DB Avalon hybrid clamshell dredge**
  - The 250’ x 77’ powered by Tier 4 diesel generators and a large battery system
  - Regenerative power while lowering or decelerating the bucket and power from the batteries and generators to hoist
  - Has the capability to connect to shore-power which would allow ZE operation
  - Currently being utilized in the Project 11 Houston Ship Channel Expansion

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ZEAT Pilot, Crew, Workboats

- **Zero Emission Industries working on 27’ fast hydrogen fuel cell vessel**
  - Initial sea trials and got up to 40 knots (unoptimized)
  - Could be used for pilot vessels, crew transfer vessels, harbor patrol, fire/rescue, fishing, etc.

ZEI Hydrogen Fuel Cell Boat

- **Potential Applications for ZEAT Vessels (highly diverse in size, application, duty cycle, etc.)**
  - Smaller boats and/or those with shorter routes likely represent more favorable, near-term opportunities for the deployment of ZEAT
  - Conversely, larger vessels, those operating for significant distances offshore, or those with heavy operational profiles will likely require additional technology advancement and proof of concept demonstration prior to commercialization

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ZEAT Research Vessel

- **Scripps plans to convert the R/V *Gordon Sproul* to hydrogen fuel cell diesel-electric hybrid system**
  - 125’ vessel with various scientific equipment that can operate up to 12 knots
  - Feasibility study indicated better performance than a comparable battery electric hybrid
  - Full ZEAT not feasible largely due to volumetric energy density of hydrogen

- ***RV Resilience* will be the first plug-in hybrid research vessel in the DOE fleet**
  - 50’ vessel that can operate on batteries at lower speeds and up to 20 knots using diesel power
  - Battery system allows the vessel to operate with zero-emissions during various operational modes for over 4 hours

R/V Sproul

R/V Resilience

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Examples of ZEAT in the U.S. and World

ZEAT Short Run Ferries

- ***Gee's Bend* short run ferry retrofitted to battery electric in service since 2019**
  - 95', 15-vehicle/132-passenger ferry
  - Operational profile conducive to battery electric vessel
    - Short route of 1.4 miles, slow speed (5-8 knots), 30-minute load/unload time for charging, five round trips daily
  - Charging takes 20-25 minutes on one side or 10-15 minutes on both sides

Gee's Bend short run ferry

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ZEAT Fishing Vessels

- **Battery electric lobster boats and shoreside charging being developed in in Canada**
  - *Hybrid One* plug-in hybrid lobster boat being used for fishing and research now

- **Plug-in hybrid-electric 36' fishing vessel the *Karoline* in operation since 2015 in Norway**

- **Skipsteknisk in Norway is designing a 229’ plug-in hydrogen fuel cell diesel-electric hybrid fishing vessel for longlining**

- **Conversion of a 46’ commercial salmon troller to plug-in hybrid in Alaska**
  - Full speed using diesel engines and battery-electric when needed, e.g., during active fishing or transition in and out of harbor

***Hybrid One* Lobster Boat**

***I Gotta Salmon* Troller**

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- **Maid of the Mist in Niagra Falls**
  - Currently operating fleet of all electric catamaran passenger vessels
  - Batteries recharge in seven minutes during the embarking/disembarking which provides enough power to conduct each 20-minute tour

Maid of the Mist Excursion Vessel

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ZEAT Tugboats

- **Robert Allan has a line of hybrid electric tugboats**
  - Three 92’ 70-ton ElectRA2800 tugs provide ship escort service in Canada
- **Damen’s RSD-E 2513 all electric harbor tug**
  - 82’ with 70-ton bollard pull
  - Delivered to the Port of Auckland and soon the Port of Antwerp
  - Recent agreement to deploy at the Port of Khalifa in Abu Dhabi
- **Navtek Naval’s Zeetug**
  - 61’ with 30-ton bollard, 86’ with 45-ton bollard pull
  - Several in operation at Port of Tuzla in Turkey
- **Hybrid electric tugs are feasible for some ship assist and escort tugs but must be considered on a case-by-case basis**
- **Full battery electric tugs may be feasible for smaller harbor tugs in California, e.g., line tender tugs**

Damen’s *Sparky* harbor tug

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ZEAT Ferries

- **Washington State Ferries has plans to electrify**
  - Immediate conversion of three Jumbo Mark II-class RO-PAX ferries and construction of 11 new hybrid electric ferries
  - Shoreside charging infrastructure will be added to 16 WSF ferry terminals.

- **Globally around 130 ZEAT ferries in operation and more planned**
  - In Canada, BC ferries currently has six Damen Island-class 265’ hybrid-electric car ferries capable of carrying 47 vehicles and 450 passengers, and was recently approved to purchase an additional seven more hybrid vessels
  - Norway has around 80 battery electric of hybrid electric ferries in operation
    - *Ampere* first battery electric car and passenger ferry entered service in 2015
    - *MS Medstraum* – 100’ 147 passenger battery electric fast ferry (>23 knots)
    - *MF Hydra* – 270’ 295 passenger/80 vehicle catamaran ferry powered by fuel cells using liquid hydrogen

MF Hydra Fuel Cell Ferry

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ZEAT Inland Towboat

- **Kirby Inland Marine's the *Green Diamond* is the first plug-in hybrid inland towboat in the U.S.**
  - 74' vessel utilizes two electric motors for 1,542 hp powered by a battery system and two onboard diesel generators
  - Design changes required including reduced fuel capacity and the size and configuration of the ballast and potable water tanks to compensate for the weight of the battery system
  - Dockside charging will allow full charge in 6 hours and complete trips on battery power approximately 80% of the time

- **Maritime partner's Hydrogen One slated for operation in 2024**
  - 98' fuel cell inland tow tug powered by methanol-to-hydrogen reformation
  - 2000 hp vessel capable of a two 30,000-bbl barge tow for 550 miles

- **Several global examples of ZEAT pusher tugs**
  - KOTUG international in the Netherlands has a line of battery electric
  - Robert Allan Ltd. designed two 67' battery diesel-electric shallow draft pushboats that are in service in Brazil

- **May be opportunities for ZEAT inland towboats in California**
  - Many of California's towboats are ocean going ATB

Green Diamond plug-in hybrid towboat

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ZEAT Pilot, Crew, Workboats

- **Several examples of ZEAT vessels in the U.S. and Globally**
  - Canaveral Pilots Association in Port Canaveral, Fla has partnered with naval architecture firm Glosten on pilot/demonstration project for the design, construction, and operation of an electric pilot boat
  - Damen Shipyards Group in the Netherlands developing 62’ electric workboat with 7.7-ton bollard pull with a top speed of 12 knots that can be used for a range activities
  - Maritime Green Horizon retrofitted a 39’ pilot vessel to all-electric operation with a top speed of 19 knots
  - Robert Allan Ldt. in Vancouver, Canada designed an all-electric pilot boat (RAlly 1600-E) aimed at service applications in which the run to the ship is 5 nautical miles or less

Damen designed all-electric workboat

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ZEAT Infrastructure

ZEAT Infrastructure

- **Buildout and availability of infrastructure to support ZEAT vessel charging and refueling will be critical to support the enhanced adoption of ZEAT vessels**
  - **Current lack of infrastructure may represent the single largest barrier to ZEAT expansion in California**

- **Electrical service and distribution requirements based on type and number of vessels, overall usage profiles, proximity to existing infrastructure, peak demands, overall usage profiles, etc.**

- **Large power requirements can stress existing grid infrastructure and incur high demand charges**
  - Vessels that require long-distance and/or high-speed operation may require DC fast chargers
  - Deployment of microgrids with distributed energy resources (e.g., solar PV, battery systems) can help manage (e.g., reduce peak demands, reduce energy costs, provide reliability and resiliency) but may be challenging due to space constraints

- **The footprint of charging and fueling infrastructure can be a major challenge at CHC docking locations including marinas, harbors, and seaports due to space constraints**

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Shoreside Charging

- **Many potential charging strategies for vessels, individual vessel requirements will dictate optimal choice**
    - **Alternating Current (AC) Charging**
        - Slower but reliable and cost-effective solution for charging electric boats at marinas or docking locations
    - **Direct Current (DC) High Power Charging**
        - Deliver large amounts of power quickly – e.g., ABB and Siemens systems
        - Current dockside infrastructure requires shore side battery ESS that is used a buffer and recharged with AC charging
    - **Automated Charging**
        - **Plug-In:** Robotic arms or automated connectors to connect into the vessel's charging port - e.g., ABB system used in European ferry projects
        - **Inductive Charging:** Charging pads are installed on the vessel and dock to transfer electricity wirelessly – e.g., Wartsilla has developed a system using this technology
    - **Other potential strategies include battery swapping systems and mobile charging units**

- **Multi-modal infrastructure are required for incentives funding program eligibility**
- **Standardization of equipment, policies, and standards related is also of major importance, particularly if publicly available or otherwise shared infrastructure becomes a reality**
    - Companies working on fast-charging systems using the CCS plug standard that is common in the automotive industry

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ZEAT Infrastructure

- **Electrical infrastructure upgrades that may be required**
  - Grid Capacity – service upgrades, transformer installation/upgrades, upgraded utility connections
  - Distribution – wiring and cabling, switchgear, panels circuit breakers
  - Site-specific Modifications – trenching and conduit installation to run new lines, upgrading or adding substations
  - Load management systems – energy storage systems, smart charging systems, power conditioning equipment
  - Regulatory – permitting, inspections, and environmental assessment

- **The Advanced Technology Demonstration and Pilot Projects Program includes funding for charging infrastructure for hybrid or full zero projects.**

- **Clean Off Road Equipment (CORE) voucher program includes funding if the project is for a full zero ZEAT vessel**

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ZEAT Infrastructure Development

- **Establishing effective charging and hydrogen fueling infrastructure will require many different considerations to ensure reliable, safe, and effective charging and fueling**

  - **Location:** Identify strategic locations for infrastructure based on the patterns of CHC travel, docking areas, operator needs, destination sites, proximity to existing infrastructure, number/type of floats, planned construction and terminal upgrades, etc.

  - **Grid Power:** Determine if existing electrical grid and infrastructure can support required power demands for both single charging and simultaneous charging of multiple vessels or battery systems

  - **Charging Rates/Times:** Select infrastructure that meets the requirements of operators including suitable charging speeds for various battery electric CHC use cases by assessing battery sizes and anticipated charging times

  - **Regulatory Compliance:** Comply with local regulations and permitting requirements

  - **Operational Protocols:** Adhere to safety regulations and standards for electrical installations and implement safety features, such as proper grounding, protective enclosures, and emergency shut-off systems.

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Hydrogen Challenges

- **Lack of hydrogen bunkering infrastructure**
  - Existing infrastructure for on-road vehicles in California
- **Stringent regulatory and safety requirements for current projects**
- **Lack of clarity regarding nature of hydrogen storage, delivery, dispensing**
  - Different pathways, e.g., Fossil vs. Renewable, pipeline vs. truck delivery
  - Gaseous vs. liquid hydrogen may be used in different scenarios
  - Potential applications for methanol or ammonia, etc.
- **Will require innovative solutions**
  - Mobile refuelers may offer advantages of flexibility, lower cost, and lack of need for dedicated workforce

Example: ZEI Hydrogen FT Case

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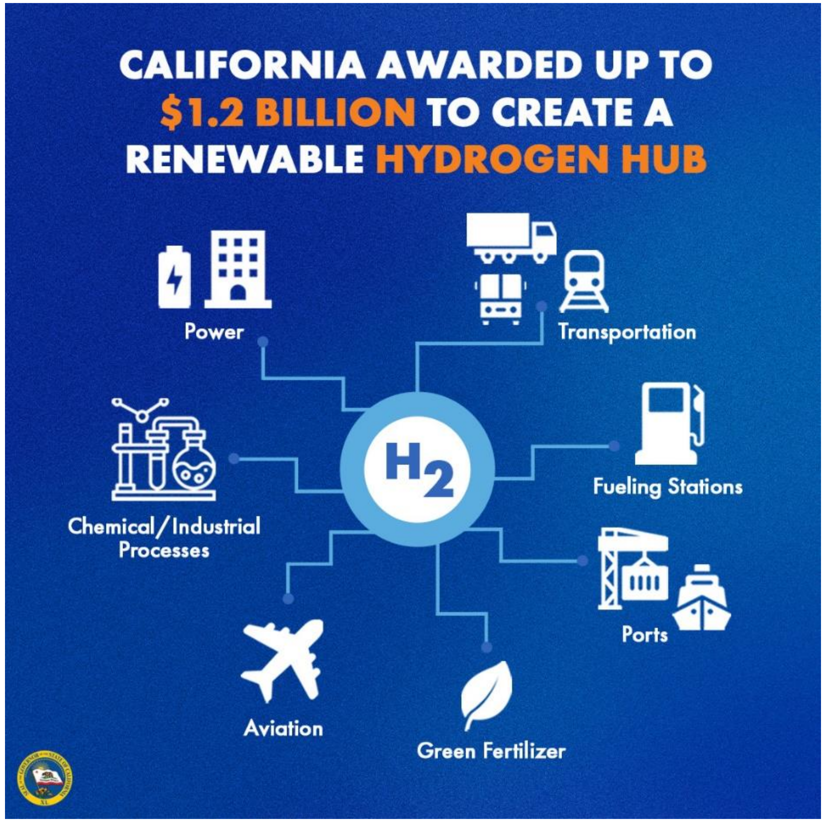
Hydrogen Challenges

- **Limited availability of low-cost, low carbon hydrogen**
  - 95% of current hydrogen production is from steam methane reformation of natural gas (U.S. Department of Energy)

- **Momentum in California to produce renewable, clean, cost-effective hydrogen for difficult to electrify sectors including maritime**
  - 2022 CARB Scoping Plan for Achieving Carbon Neutrality included large amounts of renewable H_2
  - Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES) California Hydrogen Hub received $1.2 billion in Federal funding
    - Planned projects at the Ports of LA, LB, and Oakland
  - Senate Bill (SB) 1075 – CARB, CEC, CPUC to produce a comprehensive report on the development, deployment, and use of hydrogen across all sectors to be posted by June 1, 2024



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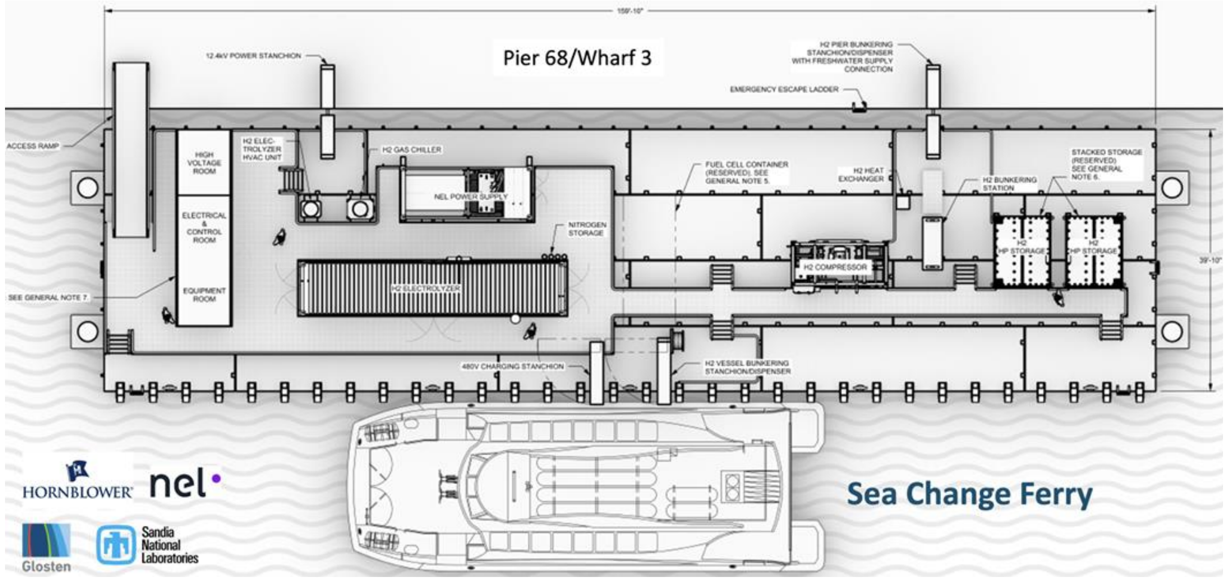
Waterfront Maritime Hydrogen Demonstration Project (DOE Funded)

- **Hornblower leading the design and construction of the first floating fueling H_2 station for commercial harbor craft**
  - Demonstrate bunkering of fuel-cell vessels with green H2, establishing a technical foundation for maritime H2 production, compression, storage and over-the-water fueling
  - 160’ barge at Pier 68/Wharf 3 that can produce 500 kpd of renewable hydrogen from renewable electrolysis
  - **<u>Project fate uncertain given Hornblower’s recent bankruptcy</u>**



Source: U.S. DOE

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Challenges for ZEAT Vessels

Challenges to ZEAT CHC

Regulatory Hurdles

- **Applicable Code of Federal Regulations design standards are stringent and in many cases are not established**
  - Battery standards are established by hydrogen is less advanced

- **U.S. Coast Guard is generally supportive of new technologies but must approve first-of-kind vessels and infrastructure on a case-by-case basis**
  - Currently a design review basis pathway
  - Likely that the process will become simpler and smoother as more experience is gained and protocols, education, training, and federal agency coordination develop

- **Establishment of policy letters can streamline the regulatory process**
  - Clarify requirements including clear, detailed guidance on regulatory requirements, standards, and procedures associated with vessel design, construction, and inspection
  - Consistency and predictability to reduce risk and increase vessel build efficiency with fewer barriers
  - Expediate the review process which reduces timelines and cost
  - Risk mitigation by identifying safety concerns and providing proactive guidance to mitigate them
  - Improved communication between designers, builders, regulators, and other stakeholders

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Challenges to ZEAT CHC

Technological Challenges

- **Marine environment is challenging for current fuel cell and battery technologies**
  - Energy density limitations of current batteries restrict use to certain CHC vocations
  - Environmental conditions are harsh, e.g., salt water environment
  - Performance – engines used heavily, working at 80-90% power, hard for fuel cells, pumps, blowers that have to be at or near capacity for sustained periods of time

- **Growing availability of commercial marinized technologies and vessel components**
  - Current systems and/or components may not be complete systems which can add significant additional engineering time and required equipment
  - Development of turnkey systems will support commercialization

- **Direction of ocean-going vessel technology evolution many dictate advancements in CHC**
  - More momentum for alternative fuel and infrastructure development, e.g., IMO Green Shipping Corridors
  - Availability of bunkering, technological advancements, etc. can make it easier for CHC to transition as well

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Challenges to ZEAT CHC

Stakeholder Engagement

- **Deploying ZEAT vessels and infrastructure requires extensive collaborations with numerous stakeholders potentially with competing priorities**
    - U.S. Coast Guard, Port Authorities, Regional and local governments, neighboring tenants

    - **Coordination should begin early and often with all stakeholders**
    - Close collaboration with the U.S. Coast Guard
    - Utilities generally get involved with projects during design and build phases, but it will be important to engage during the planning phase given the challenges and cost of delays

- **Workforce training will be needed**
    - Training captain and crew in how to operate a novel vessel structure
    - Engineer needs to be trained on the electronics side of the vessel, e.g., how the battery system works, safety features, etc.
    - Publishing training and operating manuals

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Conclusions

Conclusions

- **Potentially technologically feasible opportunities for converting some CHC vessels to ZEAT in California in the near- to mid-term**
  - Short run ferries, catamaran ferries with short- to medium- routes
  - Excursion vessels with amenable routes and turn around times
  - Line tender tugs (or similar), select ship assist tugs
  - Pilot, crew vessels, work boats with less rigorous routes and duty cycles
  - Small harbor dredges operating close to shore and with access to appropriate infrastructure
  - Some small or near-shore commercial fishing boats or commercial passenger fishing vessels that can handle vessel design and operational changes

- **Assessment of near-ZEAT and ZEAT deployment must be made on a per vessel and per operational location basis**
  - Requires thorough and detailed assessment of vessel design, duty cycle, activity patterns, safety requirements, workforce, maintenance, ….
  - **Must be evaluated around currently available or potentially feasible shoreside infrastructure scenarios**

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Conclusions

- **Designing, constructing, and operating ZEAT vessels are equivalently complex as designing, constructing, and operating required infrastructure**
  - Need to establish infrastructure to pave the way for more ZEAT vessels (i.e., chicken and the egg)

- **Generally, CHC owner and operators that were surveyed are aware of and seriously considering ZEAT**
  - Hesitancy due to concerns over the readiness of the vessels and infrastructure, high costs, and others

- **For many CHC vocations hybrid vessel technology will likely represent a more attractive option in the near- to mid-term until full zero emission systems progress and are proven**
  - Provides extended range and alleviates safety concerns regarding vessels losing power during operation
  - Successful demonstration of plug-in hybrid technology will increase confidence in full zero options

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Thank You