CALIFORNIA ENERGY COMMISSION

California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Blueprint for Implementation of Zero-Emission Ferry Infrastructure

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Prepared by: San Francisco Bay Area Water Emergency Transportation Authority

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PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued GFO-20-601 to fund the creation of planning "blueprints" that will identify actions and milestones needed for implementation of medium- and heavy-duty (MDHD) zero-emission vehicles (ZEVs) and the related electric charging and/or hydrogen refueling infrastructure. In response to GFO-20-601, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards April 8, 2021, and the agreement was executed as ARV-21-030 on September 9, 2021.

ABSTRACT

The San Francisco Bay Area Water Emergency Transportation Authority has long been a leader in sustainability, taking action beyond California's ambitious climate goals. It currently operates some of the cleanest ferries in the country, but these vessels still consume diesel fuel. To comply with new California Air Resources Board (CARB) regulations and continue to be a leader in the sector, WETA commissioned this Blueprint to transition their fleet of ferries to zero-emission vessels.

This report outlines the approach and findings by the project team including an overview of the Blueprint goals, analyses conducted, and application of findings to develop a path for transition. Also identified are next steps, such as WETA's pursuit of Transit and Inter-City Rail Planning and Federal Transit Administration grants to execute on the Blueprint.

Keywords: Zero Emission Transportation, Electrification, Maritime, Transportation Planning, Grid Infrastructure Upgrades, Greenhouse Gas Reduction

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EXECUTIVE SUMMARY

The San Francisco Bay Area Water Emergency Transportation Authority has long been a leader in sustainability, taking action beyond California's ambitious climate goals. It currently operates some of the cleanest ferries in the country, but these vessels still consume diesel fuel. To comply with new California Air Resources Board (CARB) regulations and continue to be a leader in the sector, this Blueprint was commissioned to transition ferries to zero-emission vessels. The Blueprint is funded by the California Energy Commission (CEC) and authored by Arup and Aurora Marine Design.

The Blueprint explored the opportunities and challenges with transitioning the San Francisco Bay Area Water Emergency Transportation Authority's fleet of ferries to zero-emission, which included an assessment of currently available technology, engagement with key stakeholders, evaluation of distribution grid upgrades, and associated costs. The project team developed optimal ferry routes to estimate peak energy demands and identified the impacts of interconnecting battery energy storage systems to the ferry terminals to manage grid capacity constraints. This information was used to develop a planned phasing timeline for transitioning ferries over the next 5, 10, and 15+ years. Findings from preliminary analyses were also used to facilitate conversations with stakeholders and iterate on the optimal solution for each terminal. Data gathered from stakeholders was then utilized to confirm the feasibility of electrical service at critical terminals and inform cost projections.

A multi-phase approach starting in 2024 will enable the San Francisco Bay Area Water Emergency Transportation Authority to establish actionable milestones to convert their fleet to electric vessels. Extensive engagement with utilities, port operators, and other utilities informed the milestones. These discussions will be ongoing as the Blueprint is implemented to best coordinate electrical service requests and opportunities for shared infrastructure surrounding the terminals.

CHAPTER 1: Overview of Implementation of Zero-Emission Ferry Infrastructure

Project Overview:

The San Francisco Bay Area Water Emergency Transportation Authority (WETA) operates 11 terminals and 15 high-speed ferry vessels throughout the San Francisco Bay. Despite their vessels operating as some of the cleanest in the nation, they still utilize diesel technology and emit greenhouse gases. WETA is striving to support the ambitious goals set by California's leaders for reducing harmful emissions and decreasing the climate impacts of transportation. Implementing zero-emission technology is the next logical step for WETA to help California meet the GHG reduction goals outlined in AB 32, which establishes a goal to reduce greenhouse gases (GHGs) to 40 percent below 1990 levels by 2030.

Zero-emission technology does not currently exist for high-speed, high-capacity ferries. The first all-electric vessels in the world entered service less than five years ago. All the electric vessels built to date are low speed (less than 12 knots) with limited range (short trip applications only). Currently, there are no all-electric vessels that can meet the demands required for high-speed commute service. Significant obstacles exist including:

- Speed fast enough to meet the schedules for commute ferry service.
- Batteries that are light enough and powerful enough to power the vessel at high speed (even for short distances).
- Charging infrastructure sufficient to re-charge batteries during short unloading and loading periods.
- Lack of sufficient power capacity at terminal locations.

This Blueprint developed a plan of action and milestones for implementation of zero-emission energy infrastructure to support the transition of WETA's fleet of high-speed ferries to zero-emission electric propulsion systems with an emphasis on resolving the technical and regulatory barriers for the shoreside infrastructure. The plan first targeted the proof of concept through representative existing and potential new service routes, reflecting both short- and medium-distance routes. The team then identified scalable and flexible recharging systems that can be applied across the WETA fleet and further to other ferry and harbor fleets.

The project team conducted research to summarize the state of electric passenger ferries, battery technology, and charging technology globally. This research led to discussions with original equipment manufacturers, including Spear, ABB, and Cavotec, to understand the implications of different technologies and identify the optimal solution at each terminal.

The team then assessed energy and power requirements of vessels within WETA's fleet by modeling electric versions of their vessels. These power requirements were used to inform terminal infrastructure requirements and facilitate conversations with stakeholders, such as the local utility and the port authority. Complete information on the project approach and analyses conducted can be found in CHAPTER 2: Approach to Ferry Electrification Feasibility Study.

Project Goals

The objectives of this Blueprint included building out a plan of action and milestones for implementation of zero-emission energy infrastructure to support the transition of the WETA ferry fleet to electric propulsion systems. The plan first targeted the proof of concept through representative existing and potential new service routes, reflecting both short- and medium-distance routes, to identify scalable and flexible recharging systems that can be applied across the WETA fleet.

Project achievement was documented by the published Blueprint, which describes an actionable, feasible plan, and identifies specific technical, regulatory, and other constraints to be resolved for enabling implementation. These constraints, such as lack of available land space or grid capacity, also hinder other similar initiatives. Measurable progress under this project is directly applicable to the ability to implement zero-emissions ferry technology and the success of its implementation. The foundational energy analysis will also support future work to expand to hydrogen fuel cell technology or methanol, where electrification may be less practicable or feasible.

CHAPTER 2: Approach to Ferry Electrification Feasibility Study

The project team approached the Scope of Work Tasks in three main implementation stages:

- **Stage 1 Baselining**: Collect and process data on operations, vessels, and terminals to define their constraints and opportunities.
- **Stage 2 Optioneering**: Develop solutions and assess their attributes and drawbacks to select optimal direction.
- **Stage 3 Blueprint & Strategy Development**: Lay out an actionable path to progress to procurement, design, and delivery of electrified ferry service.

The Zero Emission Study proceeded under two separate but parallel tracks across these stages (Figure 1: Aurora Marine Design & Arup Feasibility Study Execution Track). One track, led by Aurora Marine Design, focused on vessel-side requirements. This consisted of collecting data on existing routes and schedules, evaluating future vessel power needs, and impacts to WETA's workforce.

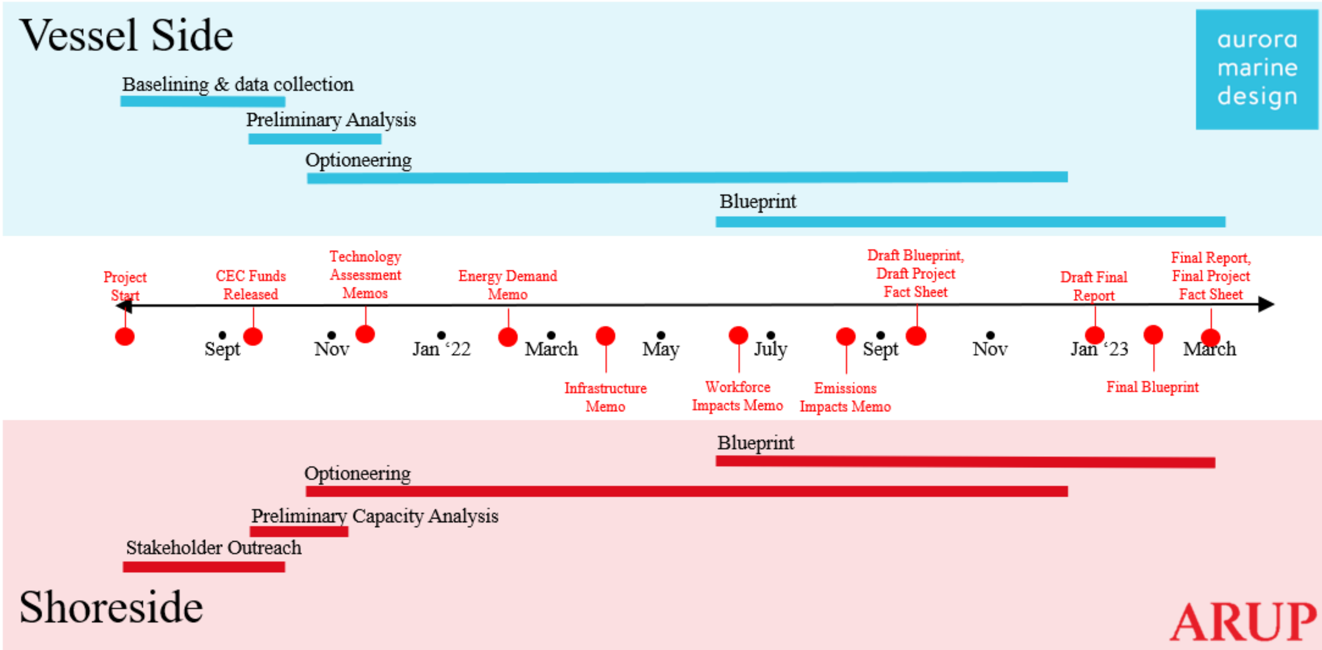
The other track focused on shoreside infrastructure and was led by Arup. Shoreside analyses included assessment of terminal peak demands, opportunities for interconnecting battery energy storage systems, and identification of optimal terminal electrical arrangements to ensure adequate power is provided to the ferries.

The separate work efforts intersected frequently throughout each stage to update and inform each team, ensuring consistency with assumptions, next steps, and conclusions. This included the following intersections of work efforts:

- Bi-weekly meetings between Aurora Marine Design, Arup, and WETA
- Bi-weekly meetings between Arup, WETA, Port of San Francisco, San Francisco Public Utility Commission
- Terminal site-walks with Arup, WETA, Port of San Francisco
- Infrequent meetings between Alameda Municipal Power, Arup, and WETA

Both tracks eventually led to the development of the full Blueprint for transitioning to zero-emission vessels.

Figure 1: Aurora Marine Design & Arup Feasibility Study Execution Track



Source: Aurora Marine Design

Electric Vessel Phasing

The Blueprint proposed implementation of zero-emission vessels in four distinct phases. These phases were based on route length, ease to transition the vessels, and ease to provide adequate power to the terminals. The first phase consisted of the shortest routes and terminals that were in development, so they could more easily be upgraded to accommodate the power required for charging electric vessels. Phase 2 and Phase 3 are medium-length routes and are anticipated to have more extensive terminal upgrade requirements. The final phase is Phase 4, which consists of the longest ferry routes and will require innovative solutions or alternative fuels to transition to zero-emission. These phases are anticipated to begin in 2025 and continue beyond 2035.

Phase 1

The Phase 1 implementation is focused on two routes and three terminals: Downtown SF, Mission Bay, and Treasure Island. A new class of 149-passenger vessels is planned for the Mission Bay and Treasure Island Routes. The initial rollout of vessels will include a minimum of three (3) vessels, with the possibility of a fourth vessel.

Phase 2

The phase 2 routes include two vessel sizes: 400-passenger vessels, which will service Seaplane, Oakland, Main St. Alameda, and 250-passenger vessels for service to Berkeley. The initial roll out of Phase 2 terminals will be accomplished with a combination of new vessels and vessel repower (conversion of existing diesel vessels to battery electric).

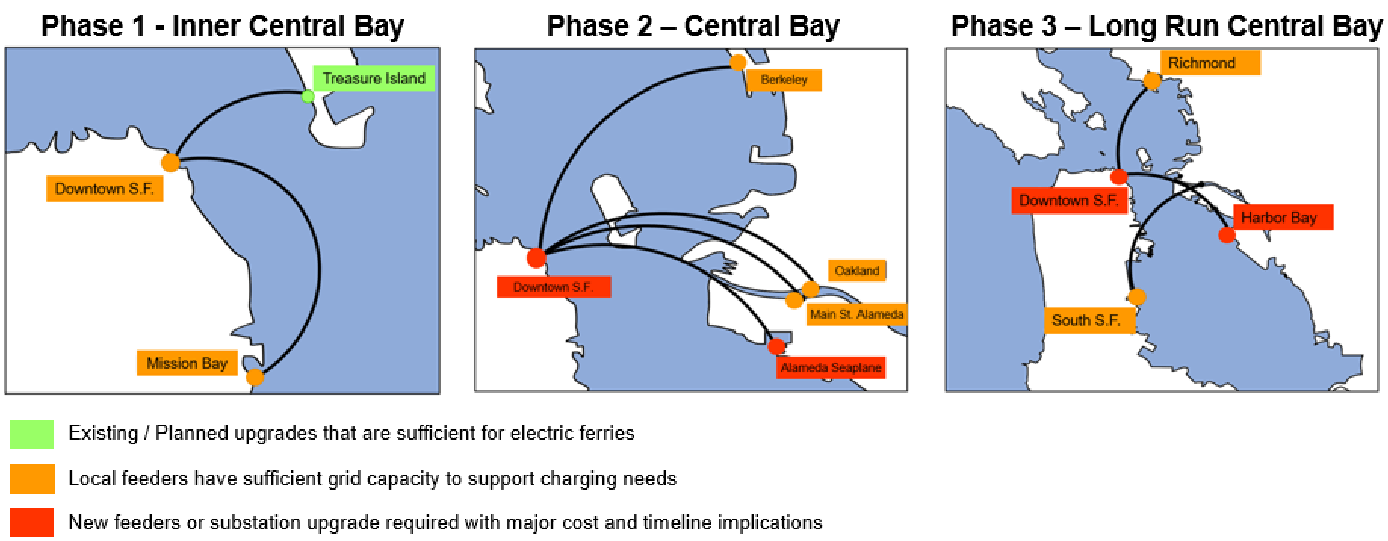
Phase 3

The terminals in Phase 3 include Richmond, Harbor Bay, and South SF. The first electric vessels docking at these terminals is expected to be implemented by 2026. The ferry routes between these terminals are longer than phase 1 and phase 2 routes and will therefore require more power. The project team's route analysis indicated that with current vessel technology, Phase 3 is feasible with battery electric technology. However, the power and energy demands are greater due to the route distance, and operational changes will be required if the routes are converted to battery electric. Depending on the success of implementation or Phase 1 & 2, and the progression of alternative fuels in the next decade, Phase 3 may be a good candidate for other zero-emission technologies.

Phase 4

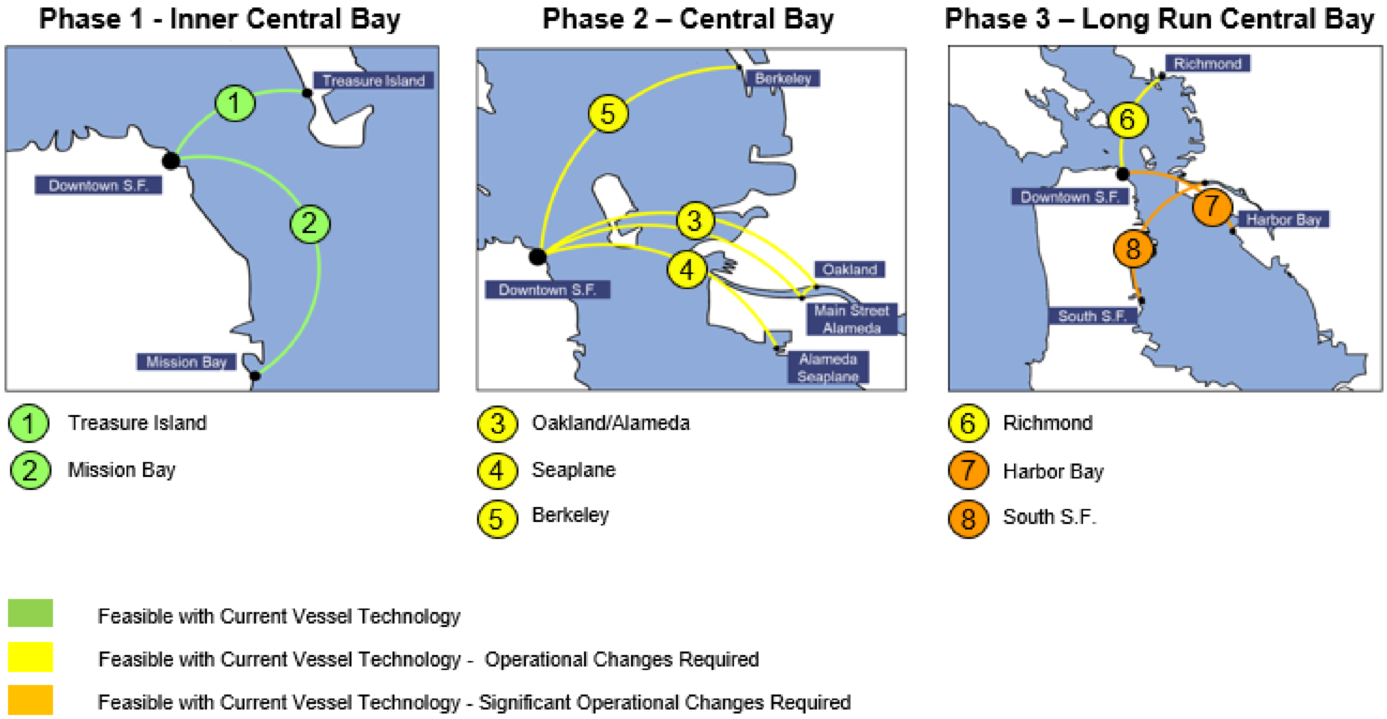
Phase 4 includes Vallejo, Carquinez, and Redwood City routes and because it is not considered feasible with current battery electric technology, these terminals were not evaluated for electric vessel charging in this study. To maintain the level of service required for phase 4 routes, the energy density of fuel required is substantially higher than battery technology can support. For zero-emission operation of the Phase 4 routes, alternative fuels or other future technology must be considered. Because the fourth phase is currently considered infeasible for electric vessels, it is not visualized in Figure 2 and Figure 3.

Figure 2: Shoreside Terminal Phases



Source: Aurora Marine Design/Arup

Figure 3: Vessel-Side Phases



Source: Aurora Marine Design

Stakeholder Engagement

An extensive stakeholder engagement process supported data collection and informed the feasibility of terminals supporting electric vessels. WETA's 11 existing and planned terminals span across seven cities, four counties, and three utility service territories (Table 1). Utility providers that the project team coordinated with were Alameda Municipal Power (AMP), San Francisco Public Utility Commission (SFPUC), and Pacific Gas and Electric (PG&E).

The stakeholder engagement was an iterative process that consisted of research on existing conditions and planned impacts of electrification, feedback collection from key personnel, data collection and analysis, project planning, and coordination across agencies.

Table 1: WETA Terminals & Stakeholders

Terminal	Municipality	Utility Provider	Engagement Details
Downtown San Francisco	San Francisco	SFPUC	• Engaged with SFPUC at the onset of the project. • Held biweekly discussions with SFPUC, the Port of San Francisco, Arup, and WETA which started in April 2022 and continued through January 2023.

Terminal	Municipality	Utility Provider	Engagement Details
Mission Bay	San Francisco	SFPUC	• Collected data on existing infrastructure, competing service needs, and feasibility of proposed solutions. • Arup supported WETA and the Port of San Francisco in submitting service applications to SFPUC.
Treasure Island	San Francisco	SFPUC	• Engaged with SFPUC at the onset of the project. • Held infrequent meetings with SFPUC, Treasure Island Mobility Management Agency, Treasure Island Development Group, WETA, and Arup to assesses feasibility of adding electrical infrastructure to meet power requirements.
Alameda Seaplane	Alameda	AMP	• Engaged with Alameda Municipal Power at the onset of the project. • Held infrequent meetings with AMP, WETA, and Arup to collect data on grid capacity, existing infrastructure, and terminal electrical infrastructure upgrade requirements. • Arup supported WETA in submitting service application requests to AMP and received cost estimates from AMP engineers.
Main Street Alameda	Alameda	AMP	
Harbor Bay	Alameda	AMP	
Central Bay	Alameda	AMP	
Oakland	Oakland	PG&E	• WETA and Arup have notified PG&E of the project. • WETA will need to submit service application requests to PG&E, at which point a PG&E representative will be assigned to the project and engagement will move forward.
Richmond	Richmond	PG&E	

Terminal	Municipality	Utility Provider	Engagement Details
Berkeley[1]	Berkeley	PG&E	• WETA is anticipating submitting service application requests in 2023 for the Phase 2 terminals in PG&E territory.
South San Francisco	South San Francisco	PG&E	

Source: WETA

Technical Analyses

The baselining phase consisted of several technical analyses, such as a technology assessment, energy demand analysis and emissions reduction calculations. The project team researched currently available zero-emission vessel technology to establish typical vessel speed, charge power, and charge technology, which informed parameters for the energy demand analysis.

A complete list of technical analyses completed as part of each task are outlined below (Table 2). Additional information is also provided on select Tasks below, which had extensive technical analyses.

[1] The Berkeley terminal is not fully developed yet and still in the planning stage with WETA and the City of Berkeley.

Table 2: Technical Analyses for Each Project Task

Task	Technical Analyses
Task 2: Technology Assessment	• Assessment of available technology for charging, batteries, propulsion systems • Assessment of current and planned ferries with zero-emission trucks (ZET) and their specifications. • Determination of limitations of current technology
Task 3: Vessel Energy Demand Estimates	• Analysis of existing and future route throughput requirements • Analysis of existing and future vessel performance for each route • Analysis of vessel charging requirements at each terminal
Task 4: Terminal Infrastructure Requirements	• Terminal peak demand projections • Electrical infrastructure arrangement evaluations • Battery right-sizing analysis
Task 5: Workforce Development	• Assessment of current workforce capabilities • Identify new skills, training, and roles required for ZET equipment operations and maintenance
Task 6: Emission Reductions	• Greenhouse gas emissions reduction assessment • Impact to surrounding disadvantaged communities

Source: WETA

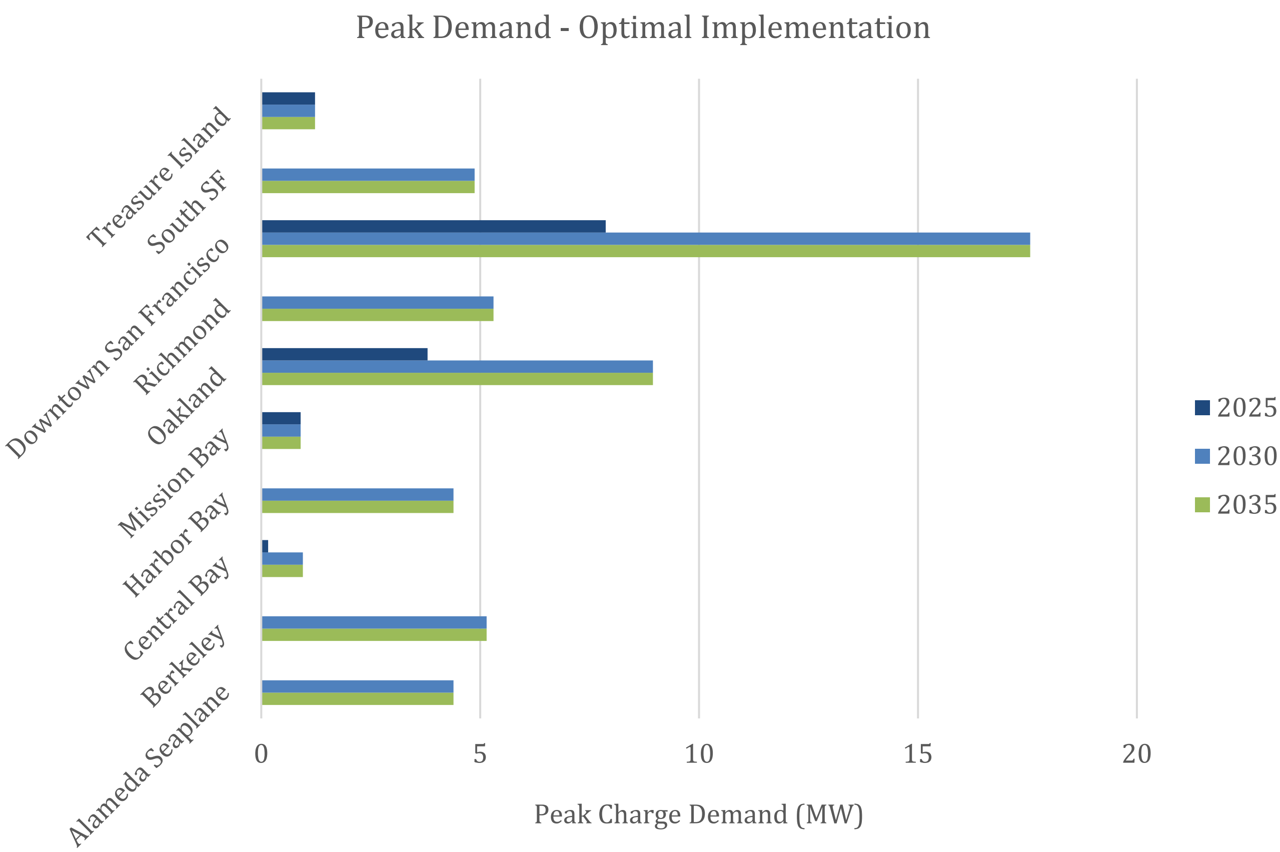
Task 3: Vessel Energy Demand

An understanding of both the vessel energy demands and route energy demands were essential to anticipating the level of service required for the shoreside charging infrastructure to accommodate electric vessels. The demand analysis shows that the phases of implementation have distinct magnitudes of charge power required and energy consumption per round trip:

- Phase 1 routes: with their shorter round-trip distances and smaller vessels, can be accomplished with charging equipment in the order of magnitude of 1 to 1.5 MW.
- Phase 2 routes: can generally be accomplished with 4 MW of charging without service changes.
- Phase 3 routes: can generally be accomplished with 5 MW of charging without service changes.

The projected peak demand for a fully electric fleet of ferries was determined and utilized in conversations with stakeholders to assess the optimal shoreside electrical arrangements (Figure 4: Anticipated Terminal Peak Demand).

Figure 4: Anticipated Terminal Peak Demand



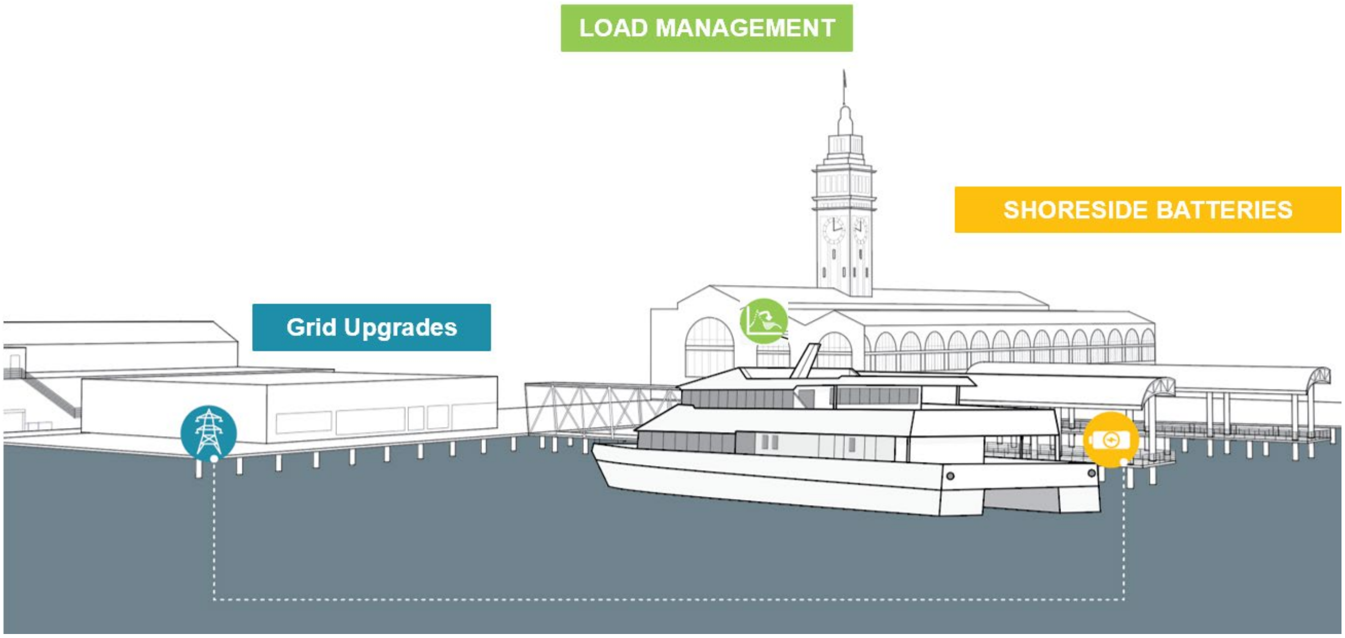
Source: WETA

Task 4: Terminal Infrastructure Requirements

Terminal infrastructure requirements were informed based on the projected peak demands at each terminal. The project team focused on the first phase of terminals for transition and set up bi-weekly meetings with SFPUC and other stakeholders (Table 1: WETA Terminals & Stakeholders) to understand the electrical infrastructure upgrade requirements at Downtown S.F., Mission Bay, and Treasure Island. For terminals in AMP's service territory, Arup set up ad hoc meetings with AMP engineers to evaluate terminal infrastructure requirements. Terminals in PG&E territories were informed based on available data, WETA's service operations, and representative terminals in other service territories. The project team will continue refining the requirements at each terminal as new information is made available and the Blueprint is executed on.

The project team conducted scenario modeling for the Downtown SF terminal because it had the greatest projected demand and presented the most challenges with accommodating the power requirements. Two significant constraints were identified for scenario modeling: available grid capacity and land space. Uncertainty around grid capacity requires optimized, balanced solutions to mitigate grid capacity constraints. The key elements of the scenarios modeled were grid infrastructure upgrades, feasibility of battery energy storage systems, and load management through opportunistic charging (Figure 5).

Figure 5: Visualization of Scenario Modeling Elements

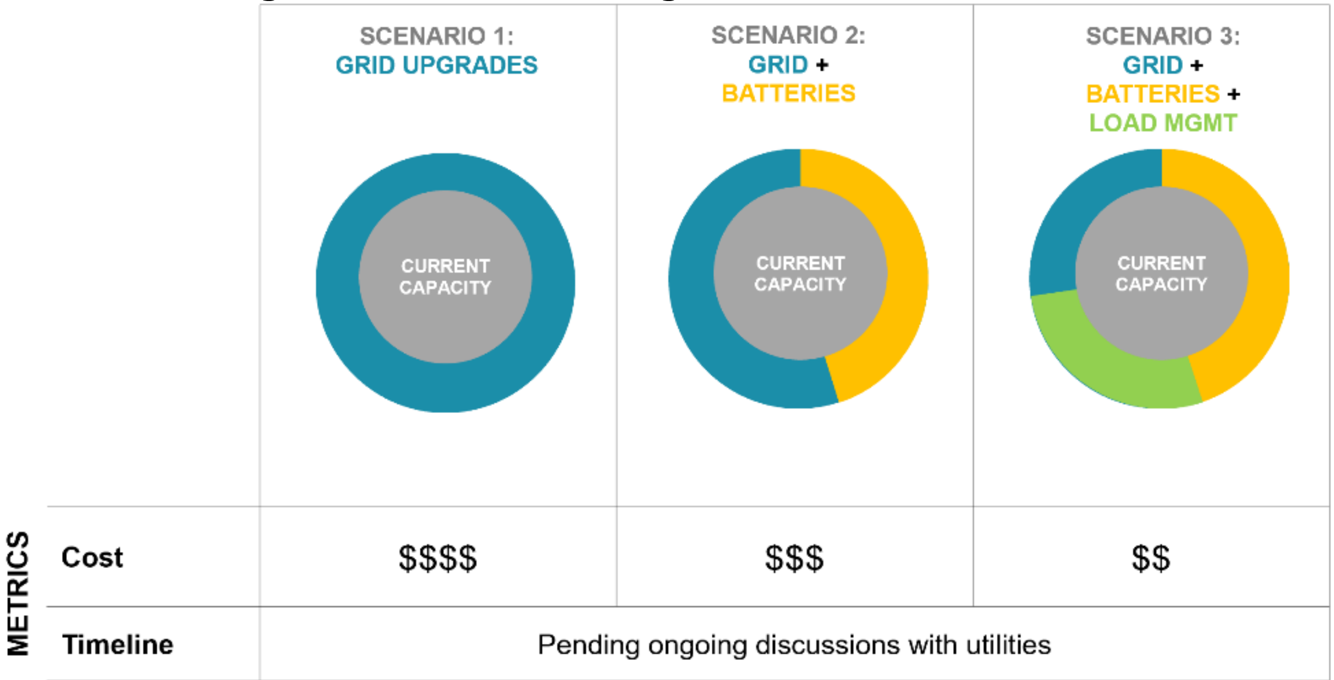


Source: Arup

Using Excel, the team modeled 4MWh batteries in each of the three floats at the Downtown S.F. terminal that accommodated schedules for two hours of the busiest rush-hour window to meet the needs of the worst-case scenario. The scenarios modeled had varying provision of power from the grid or the float battery to identify the optimal solution. The greatest challenge with these models were the strict schedules that vessel operate on. There are brief opportunities for the vessels to charge and they must have an adequate state of charge after to be able to successfully conduct their operations. Further, the model did not allow for concurrent charging, meaning one float could only charge one vessel at a time, even if there are two ferries berthed. This also meant that a battery could not charge concurrently with a ferry at a single float.

The project team manipulated charging scenarios and established a concept of a float battery charging system that can successfully be deployed at the Downtown S.F. terminal. In doing so, the float battery system would save the local utility grid an additional ~4MW of peak electrical demand, allowing that capacity to be distributed elsewhere and providing alternative opportunities to the Port of San Francisco. Solutions were tailored to each unique terminal given the variability of the constraints, stakeholder requirements, and associated timelines and costs with implementation (Figure 6). This proof of concept was only modeled for the Downtown SF terminal since it is the focal point of WETA’s services but can be replicated for other terminals.

Figure 6: Scenario Modeling Process & Considerations



Source: Arup

Task 5: Workforce Development

Ensuring that existing and new employees are adequately trained in the new equipment is critical to the success of the implementation of the zero-emission fleet transition. Changes to WETA's workforce with the introduction of ZET vessels were assessed by the project team. New workforce roles were identified that were considered necessary to the operations of the zero-emission ferries and charging infrastructure. For the existing workforce, the project team identified new training specific to the ZET technology that would build up WETA's current employees. Existing commissioning and new hire training protocols were modified based on the expected new ZET skills and safety training. Workforce-related risks were also identified, and appropriate risk mitigation strategies were proposed for the successful implementation of ZET technology.

Task 6: Greenhouse Gas Emissions Reduction

WETA already operates vessels that emit significantly fewer emissions than comparable marine services. The most recently developed ferries by WETA were the first passenger ferries to achieve the Environmental Protection Agency's Tier 4 emission standards. To date, the Authority has focused on the cleanest diesel fuel technology available, including the use of selective catalytic reduction to decrease the emission of nitrogen oxides generated by diesel engines. The project team conducted a greenhouse gas emissions reduction analysis to evaluate the emission reduced from transitioning a fleet of vessels from traditional diesel ferries to zero-emission ferries.

The project team collected publicly available data on utility emissions factors and their carbon-free electricity generation dates to calculate a linear reduction for grid emissions factors. For consistency with this analysis and because PG&E owns the distribution infrastructure in the San Francisco Bay Area, PG&E emissions factors were used for calculations. This assessment focused on two representative routes which were the Treasure Island and Oakland/Alameda routes.

CHAPTER 3: Findings & Results

Results

The project team identified two major challenges throughout the development of the Blueprint, one of the greatest being the management of analysis iterations given the variation in parameters. For example, the project team had to engage utilities to understand requirements and costs of grid upgrades but couldn't establish the exact grid connection required without determining how much charging could be feasible from other origin terminals. This created a 'Chicken and Egg' challenge.

To manage this, the project team engaged with stakeholders early and often through consistent meetings. Conservative estimates for the energy and peak power demands were utilized to facilitate discussions while the team continued to refine the analyses through route optimization and modeling of technology. This approach allowed for future value engineering and ensured that the proposed solution that will be advanced will have sufficient infrastructure.

The other major challenge was accommodating the space and grid constraints at the Downtown S.F. terminal. The team addressed this challenge by conducting site walks, gathering extensive data from SFPUC and the Port of San Francisco, and modeling a variety of solutions in Excel until the optimal outcome was identified. A conclusive recommendation for which scenario to implement at the Downtown S.F. is not within the scope of the Blueprint, and information provided may be subject to change as requirements and new information evolve over time. However, the Blueprint did highlight advantages and disadvantages to the various scenarios considering things like implementation timeline, costs, maintenance requirements, and feasibility of accommodating power needs.

The project team was able to successfully develop a Blueprint for converting WETA's ferry operations to zero-emission. Notable successes include:

- Identifying a clear timeline for implementing electric ferries, starting in 2025.
- Developing a successful proof-of-concept for including battery energy storage systems at the ferry terminals to reduce peak demands and meet the available grid capacity.
- Coordinating with utilities and stakeholders to ensure adequate power will be available at the terminals to support the fleet of electric ferries.
- Identifying grant funding to procure electric vessels and upgrade terminals.

Implementation of the Blueprint, however, requires ongoing planning and close coordination with stakeholders. The Blueprint provided a four-phased approach over the next 20+ years to transition WETA's fleet of vessels to zero-emission and were primarily determined based on route length and ease to transition. The first three phases will transition routes to electric vessel, whereas the fourth phase evaluated considers the potential of alternative zero-emission fuels, including hydrogen and methanol. This Blueprint will be a guide for WETA in their initial implementation of zero-emission vessels and will be updated as phases are executed.

Utilizing route and vessel data, the project team was able to develop operational profiles for the terminals (Figure 4). This data allowed the project team to identify terminal infrastructure upgrade requirements, potential electrical arrangements, and anticipated costs. These operational profiles project significant added demand to the local grid, including 17.5 MW of peak demand at the SF Terminal. Many of the local grids are already constrained and have other entities competing for additional service requests. A combination of battery energy storage systems, load management, and grid infrastructure upgrades can alleviate the anticipated peak demands at these terminals, but these solutions will need to be tailored to each unique terminal. Extensive input from stakeholders including the utilities, municipalities, and port operators will inform the best solution at each terminal and will be ongoing as WETA implements the Blueprint. A complete description of terminal analyses to date is detailed in *Blueprint for Zero Emission Vessel Transition*, sections 4, 5, and 6.

The transition to zero-emission vessels will also shift the needs within WETA's workforce to include roles focused on charging infrastructure maintenance and repair, and energy management. There is no expected change in the number of full-time employees with electric vessels vs. diesel vessels, but new workforce roles and training will be required. The zero-emission vessels' propulsion systems and shoreside infrastructure will require specific training to address the complexities and unique safety practices. In general, a greater importance will have to be placed on electrical system training, skills, and safety. While all current support staff are trained in electrical systems and power generation, new training will be required to ensure the baseline level of competency is adequate for the specific technologies implemented. A complete description of the training, workforce roles, and safety practices to date is detailed in Blueprint for Zero Emission Vessel Transition, section 11.2 Workforce Development.

Advancements in Science & Technology

The primary focus of the study is the implementation of battery-electric technology where the technology is feasible. Where feasible to use (i.e., shorter routes, with adequate charging capacity), battery electric is the most mature and most efficient technology. Based on the project team's analysis, medium-length routes are at the edge of what is feasible with current battery electric vessels, while long-length routes are not feasible. For these routes, other zero-emission fuels may be considered as an alternative to battery electric vessels, depending on the technological progress and the costs compared to electrifying the routes. Other zero-emission alternative fuel (non-battery electric) technologies considered focus on liquid hydrogen and methanol.

While battery-electric zero emissions technology is relatively developed in the marine space, hydrogen and methanol are both in much earlier phases of development. Several of the issues that make battery-electric vessels difficult to implement on the medium-length and long-length routes are still difficult to overcome with these alternative fuels. Because of the level investment in hydrogen and methanol fuels, feasibility is expected to improve over time. At the same time, battery-electric technology is expected to improve, which has the potential to improve its feasibility in medium-length routes. As a result, the exact technology mix that could be used for medium-length and long-length routes is still not determined.

There are several challenges related to the use of hydrogen (with currently available technology) that make battery-electric vessels more favorable where battery-electric is feasible. As noted, several of these challenges are expected to be improved over time with more development:

- Overall energy efficiency of hydrogen as a fuel system is much lower than battery electric.
- Cost of green hydrogen as a fuel is substantially higher than diesel.
- Availability of green hydrogen and access to fueling locations are currently limited.
- Marine training in hydrogen safety is currently limited.
- Energy density of hydrogen, while better than battery-electric, is still substantially lower than for diesel. As a result, hydrogen vessels are still range and power restricted when compared to diesel.
- The volume required for hydrogen storage is a challenge for small ferries. In current pilot projects, the hydrogen is stored on the passenger deck (reducing passenger capacity) or on the roof.
- The weight, size, and complexity of current hydrogen fuel cells is a challenge for small ferries. In current pilot projects, fuel cells are on main deck, reducing passenger capacity.

Green methanol is in an earlier stage of development than hydrogen but is considered particularly attractive for future use in the marine industry because it has fewer integration challenges than hydrogen. Methanol turns to liquid at room temperature (unlike hydrogen), making it easier to store and transport on land, and easier to fit in the space constraints of vessels. Additionally, methanol has the potential to be used in combustion engines or fuel cells; this gives it the potential to be more adaptable to the constraints of a wider variety of vessels.

CHAPTER 4: Recommendations on Future Projects

Next Steps

WETA anticipates implementing the first electric vessel in 2024 and will continue converting their fleet to zero-emission vessels beyond 2035. This implementation will require frequent coordination with stakeholders to find the optimal solution for transitioning vessels and ensuring adequate power is available at the terminals. This coordination is not unique to ferry transition, but a practice in which all fleet operators will have to engage as more fleets electrify. Further, the constraints evaluated are potential concerns across sectors as policy shifts are requiring more entities to shift to zero-emission operations.

Replacing or reducing the use of fossil fuels along working waterfronts will require a substantial increase of electrical capacity, alternative fuel storage and fueling infrastructure, and operational changes to utilize these resources. Collaboration with stakeholders indicated that significant infrastructure improvements are required at all working waterfronts (ports, docks, piers) if ZET adoption is to be feasible for marine vessels. This is particularly evident in Downtown San Francisco, where several vessel operators' infrastructure necessitates improvements along a short section of waterfront. A holistic assessment of waterfront infrastructure in several locations, which includes multiple power users and shared resources, will improve the implementation of infrastructure improvements.

WETA has already moved forward with implementing the first phase of the Blueprint and has pursued grant funding through Transit Inter-City Rail Planning and Federal Transit Administration grants. These funds will enable WETA to procure electric vessels, conduct engineering work for shoreside infrastructure development, continue coordination with utilities, and design and install charging equipment. WETA is continuing to pursue funding to support future projects to support their emissions reduction goals.

As a recommendation for improving the CEC's Fuels and Transportation Division project management process, the project team suggests publicly disseminating the Blueprints developed by each agency. Access to the information in other Blueprints, technology evaluations, and innovative solutions could expedite California's transition to a zero-emission transportation future.

GLOSSARY

ALTERNATING CURRENT (AC)—Flow of electricity that constantly changes direction between positive and negative sides. Almost all power produced by electric utilities in the United States moves in current that shifts direction at a rate of 60 times per second.

BATTERY - A device that stores energy and produces electric current by chemical action.

CALIFORNIA AIR RESOURCES BOARD (ARB) -- The "clean air agency" in the government of California, whose main goals include attaining and maintaining healthy air quality; protecting the public from exposure to toxic air contaminants; and providing innovative approaches for complying with air pollution rules and regulations.

CALIFORNIA ENERGY COMMISSION - The state's primary energy policy and planning agency. The agency was established by the California Legislature through the Warren-Alquist Act in 1974. It has seven core responsibilities:

- Developing renewable energy
- Transforming transportation
- Increasing energy efficiency
- Investing in energy innovation
- Advancing state energy policy
- Certifying thermal power plants
- Preparing for energy emergencies

DEMAND - The rate at which energy is delivered to loads and scheduling points by generation, transmission, or distribution facilities.

DIRECT CURRENT (DC)—A charge of electricity that flows in one direction and is the type of power that comes from a battery.

DISTRIBUTED ENERGY RESOURCES - Small-scale power generation technologies (typically in the range of 3 to 10,000 kilowatts) located close to where electricity is used (for example, a home or business) to provide an alternative to or an enhancement of the traditional electric power system.

EMISSION FACTOR -- For stationary sources, the relationship between the amount of pollution produced and the amount of raw material processed or burned. For mobile sources, the relationship between the amount of pollution produced and the number of vehicle miles traveled. By using the emission factor of a pollutant and specific data regarding quantities of materials used by a given source, it is possible to compute emissions for the source. This approach is used in preparing an emissions inventory.

GREENHOUSE GAS -- Any gas that absorbs infra-red radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), halogenated fluorocarbons (HCFCs), ozone (O3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs). (EPA)

PACIFIC GAS AND ELECTRIC COMPANY (PG&E) -- An electric and natural gas utility serving the central and northern California region.

SAN FRANCISCO BAY AREA WATER EMERGENCY TRANSPORTATION AUTHORITY (WETA) – The San Francisco Bay Area Water Emergency Transportation Authority (WETA) is a regional public transit agency tasked with operating and expanding ferry service on the San Francisco Bay and with coordinating the water transit response to regional emergencies.

SAN FRANCISCO PUBLIC UTILITIES COMMISSION (SFPUC) – The San Francisco Public Utilities Commission provides retail drinking water & wastewater services to the City of San Francisco, wholesale water to three Bay Area counties, green hydroelectric & solar power to Hetch Hetchy electricity customers, and power to the residents & businesses of San Francisco through the CleanPowerSF program.