Water Emergency Transportation Authority

Blueprint for Zero Emission Vessel Transition

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aurora marine design

WETA

ARUP

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Table of Acronyms

AMD	Aurora Marine Design
AMP	Alameda Municipal Power
BESS	Battery Energy Storage System
CARB	California Air Resource Board
CEC	California Energy Commission
DPF	Diesel Particulate Filter
DPM	Diesel Particulate Matter
EPA	Environmental Protection Agency
GHG	Greenhouse Gas Emissions
IMO	International Maritime Organization
NMC	Nickel Manganese Cobalt
PG&E	Pacific Gas and Electric
PM	Particulate Matter
PV	Photovoltaics
SFPUC	San Francisco Public Utility Commission
TIDG	Treasure Island Development Group
TIMMA	Treasure Island Mobility Management Agency
WETA	Water Emergency Transportation Authority
ZEAT	Zero Emissions and Advanced Technologies
ZEV	Zero Emission Vessel

1. Executive Summary

San Francisco Bay's Water Emergency Transportation Authority (WETA) has long been a leader in sustainability, taking action beyond California's ambitious climate goals. WETA 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 (ZEV). The Blueprint is funded through California Energy Commission (CEC) grants and authored by Arup and Aurora Marine Design (AMD).

The Blueprint explored the opportunities and challenges with transitioning WETA'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 WETA's fleet 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.

Phasing is planned to start as early as 2024 and continue beyond 2035. The short- to medium-length routes make up the first three phases of the transition and will be converted to electric vessels. Despite observed grid capacity constraints, the Blueprint provides greater confidence that a properly sized electrical service connection and distribution to support ZEV ferry charging is possible, even at the Downtown S.F. terminal, where peak demand loads are the highest. Extensive engagement with utilities, port operators, and other utilities will be ongoing as WETA implements the Blueprint to best coordinate electrical service requests and opportunities for shared infrastructure surrounding the terminals.

The fourth phase consists of the longest routes in WETA service which are currently considered infeasible for electric vessels. While the focus of the Blueprint is battery electric vessels, alternative fuels were explored for longer routes, including hydrogen and methanol.

2. Background

The Water Emergency Transportation Authority (WETA) currently operates six ferry routes and in 2019 served over 3 million passengers throughout the San Francisco Bay. As a leader in sustainable practices, WETA leverages every opportunity to reduce ferry-related emissions. Notably, WETA's latest additions to their fleet carry the distinction of being the first passenger ferries to achieve the Environmental Protection Agency's Tier 4 emission standards [1]. The Authority has also 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. Notwithstanding WETA's current decarbonization efforts, it is clear that a comprehensive approach to the successful implementation of Zero Emission Vessels will need to incorporate electrical charging across the fleet.

As a demonstrated leader in sustainable operations, WETA pursued grant funding through the California Energy Commission (CEC) and partnered with Arup and Aurora Marine Design (AMD) to develop a Zero Emission Vessel Feasibility Blueprint. This Blueprint provides a roadmap for WETA to transition their fleet of high-speed ferries to zero emission. Important factors considered include vessel technologies, terminal infrastructure requirements, key stakeholders, timelines, and costs.

2.1. Regulatory Requirements

The impact of maritime emissions is well established, and regulatory agencies are implementing increasingly strict policies on ferry operations. The Fourth International Maritime Organization (IMO) greenhouse gas (GHG) emissions report from 2020 reported that maritime operations accounted for nearly 3% of global anthropogenic CO2 emissions. [2] Commercial harbor craft in particular produces significant air pollutants including diesel particulate matter (DPM), fine particulate matter (PM 2.5), nitrogen oxides (NOx), sulfur oxides (SOx), and greenhouse gases (GHG).

To address emissions in the maritime sector, the California Air Resources Board (CARB) adopted the Commercial Harbor Craft Regulation in 2008, which was further amended in March 2022. The newest amendments push for vessels to be compliant with the Environmental Protection Agency's (EPA) Tier 4 standards—which have the cleanest combustion engines—and equipped with diesel particulate filters (DPF). To further phase out diesel propulsion systems in favor of Zero Emissions and Advanced Technologies (ZEAT), such as electric vessel or hydrogen fuel technology options, CARB also mandates that all short run ferry vessels be completely zero-emission by the end of 2025 [3]. This mandate includes both new and existing vessels. None of WETA's existing operational routes are considered short run ferries, but the planned Treasure Island and Mission Bay routes will service shorter routes and will be required to be zero-emission.

Short run ferries will also be required to have DBF on all new ferries as of this year (i.e., 2023) and existing ferries will need to have fully adopted DPFs by 2029. DPF have been shown to be an effective technology for reducing emissions associated with diesel engines; however, there is additional weight, increased maintenance, and considerable space requirements. Given these constraints, it can be difficult for existing vessels to adopt DPF technologies. In the case of the WETA fleet, DPF systems were not commercially available when the vessels where built, which means that they are not designed to incorporate DPF systems. The potentially onerous additional requirements of DPF adoption further increases the attractiveness of ZEAT propulsion, especially for the refit of existing vessels.

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[1] *Regulations for Emissions from Heavy Equipment with Compression-Ignition (Diesel) Engines*

[2] https://www.imo.org/en/OurWork/Environment/Pages/GHG-Emissions.aspx

[3] "Short run ferries" are defined as vessels whose round-trip service is between two points less than 3 nautical miles apart.

2.2. Current Operations

As of November 2022, WETA operates 11 existing terminals and has four additional terminals planned for development (Figure 1: Map of WETA Operated Terminals Across the Bay). The focal point of the routes is the main Downtown San Francisco Terminal at the Ferry Building. The Downtown Terminal has 6 berths and 3 floats. Apart from the South San Francisco route, all ferry routes are served by the Downtown Terminal, making it critical to the transition of the fleet to zero emission vessels (ZEVs). The other terminals in operation generally cater to one route and include one or two berths.

Figure 1: Map of WETA Operated Terminals Across the Bay. Credit: WETA[4]

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[4] **Central Bay OMF**: Central Bay Maintenance Facility
San Francisco: Downtown S.F.

3. Electrifying the WETA Fleet: A Phased Approach

Terminals and Vessels have been categorized into four different phases based on their ease of transition to ZEV operations. The phasing is the same for terminals and vessels (Figure 2: Shoreside Terminal Phases, Figure 3: Vessel-Side Phases). The prioritization of implementation phases allowed the project team to efficiently calculate timelines, allocate resources, and focus on routes that could be upgraded in the near-term.

Ease of transition primarily considered route length and planned terminal construction as well as technology availability and electric ferry procurement timelines.

The first three phases are short- to medium-length routes and have been studied in detail within the Blueprint. Phase 4 consists of longer more energy intensive routes that were determined to not be feasible with existing technology. Phase 4 routes will require additional future planning and technology maturity to accommodate the larger power requirements (Blueprint Section 7 and 8 for Phase 4 additional discussion).

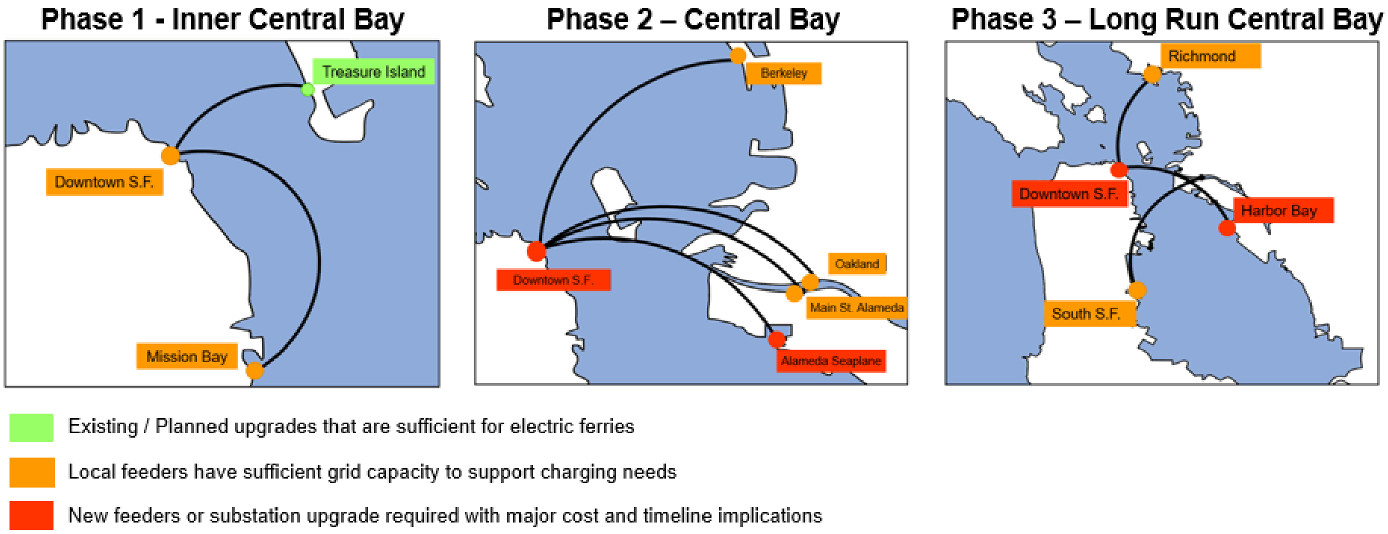
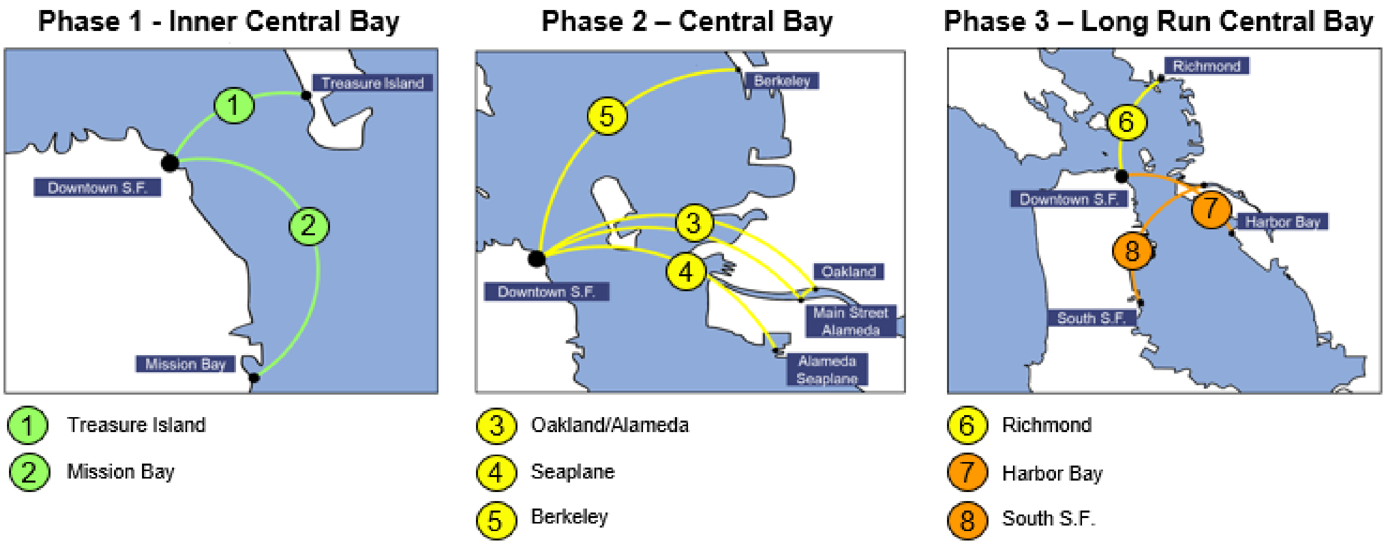


Figure 2: Shoreside Terminal Phases Credit: AMD/Arup



🟩 Feasible with Current Vessel Technology

🟨 Feasible with Current Vessel Technology - Operational Changes Required

🟧 Feasible with Current Vessel Technology - Significant Operational Changes Required

Figure 3: Vessel-Side Phases Credit: AMD

Route length, service frequency, layover time, speed of travel, and passenger capacity (weight) are all important to electrifying the ferry fleet because each impacts the vessel energy consumption and terminal charging needs. Managing these factors can reduce the size of the onboard vessel battery, float infrastructure, and shoreside energy infrastructure, but efforts to reduce energy needs can also negatively impact quality and cost effectiveness of service, requiring a balanced approach to transition.

Planned construction and terminal upgrades are also important considerations because infrastructure service is easier, and more cost effectively incorporated at the time of initial design and construction. Terminals that are planned to be newly created or significantly upgraded are more likely able to cost effectively incorporate fleet electrification upgrades.

Terminals with local land availability (e.g., parking areas) or reduced shoreside infrastructure congestion (above and below ground) may more easily incorporate service upgrades and localized distributed generation and storage (e.g., solar photovoltaics and battery storage).

Table 1, below, provides an overview of each terminal by phase, including critical characteristics to terminal electrification, such as terminal operating status, float type, land availability for PV + energy storage, and area congestion. Utility provider is also indicated, which includes either San Francisco Public Utility Commission (SFPUC), Alameda Municipal Power (AMP), or Pacific Gas & Electric (PG&E).

Land availability for PV + battery energy storage systems (BESS) is critical because these resources can alleviate peak demands and increase the feasibility of electrifying the fleet of ferries. Float type is also an important characteristic because many floats are made of steel and are hollow, presenting opportunities to house electrical equipment in the instance of landside congestion. These characteristics are further discussed in section 3.2, Electrification Infrastructure Requirements.

Table 1: Planned Ferry Electrification Phases and Corresponding Terminal Characteristics [5]

Proposed Ferry Electrification Transition Phase	Name	Terminal Operating Status	Utility Provider	Float Type	Land Availability for PV + Energy Storage	Infrastructure Congestion
1	Downtown S.F.	Operational	SFPUC	Steel	Highly Constrained	High
	Treasure Island	Planned 2024	SFPUC	Steel	Highly Constrained	Low
	Mission Bay	Planned 2025	SFPUC	Pending	Highly Constrained	Medium
	Central Bay	Operational for maintenance	AMP	N/A	Limited	Low
2	Oakland	Operational	PG&E	Steel	Available	Low
	Alameda Main Street	Refurbishment Due	AMP	Steel	Available	Medium
	Alameda Seaplane	Newly Operational	AMP	Steel	Available	High
3	Harbor Bay	Operational	AMP	Steel	Available	High
	Richmond	Newly Operational	PG&E	Concrete	Available	Medium
	South SF	Operational	PG&E	Concrete	Available	Medium
	Berkeley	Planned 2026	PG&E	Pending	Highly Constrained	Medium

3.1. Vessel Energy Demand

An understanding of the current and future anticipated level of service is required to estimate the size of the charging infrastructure for each terminal. This is an important consideration to allow WETA to transition the current fleet to battery-electric vessels and continue to expand service. Availability and incorporation of utility service into the shore-side infrastructure design can require significant lead times and benefit from shared infrastructure investments.

Existing and Future Fleet Overview

The WETA vessel fleet consists of vessels ranging from 225 passenger- to 445 passenger-capacity. The vessels fall into two categories: lower-speed vessels with propellers designed primarily for central bay service, and higher-speed vessels designed for north bay service. A summary of the principal particulars of the existing WETA fleet and concept vessels are shown in Table 2**.**

Table 2: WETA Existing Fleet Summary

Vessel	Vessel Class	Service Status	Length	Passenger Capacity	Installed Power	Propulsion	Service Speed
			m		*kW*		*kts*
Peralta	Peralta	In Service	37	331	2796	Propeller	25
Intintoli	Solano	In Service	41.3	349	5120	Waterjet	34
Mare Island	Solano	In Service	41.3	330	5120	Waterjet	34

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[5] Phase 4 terminals are not included in this table because electrification of those routes is currently not feasible. Consideration of alternative zero-emission fuels will be studied for those routes.

Vessel	Vessel Class	Service Status	Length *m*	Passenger Capacity	Installed Power *kW*	Propulsion	Service Speed *kts*
Gemini	Gemini	In Service	35.9	225	2100	Propeller	26
Pisces	Gemini	In Service	35.9	225	2100	Propeller	26
Taurus	Gemini	In Service	35.9	225	2100	Propeller	26
Scorpio	Gemini	In Service	35.9	225	2100	Propeller	26
Hydrus	Hydrus	In Service	41	400	2904	Propeller	27
Cetus	Hydrus	In Service	41	400	2904	Propeller	27
Argo	Hydrus	In Service	41	400	2904	Propeller	27
Carina	Hydrus	In Service	41	400	2904	Propeller	27
Pyxis	Pyxis Class	In Service	44	445	5120	Waterjet	34
Lyra	Pyxis Class	In Service	44	445	5120	Waterjet	34
Vela	Pyxis Class	In Service	44	445	5120	Waterjet	34
Dorado Class 1	Dorado	In Service	39.3	320	3840	Waterjet	32
Dorado Class 2	Dorado	Under Construction	39.3	320	3840	Waterjet	32
Dorado Class 3	Dorado	Under Construction	39.3	320	4264	Waterjet	32
Dorado Class 4	Dorado	Under Construction	39.3	320	4264	Waterjet	32
149E	New	Planned New Vessel	24	149	1000	Propeller	25
400E	New	Planned New Vessel	41	400	2500	Propeller	26

3.2. Route Energy Demand

Peak hourly energy demand assumptions for future growth were estimated based on operational data from the existing fleet. The performance data was also used to develop “electric” versions for the different existing vessel sizes. The performance curves (I.e., propulsive power requirements at a range of operating speeds) were then used to develop power demand metrics for the vessels. For the planned Treasure Island and Mission Bay service routes, 149-passenger concept vessels were developed to generate performance data.

For each route, a primary vessel class was allocated based on current and future operations. Power and energy requirements were determined utilizing a route analysis tool developed for the WETA fleet.

Assumptions

The following primary assumptions drive the energy demand analysis:

- All Phase 1, Phase 2, and Phase 3 routes are converted to 100% battery electric in the long term (I.e., after 2035).
- Each route experiences growth over the next 15 years, which is accomplished by increasing the number of vessels in service
- To the extent possible, service profiles for the WETA fleet are maintained (times at dock, round trip times, operating speeds) within reasonable operational thresholds
- Based on analysis of WETA's service, charging at each dock (opportunity charging) is optimal to minimize vessel battery size and maintain a similar level of service for all routes beyond Phase 1. Phase 1 routes will recharge once per round trip
- Phase 4 routes were not included in the energy demand analysis because they are not considered to be viable using battery-electric technology because of their route distance and speed. Improvements in battery and charging technology are not expected to sufficiently to overcome the operational requirements of the Phase 4 routes in the long term

Table 3: Energy Demand Analysis Assumptions**,** summarizes the general assumptions used in the route analysis to estimate energy usage.

Table 3: Energy Demand Analysis Assumptions

Parameter		Preliminary Assumptions
Vessel power		Full load performance curves for existing WETA vessels
House loads		Normal underway house loads estimated for each vessel
Power while docked		No propulsive power used while docked House loads included while docked
Battery electric propulsion efficiency- battery to propulsor		90%
Battery electric propulsion efficiency- shore to battery		90%
Time to connect charger		1 Min
Time to disconnect charger		1 Min
Maneuvering time required for docking/undocking	Docking	3 min for above 149 passengers (pax)
		2 min for below 149 pax
	Undocking	3 min for above 149 pax
		2 min for below 149 pax
Charging assumptions		Phase 1 routes- 1 charge per round trip Phase 2 routes- 2 charges per round trip

Route Analysis & Key Conclusions

The project team utilized a route analysis tool which included the performance particulars of each vessel and the parameters of each route—current and planned—for the WETA fleet. The tool allows for rapid output of vessel power and energy usage by changing parameters such as route speed, docked time, and charging time. Various outputs include energy usage, charging power, round trip time, and a load profile for the vessel that can be used to analyze battery degradation. Table 4: WETA Central Bay Route Energy Demands and Parameters, summarizes WETA's route-specific energy demands for the Phase 1 through Phase 3 routes.

Table 4: WETA Central Bay Route Energy Demands and Parameters

Route	**Vessel Size**	**Vessel Basis For Power Estimate**	**Round Trip Time**	**Round Trip Length**	**Service Speed**	**# Of Charge Locations**	**Energy Per Round Trip (Grid-side [6])**	**Charge Time Per Round Trip**	**Charge Power Required Per Vessel**
	Pax		*min*	*mi*	*kts*	*Per Round Trip*	*kwh*	*min*	*kW*
Treasure Island	149	149E	30	3.6	25	1	158	8	1229
Mission Bay	149	149E	35	4.9	25	1	185	11	1047
Oakland/ Alameda	400	Hydrus	80	13.0	26	2	1266	20	3798
Seaplane	400	Hydrus	60	11.2	26	2	1085	16	4069
Berkeley	250	Gemini	65	14.2	24	2	1171	16	4391
Richmond	250	Gemini	90	20.0	26	2	1625	20	4874
Harbor Bay	300	Dorado	70	16.8	26	2	1610	18	5367
South San Francisco	300	Dorado	120	27.2	26	2	2500	28	5357

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.

Phase 2 and 3 route power requirements are close enough to be serviced by the same charging systems, while Phase 1 routes can be serviced by smaller charging equipment. The provides WETA with the opportunity to standardize charging to a high degree. The final installed charge power at the terminals, as well as the time required to connect and disconnect the chargers, will influence the actual round-trip times that each service will be capable of. Charge power required for Richmond service, for example, can be reduced to 4 MW by increasing the charge time per round trip by 5 minutes (at the expense of 5 minutes of additional round-trip time). In the other direction, providing 5 MW of charging to the Oakland/Alameda service would reduce the required charge time by 5 minutes, which can provide additional operational buffer for the service. As mentioned in Section 2.5,

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[6] Grid-side energy requirements represent the anticipated power draws from the utility

automated charging systems with 4 MW charging capacity are available today and currently planned for charging of several ferries of similar size to WETA's.

To estimate terminal energy and power requirements at each terminal over time, an implementation schedule was developed with WETA input which incorporates the expected increase in level of service from WETA's service growth estimates, shown in Figure 4 and Figure 5. The implementation schedules are based on a more conservative fleet transition and an optimal fleet transition. The resulting full fleet build out resulted in the projected energy usage and charge demands at each terminal (Figure 6 and Figure 7).

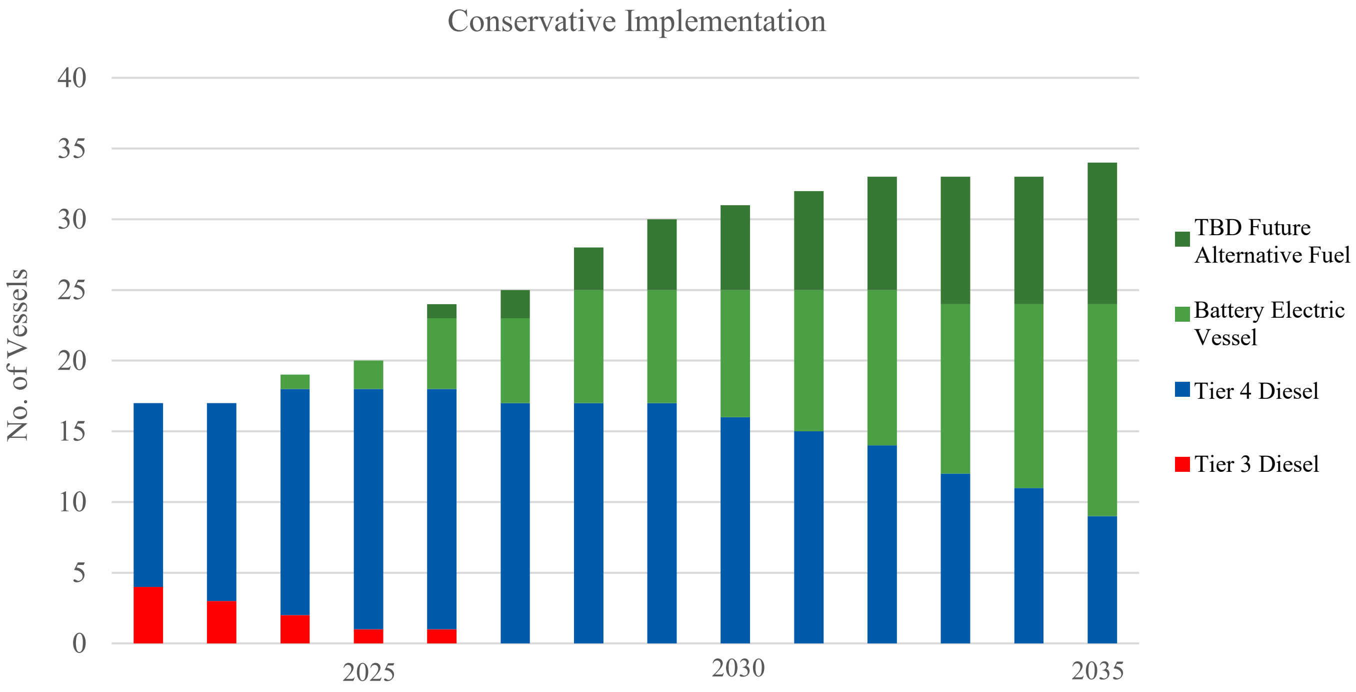

Figure 4: Conservative Timeline of WETA ZEV Implementation

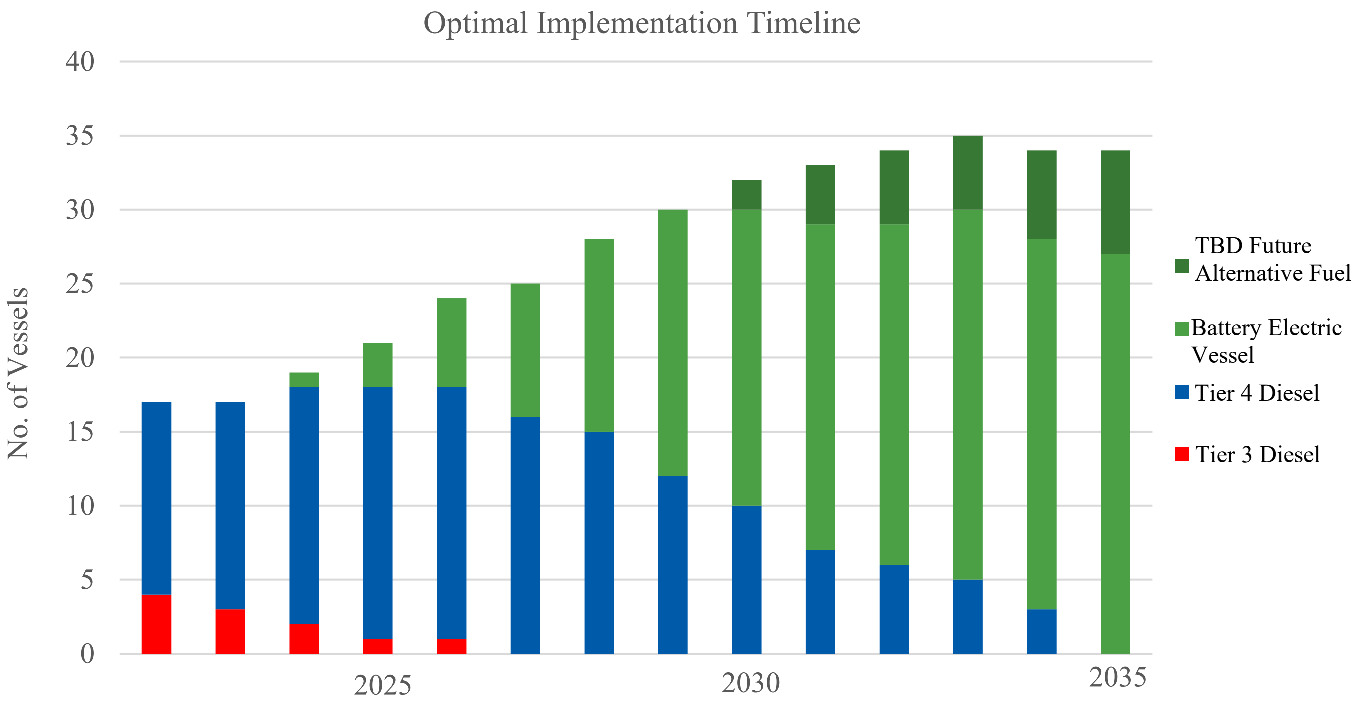

Figure 5: Optimal Timeline of WETA ZEV Implementation

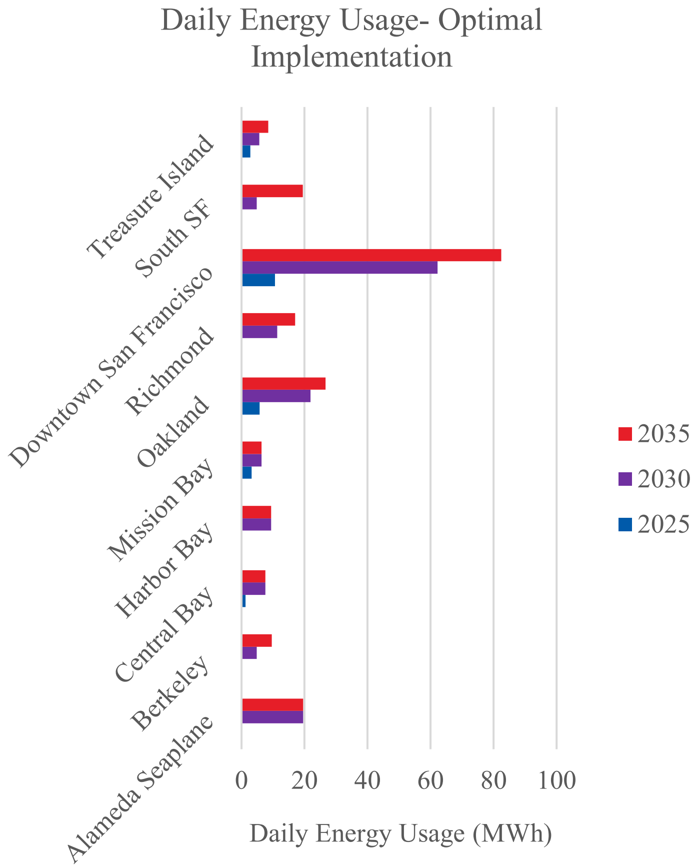

Figure 6: Daily Energy Usage at Each Terminal by Milestone Implementation Years

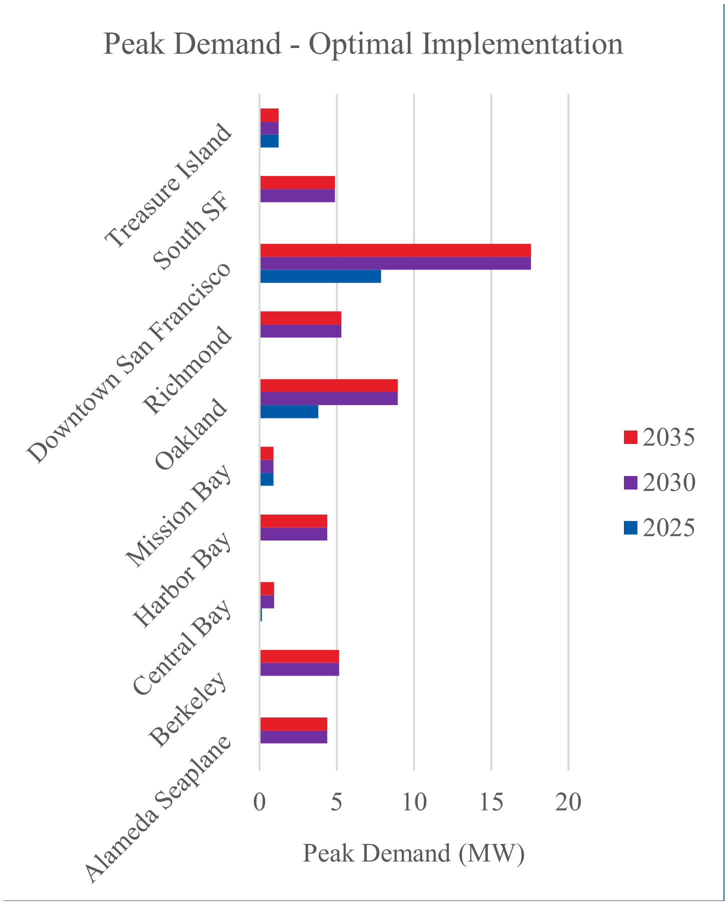

Figure 7: Peak Charge Demand at each Terminal at Milestone Implementation Years

3.3. Shoreside Electrification Infrastructure

The project team analyzed the existing terminals and future electrification requirements to evaluate electrical infrastructure arrangements. The primary considerations across all terminals are service voltage, available grid capacity, and feasibility of interconnecting distributed energy resources (DERs). Preliminary analyses have been conducted to assess opportunities for interconnecting DERs, including PV and BESS. DERs can be optimized to reduce peak demands, lower energy costs, and provide resilience to the terminals. However, many of the terminals are severely space constrained and cannot accommodate PV or BESS systems. Service voltage considerations and PV analyses are outlined below. A complete BESS analysis is provided in section 3.4 Terminal Energy Storage.

Terminal-specific infrastructure requirements and available grid capacity are described in greater detail in the phased terminal implementation sections.

Utility Service Voltage

For WETA to maintain quality of service and maximize the number of passenger journeys that it currently provides, fast refueling is necessary. This requires large amounts of power to be delivered to the vessel in short amounts of time, resulting in unique electrical demand profiles. To adequately support vessel electrification, the electrical infrastructure at the terminals must be upgraded. Electrical service and distribution requirements at terminals vary based on several factors, including number of floats, number of vessels charging concurrently, proximity to electrical infrastructure, overall energy usage profiles, and peak demand.

Arup considered three options for utility service to outline the optimal arrangement for WETA's terminals: low voltage, medium voltage, and direct current (DC). Table 6: Service Considerations and Limitations, outlines the opportunities and drawbacks to the three voltage options.

Table 5: Voltage Considerations and Limitations

Voltage Option	Opportunities	Drawbacks	Potential Power Limits
Low Voltage Site Distribution	• Easier maintenance • Lower cost equipment • Space efficiency of equipment	• Load limitations • Large feeder sizes	**Upper Limit - 4 MW –** Custom equipment or doubling of infrastructure needed after 4MW. Medium voltage should be the default beyond this size
Medium Voltage Site Distribution	• Supports larger loads • Smaller feeder sizes	• Requires Medium Voltage (MV) certification for O&M • On-shore DERs require step-up transformers • Higher cost equipment	**Lower Limit – 1 MW –** the increase in equipment and operational requirements outweigh the benefits of smaller power feeders. Lower voltage distribution would be the default below this power rating.
DC innovative connection	• Higher efficiency/less transformation losses • Less equipment	• Specialist skillset required for O&M • Equipment likely to be custom • Higher cost considerations	This technology is a custom solution and does not have the same known limits expressed as above.

Due to the customized nature of a DC solution, the project team focused on the low voltage and medium voltage service options. In general, the team recommends implementing low voltage service wherever the peak demand load allows, as equipment cost, and maintenance are cheaper. Medium voltage service is recommended for those sites with peak demand loads above 4MW, and/or sites with long distances or significant above ground feeder runs between the utility point of service and the floats/charging equipment. Site specifics such as utility availability, length of feeders, shared infrastructure, and whether PV or battery storage are being implemented will inform the ultimate selection of service type at each site.

Solar PV

Terminals with designated parking areas are the most feasible sites for adding PV, as canopy systems are common and cost effective. Sites with parking areas and land availability include Main St. Alameda, Alameda Seaplane, Harbor Bay, and Richmond. Estimated annual energy generation from PV is provided for future consideration (Figure 8) but it has not been factored into the terminal specific energy analyses in this report. Future power and infrastructure requirements for electric vehicles at terminal parking sites was also not considered as part of the Blueprint.

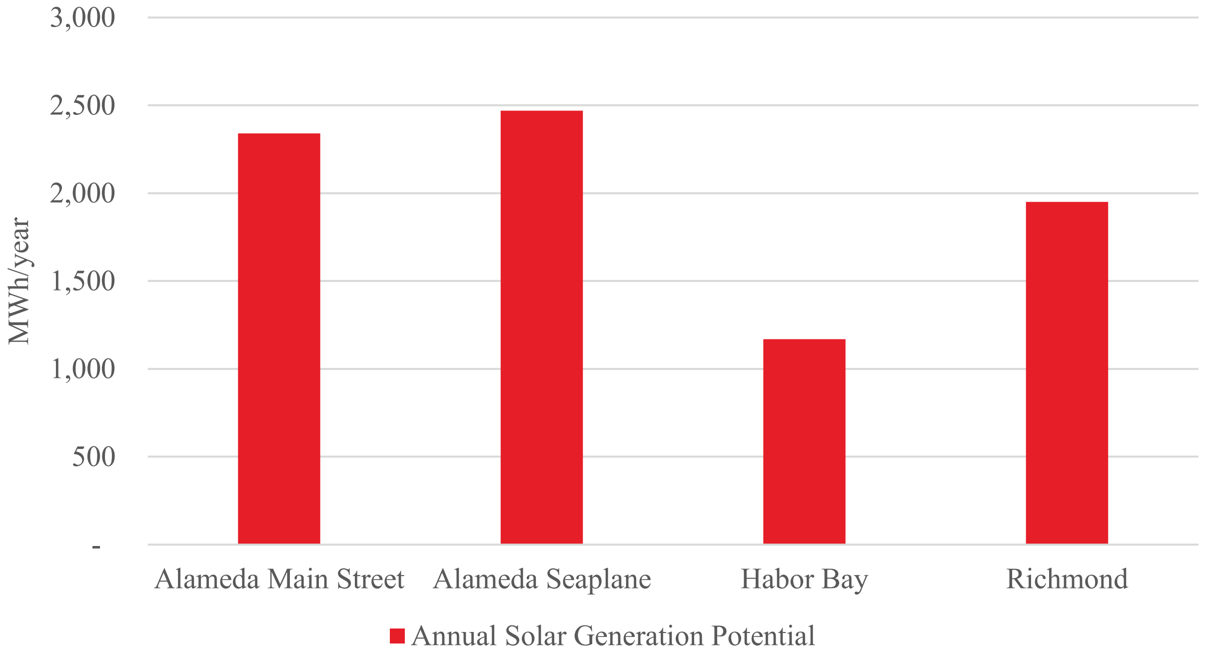

Figure 8: Available Solar Generation Potential

3.4. Terminal Energy Storage

Battery System Arrangement

To assess the BESS needs at each terminal, the project team started by identifying the energy requirements of varying vessels and their requisite peak demands in a worst-case charging scenario. Worst-case charging scenarios per terminal are defined as instances when the maximum number of vessels are charging concurrently, per their respective scheduled routes. Electrical distribution connection sizes, both at the point of connection to the utility as well as to individual floats, are crucial to accurately sizing BESS and ensure that vessel charging is feasible.

The float area and depth can indicate available space for electrical charging infrastructure. As shown in Table 1: Planned Ferry Electrification Phases, most of the floats are made of steel, which mean they are hollow with several internal compartments that are either empty or filled with water for ballast. The hollow floats present an opportunity for BESS and power electronics to be installed inside of the floats, reducing the equipment footprint on land. Conceptual arrangements were developed for integrating BESS and charging equipment into the floats at one of WETA's terminals, Downtown SF, as shown in Figure 9 and Figure 10 below. Incorporating BESS equipment in floats will be considered on a case-by-case basis as WETA continues to conduct site-specific analyses, with a preference at terminals that have severe land-side constraints.

The project team developed electrical arrangement scenarios for the Downtown S.F. terminal in which the floats host the fast chargers necessary for ferry electrification. These chargers are currently understood to operate on a common DC bus, which provides a linkage between AC site power distribution and up to 4MW of a fast charge connection per vessel. A single point electrical connection at the floats via medium voltage transformers also provides an isolated and separately grounded environment for the vessel charging equipment.

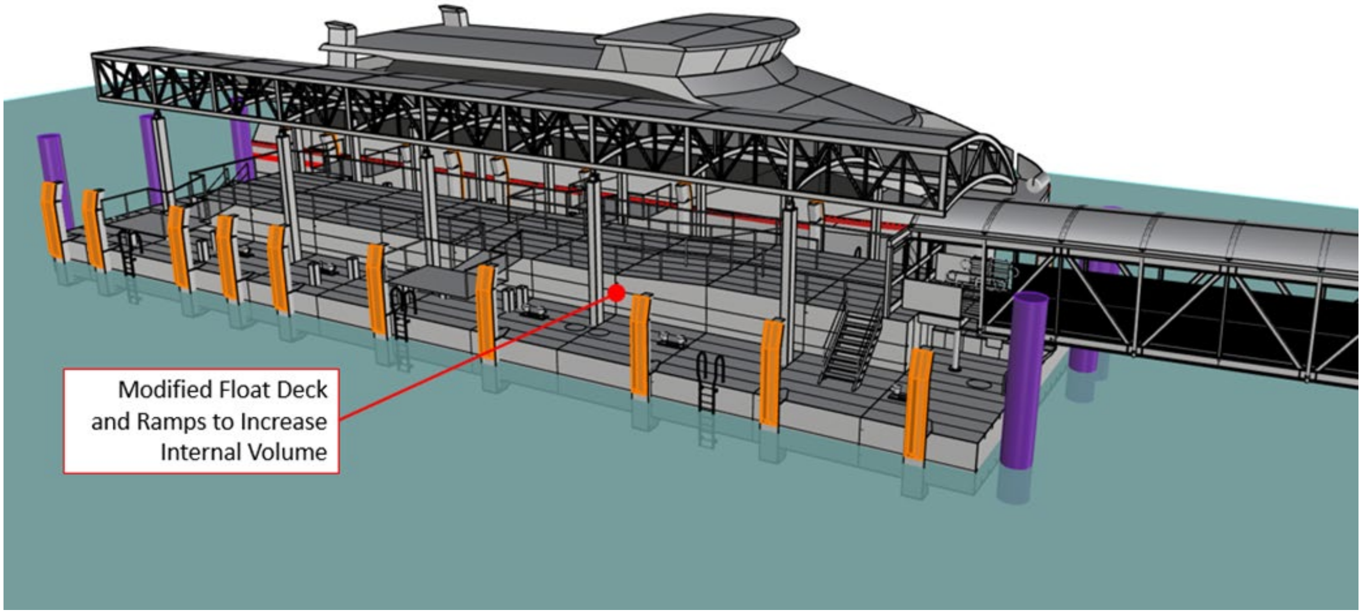

Figure 9: View Showing S.F. Downtown Float with a Docked WETA Vessel, Modified to Increase Internal Float Volume Credit: Aurora Marine Design

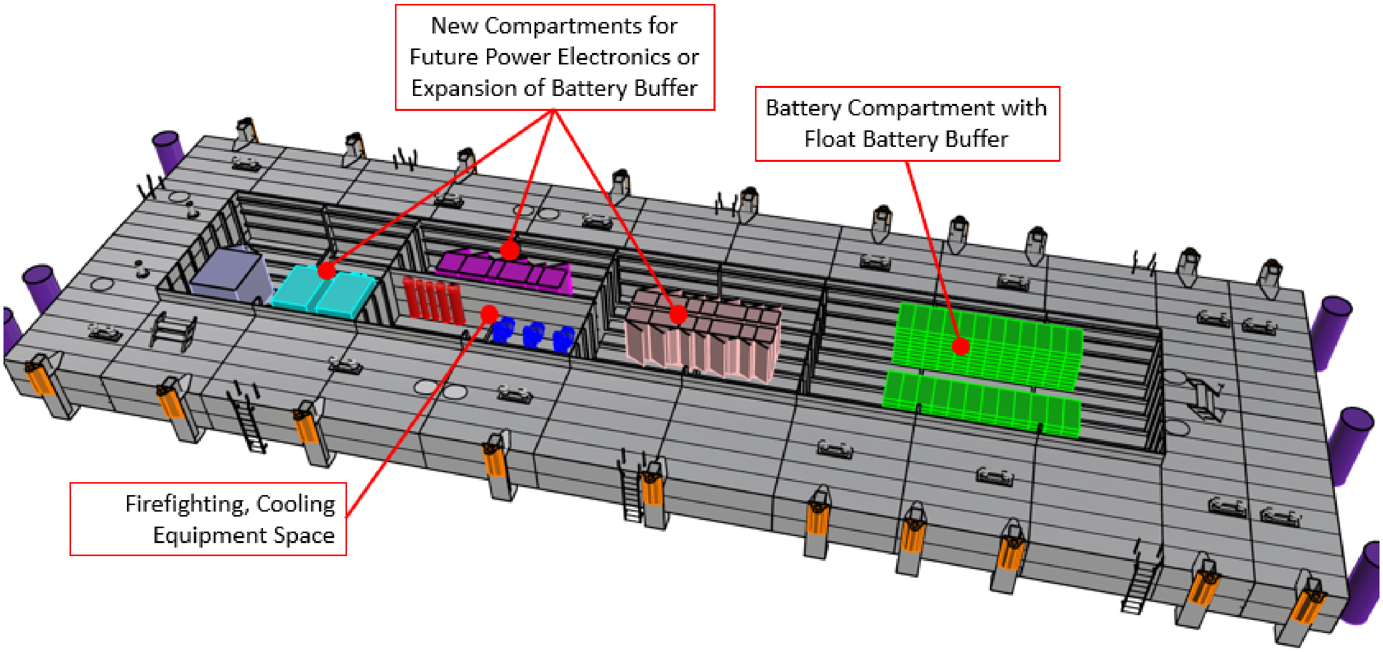

Figure 10: Cutaway View Showing S.F. Downtown Float with Conceptual Internal Compartmentation and Electrical Equipment. Credit: Aurora Marine Design

Battery Sizing Analysis Inputs

The local grid needs to be capable of delivering the full charging requirements of each terminal. However, existing grid conditions around the bay indicate that some terminal locations lack spare utility grid capacity, which becomes particularly challenging as other sectors also strive to electrify their practices. Local grids are expected to become more robust, despite WETA's electrification initiatives but battery aided vessel charging can alleviate capacity constraints with the function of minimizing service connection sizes from the local utility grid. The project team conducted a battery sizing analysis to provide a confident proof of concept of a functionally specified float battery charging system.

As many of the entities along the S.F. waterfront aim to electrify their operations, a new utility substation a will be required to meet the future power needs in the area. SFPUC and the port have plans to develop the new substation at seawall lot (SWL) 328 (Figure 11Table 9). Based on conversations with stakeholders, it is expected that WETA will have a new grid connection of 10MW, which would utilize the full capacity of a single 12kV utility grid circuit. The battery sizing analysis was conducted with the 10MW constraint, meaning a successful proof of concept projected peak demands below 10MW.

Battery Technology & Space

Given the highly constrained land availability at S.F., the project team considered the possibility of housing the BESS in the float. Floats were identified as having the ability to create new additional spaces for electrical equipment via a structural expansion. The proposed float expansion layout reserves space for electrical systems, excluding batteries, to connect to shore AC power and distribute to charging operations on the float. The remaining space is available for BESS—setting an upper limit on the physical footprint of battery products and enabling the project team to determine the maximum battery size that can be deployed in the floats.

Once an envelope for battery storage area is in hand, battery chemistry is considered for identifying a deployable product within the available space. Lithium Ion is the primary battery technology for electric vessels. Three subcategories of lithium ion have been deployed by marine battery manufacturers: Nickel Manganese Cobalt (NMC), Lithium Iron Phosphate (LFP), and Lithium Titanate (LTO). Further, battery modules can be configured to favor either higher total energy (energy batteries) or higher available power (power batteries). Many experimental battery technologies exist that promise to improve or replace lithium ion; the most promising technology in the near term is solid-state batteries.

It is important to note that there is a significant difference between marine batteries and those used in electric vehicles and other terrestrial uses. The manufacturing of the batteries is specialist and bespoke necessary to cater for the maritime environment and intensity of operations. This has big implications for multiple attributes, in particular price.

By selecting a manufacturer product using NMC chemistry, the study can define a maximum deployable battery capacity within the available space. Given the constraints detailed above, the project team identified a maximum of 4,000 kWh of energy storage per float at Downtown SF. Inherent properties of the NMC lithium battery product also define depth-of-discharge parameters, which impact the lifetime health of the battery and were used to assess the study outputs. By utilizing the depth-of-discharge in the design selection parameters, the project team identified that preferred operation of the batteries would not see battery discharge to less than 80% capacity to maintain a target operational lifecycle of 10 years.

Vessel Charging Schedules

The key input to simulating a successful proof of concept for float battery charging is the schedule at which vessels arrive at a terminal and require charging at a float. The importance of this input is compounded at S.F. by the technical limitation that the float battery is incapable of providing concurrent charging to more than 1 large vessel per float, at any given time due to the 10MW feeder restriction. Furthermore, the action of recharging batteries on the float also constitutes a "charging" operation which cannot be concurrent to charging a vessel.

In the case of SF, schedule is a critical parameter to the analysis as the final projected phase of electrification will see up to 16 large electric ferry vessels attempting to charge at only 3 available floats throughout the day. This required the extrapolation of an assumed future vessel operating schedule, which limited the number of vessels requiring charging at S.F. to no more than 3 at any given minute. Minute-by-minute energy demand data was then created for the 2 morning rush hours from 6:30am and 8:30am where the arrival density at S.F. is the greatest and the first peak energy demand of the day is expected (arrival density and peak energy demand is mirrored for the afternoon rush hours). Additional hours up to 12pm of vessel schedules proceeding the rush hours were further extrapolated and examined to assess the float batteries' ability to rebound capacity after the rush hours have passed. In the instance of a fully electric fleet of 16 vessels, WETA will also explore alternative load management options at S.F. to maximize charging, such as construction of Gate A with charging capabilities to support opportunistic charging of vessels.

Analysis Methodology

The following is a summary of the study inputs used to analyze the concept of a successful float battery charging system at Downtown SF.

- 10MW peak electrical demand from grid
- Max possible battery energy storage per float 4,000 kWh
- Preferred battery depth of discharge not less than ~80% under normal operation
- No more than 1 vessel requiring charging per float at any given minute, 3 vessels total for Downtown SF
- Float battery capacity at 100% prior to start of rush hour period

The analysis modelled two approaches to simulating battery charge and discharge profiles. In the first method for modelling battery discharge, the float battery contribution is maintained at a specific power rating and the power supply from the grid is allowed to fluctuate with vessel energy demand. The inverse was applied to the second method: the grid contribution is maintained at a specified power rating and the power supply from the float battery is allowed to fluctuate with vessel energy demand. The remaining minutes where the observed vessel charging demand is zero, the available grid power is used to replenish the float batteries.

For interpreting the simulated outcomes in all cases, confidence in the proof of concept would seek to maintain a worst case of ~70% battery capacity at the floats immediately following the rush period. Further assessment of the float battery capacity at 12pm is necessary to visualize battery capacity prior to the evening rush hour period where float batteries are again expected to be under high demand.

Study Results

Table 6: Battery Analysis Result Summary

		Contribution		**Electrical Demands from Grid**		**Float Battery Capacity**		**Minimum Battery Discharge Rate**
		Float Battery	*AC Grid*	*Min*	*Max*	*After Rush Hours*	*At 12pm*	
Method 1	Alternative 1	2,000 kW/ 4,000 kWh	Variable	6,000kW	8,461kW	40%	97%	0.5C
						57%	99%	
						58%	100%	

		Contribution		**Electrical Demands from Grid**		**Float Battery Capacity**		**Minimum Battery Discharge Rate**
		Float Battery	*AC Grid*	*Min*	*Max*	*After Rush Hours*	*At 12pm*	
	Alternative 1	1,500 kW/ 4,000 kWh	Variable	4,500kW	9,961kW	55% 68% 69%	98% 99% 100%	0.38C
Method 2	Alternative 2	Variable	9,750 kW	4,500kW	9,961kW	69% 80% 84%	100% 100% 100%	0.2C to 0.53C

As the results in Table 6 indicate, all three alternatives return the batteries on the floats to near full capacity by 12pm, which ensures the general proof of concept can handle a full 24hour operational cycle. Further considerations include the impact to the grid, the battery lifecycle effects of discharging below 80%, and the battery charge rates required for an effective solution.

Method 1 Alternative 1 results in normalized grid usage but at the cost of peak battery discharge down to 40%--well below the preferred 80%. A deep battery discharge could reduce the number of years float batteries are functional before replacement is necessary. A static 0.5C charge rate is an industry standard which most technology vendors comply with.

In method 1 alt 2 we see increasing peaks of grid requirements with higher highs, lower lows, and an increase in remaining float battery capacities. With a peak battery discharge of 55% the expected float battery lifespan should be increased from the previous model, and a lower charge rate implies similar integration availability as the previous model while further reducing the strain on the batteries during operation.

Method 2 shows even greater float battery capacities while providing the greatest delta in grid demand. Because float battery capacities regularly reach 100% throughout the modeled timeline, grid energy demands to the floats for recharging at times will be negligible. The peak battery discharge at 69% is near the targeted 70% for confidence in proof of concept. The confidence target of 70% discharge is greater than the preferred 80% per the basis of design battery parameters, with an average battery discharge of 78% between all three floats. In this final model the battery charge rates are both dynamic instead of static, and they increase to a peak usage of 0.53C. This battery operational regime introduces an increased requirement from a technology integration standpoint.

Conclusion

The resulting analysis indicates that the concept of a float battery charging system can be successfully deployed at the 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. The study also consequently identified the criticality of vessel schedules and their impacts on electrical charging demand. The results of this study are entirely dependent on the flexible vessel schedule which meets the constraints described above. Successful deployment of electric vessels is further impacted by the range of battery charge rates explored in each alternative of this study, allowing technology integrators to provide a variety of functional solutions.

Lastly, this study is only focused on the S.F. terminal, but there is precedent for future applications of this battery sizing methodology at other WETA terminals. For other terminals with observed constraints on land availability and local grid capacity, it can be assumed that a float battery charging system may be successfully examined and deployed to reduce or limit the size of new electrical service connections.

3.5. Cost Considerations

A fleet transition to zero-emission vessels requires investment. The project team developed rough order of magnitude costs for the transition to ZEV in Phases 1-3 including vessel costs, electrical equipment upgrades at terminals, and operational costs. The projected costs are highlighted for each terminal in their respective phases. Greater effort was undertaken to develop cost and design feasibility for Phase 1 terminals, especially the SFFB ferry terminal given its critical role in the ZEV transition and its heightened level of energy demand and congestion. Phase 4 costs were not estimated due to technology uncertainty and later transition date.

The electrical infrastructure upgrade costs are based on 2022 market rates and conversations with utility service providers. Terminal infrastructure costs are inclusive of the electrical infrastructure required, which encompasses elements such as conduit, transformers, duct banks, switchgear, and utility disconnects.

Due to the early phase of planning and 15+ year time horizon for the multi-phase transition, better cost information is available for earlier phases of the transition. Highly congested terminals, notably the Downtown S.F. terminal, have additional cost uncertainty such as seismic and structural upgrades, and civil works (trenching, tunnelling). These potential costs have not been estimated but are assumed most relevant to select scenario alternatives considered for the Downtown S.F. terminal, so contingency has been accounted for.

3.6. Stakeholder Engagement

The terminals are located across seven cities, four counties, and three utility service territories. This results in coordinating a breadth of regulating bodies, each with varying utility requirements and entitlement processes for upgrading terminals to ensure they meet the necessary power requirements. The project team employed an iterative stakeholder engagement process (Figure 9) to coordinate with several stakeholders at each terminal, including port authorities, utilities, and more. This engagement started at the beginning of the Blueprint development, and has been critical to understanding the existing infrastructure, key players, and competing priorities or projects that stakeholders are managing. This process is dynamic and will vary depending on both the terminal and the stakeholder.

Coordination

The project team consistently met with key personnel to ensure the project was progressing in a timely manner and that it didn’t conflict with other projects at the terminal.

Research

The research phase consisted of identifying key personnel who will be impacted by the transition to zero emission vessels impacts and establishing opportunities for coordination.

Feedback

Feedback was critical in understanding different stakeholder’s perspectives and producing the best plan.

Data Collection & Analysis

Extensive analyses of data collected from stakeholders provided the project team a complete understanding of existing infrastructure, ensuring that the proposed project is the optimal solution for each terminal.

Project Planning

Developing the optimal solution for each terminal was an iterative process between the project team and stakeholders, which incorporated all of the key elements defined here.

Figure 11: Stakeholder Engagement Process *Credit: Arup*

4. Phase 1 Terminal Implementation

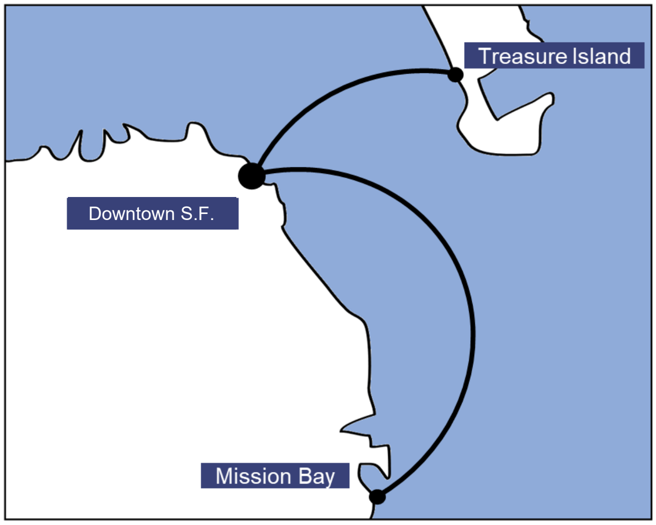

Figure 12: Map of Phase 1 Terminals & Routes

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. Ridership growth forecasts indicate that two vessels for each route will suffice for each route until the mid-2030s, when a third vessel will be added to each service. A summary of the phase 1 vessel implementation is shown below. Table 7 shows preliminary specifications for the 149-passenger battery electric vessel.

Table 7: Phase 1 Terminal Stakeholders & Infrastructure Cost

Phase 1 Terminals	Utility Provider	Distribution Network Operator	Additional Stakeholders	Terminal Electrical Infrastructure Estimated Costs *(Million $)*	
				Low	*High*
Downtown SF	SFPUC	PG&E	Port of SF	$ 2.70	$ 5.00
Treasure Island	SFPUC	PG&E	TIMMA[7] TIDG[8]	$ 2.80	$ 2.80
Mission Bay[9]	SFPUC	PG&E	Port of SF	*$ 1.80*	*$ 3.00*

Table 8: Phase 1 Vessel Implementation Year and Cost

Vessel	Primary Service	Completion Year	Estimated Cost *(Million $)*	Funding Source
149E #1	Treasure Island	2024	$6.00	TIRCP Grant/ Others
149E #2	Mission Bay	2025	$6.20	TIRCP Grant/ Others
149E #3	Treasure Island	2026	$6.40	FTA Funds/ Others
149E #4	Mission Bay	2027	$6.60	TBD
149E #5	Treasure Island	2035	$8.30	TBD
149E #6	Mission Bay	2035	$8.30	TBD

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[7] Treasure Island Mobility Management Agency (TIMMA)

[8] Treasure Island Development Group (TIDG)

[9] The Mission Bay terminal is still in development. These costs are estimates based on other representative terminals and will be updated through ongoing stakeholder engagement.

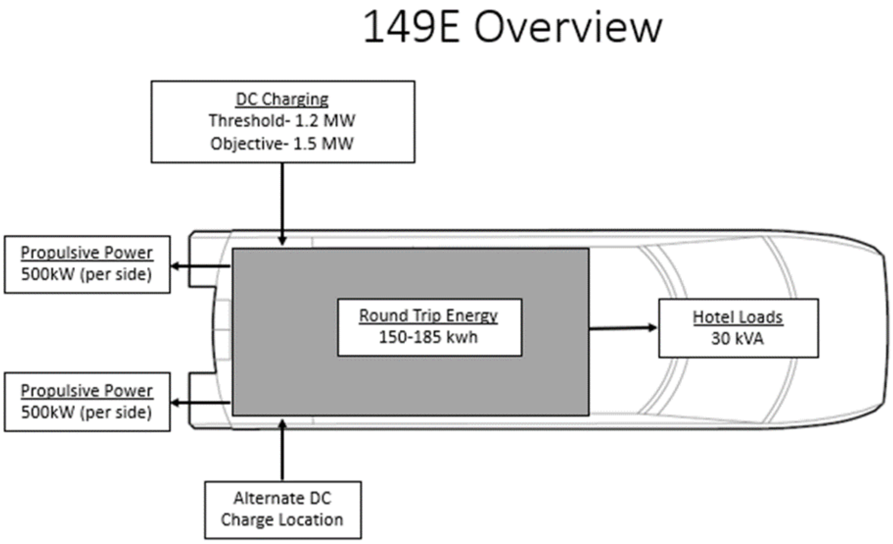

Figure 13:149 E Conceptual energy and power specifications

4.1. San Francisco Ferry Building Terminal

The Downtown San Francisco Terminal is at San Francisco's historic Ferry Building. This terminal consists of six berths and is the focal point of WETA's ferry operations as many of the ferry routes berth at this location. The local electrical distribution grid is significantly constrained and will require upgrades to be able to accommodate the 17.5 MW of peak demand load from the electric ferry charging. This terminal is also severely space constrained, as mentioned in Section 3.3 Shoreside Electrification Infrastructure. This section outlines the assessment of the site's capability to host necessary electrical upgrades for ferry charging operations. The following approach was applied to Downtown S.F. but can be used for all other terminal assessments. Initial conclusions below detail terminal power needs and options.

Terminal Power Sources

Three options were explored by the project team to assess solutions to provide power to the floats for charging. (Table 9).

Table 9: Downtown S.F. Terminal Power Source Options

No.	Power Source Options	Description
1	Utility power only (*no battery storage*)	• Utility delivers full power to site • No battery storage provided by WETA on site
2	Combination of utility power and battery storage on floats	• Utility delivers power to site • Battery storage provided at floats to supplement utility power
3	Combination of utility power and battery storage on floats + shore	• Utility delivers power to site • Battery storage provided at floats and on shore to supplement utility power

Option 1 sets a baseline for the terminal site costing and charging capability, against which the other options were weighed for viability. With no batteries to reduce the peak demand, this option would represent the worst-case scenario for new service connection size from the utility and distribution from the service point of connection to the floats.

Option 2 uses battery storage to reduce the peak demand load and consequently the service connection size required from the utility. The unique opportunity at the terminal to retrofit additional space onto the floats provides space to locate batteries adjacent to the charging infrastructure. This arrangement would not only reduce the peak demand at the utility service connection but would also reduce the size of the power distribution feeders from the service point of connection to each float.

Option 3 was studied as a method to further reduce peak demand at the utility service point of connection but was eliminated because of the additional shoreside space requirements and lack of efficiency in design when compared to Option 2.

Implementation Plan: Requirements

The existing utility power at the San Francisco Ferry Terminal and Plaza is provided via a 225kVA, 208V, 3ph transformer that is located on the rear deck of the existing Agriculture Building. The power feed leading to this transformer is currently a privately owned service extension from the Pier 1 Building located ~1,300ft Northwest, of the ferry terminal, and is routed underground along the eastern side of Embarcadero before it turns into the Plaza deck.

Power to the Downtown S.F. terminal has three main considerations:

- Limited above-grade space at ferry terminal site
- Limited utility service capacity
- Distribution of power to 3 floats with 2 berths each, and an existing terminal site transformer

The following implementation plan focuses on Option 2 because of its effectiveness in minimizing utility service connection needs and balancing space availability on both the float and shore. The implementation scenarios presented below are largely agnostic of the technology option deployed, varying in terms of space and cost needed to install equipment. This portion of the Blueprint is intended to provide high-level insight into the feasibility of deploying the infrastructure needed to support ferry charging operations. Final site-specific design for any terminal will be delivered by contracted engineers of record.

Implementation Plan: Execution

Within Power Option 2 there are three different utility interconnection scenarios. In all scenarios, the implementation begins upstream of the terminal with the addition of a new SFPUC owned substation at Seawall Lot 328 (Figure 14). While initially planned with limited capacity, the substation will grow to accommodate the future electrical demands in the area in addition to the Downtown S.F. ferry terminal. Power for the terminal is to be routed under public roadways, with varying degrees of private ownership and responsibility between the scenarios. Coordination with SFPUC has informed the primary service feeder routing used for these scenarios and is subject to change given continued assessment of the local power needs by other stakeholders, such as the Port of SF. Given the size of electrical demands estimated for the Downtown S.F. ferry terminal, all scenarios will secure medium voltage primary utility services to distribute power to the floats.

These scenarios are compared against each other in terms of their cost, ownership, and effort to deploy. Table 10, below, outlines the three different utility interconnection scenarios.

Table 10: Utility Interconnection Scenarios for Downtown S.F. Terminal

No.	Service Connection Scenario Title	Description
1	Utility Point of Connection (POC) and Switching @ West of Embarcadero	Above-grade equipment with standard utility meter and main configuration.
2	Utility POC and Switching @ East of Embarcadero	Below-grade utility main disconnect with above-grade switching and metering at AG building deck area.
3	Remote Utility POC with Switching @ East of Embarcadero	Below-grade switching with remote utility meter and main at SFPUC substation and private service feeder under Embarcadero.

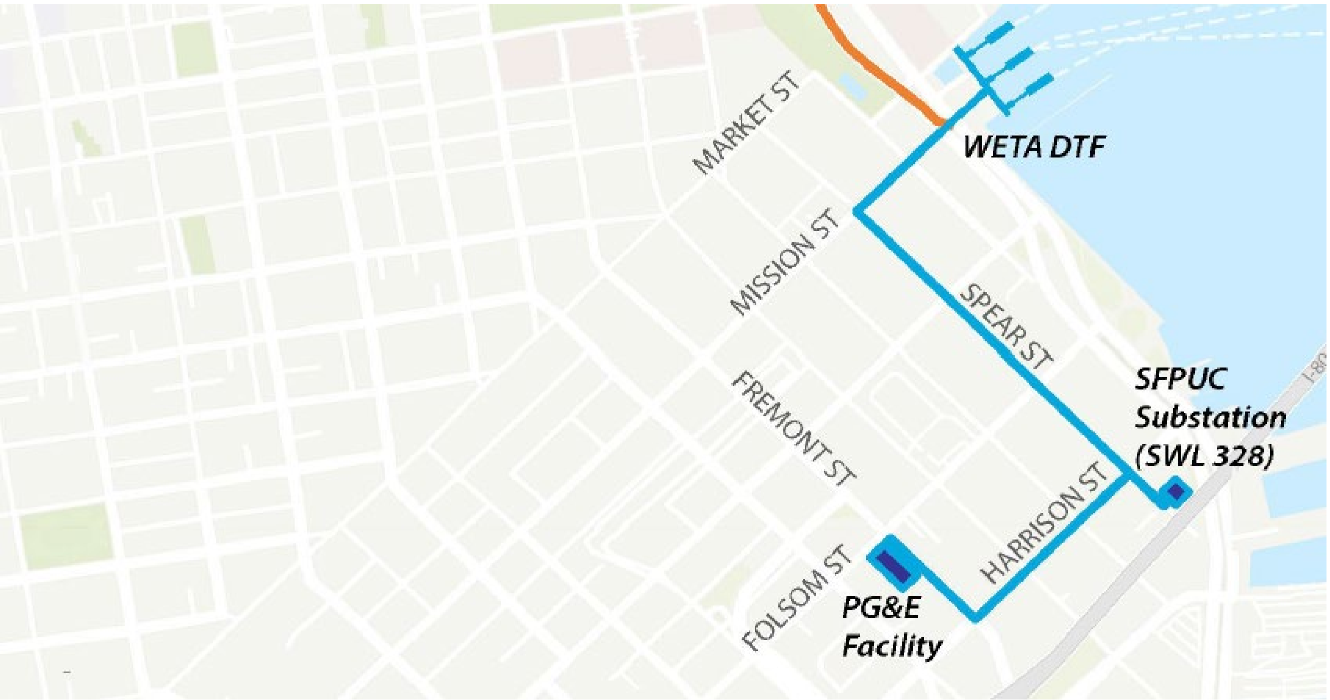

Figure 14: New SFPUC Substation Proposed at Seawall (SWL) 328 *Credit: Port of SF*

The next element of the study focuses on identifying SFPUC requirements and available space for electrical distribution equipment. Preliminary site visits to the Downtown S.F. terminal informed possible physical locations to consider for electrical infrastructure as well as routing methods for feeders. Existing conditions at the Downtown S.F. ferry terminal site, such as reusable direct buried vaults and conduits, were also considered. Due to the gross electrical demands required at each float and limited opportunity for additional space availability, the site power is planned to be distributed and connected to the floats via medium voltage connections.

Scenario 1: Utility Point of Connection and Switching at West of Embarcadero

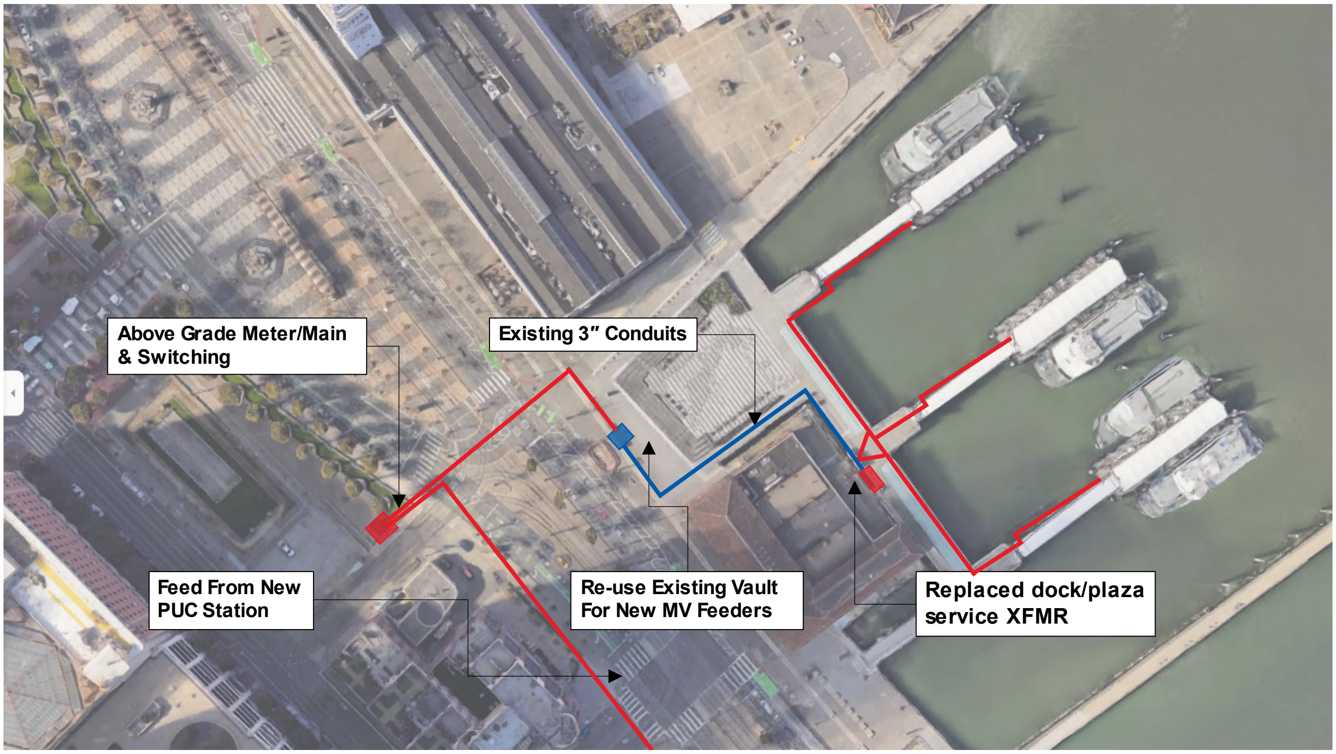

Figure 15: Utility Point of Connection & Switching West of Embarcadero *Credit: Arup*

In service connection Scenario 1 (Figure 15), the Northwest corner of Embarcadero and Don Chee Way was identified as a possible location for above ground equipment. SFPUC requirements include 8ft of clearance in front of and behind above-grade equipment. Front clearance is available at the location; however, the rear side of the proposed equipment will require a variance from the SFPUC. By locating the meter and main disconnect at this location, the SFPUC would own and operate the service feeders originating from the substation up to this point.

Electrical feeders would then need to cross the Embarcadero to reach the Ferry Plaza, where existing underground conduits and vaults would be utilized to provide power to the existing plaza switchgear as well as creating a point on the dock from which feeders may be extended to the floats.

It should be noted that in all scenarios, attempts to cross Embarcadero with new electrical feeders will present negotiation challenges around existing underground utilities and substructures. Ongoing discussions between stakeholders and contracted engineering engagement will be needed to determine the selection of an optimal location for crossing the roadway and may change the routing methodology presented in the Blueprint.

Scenario 2: Utility Point of Connection and Switching at East of Embarcadero

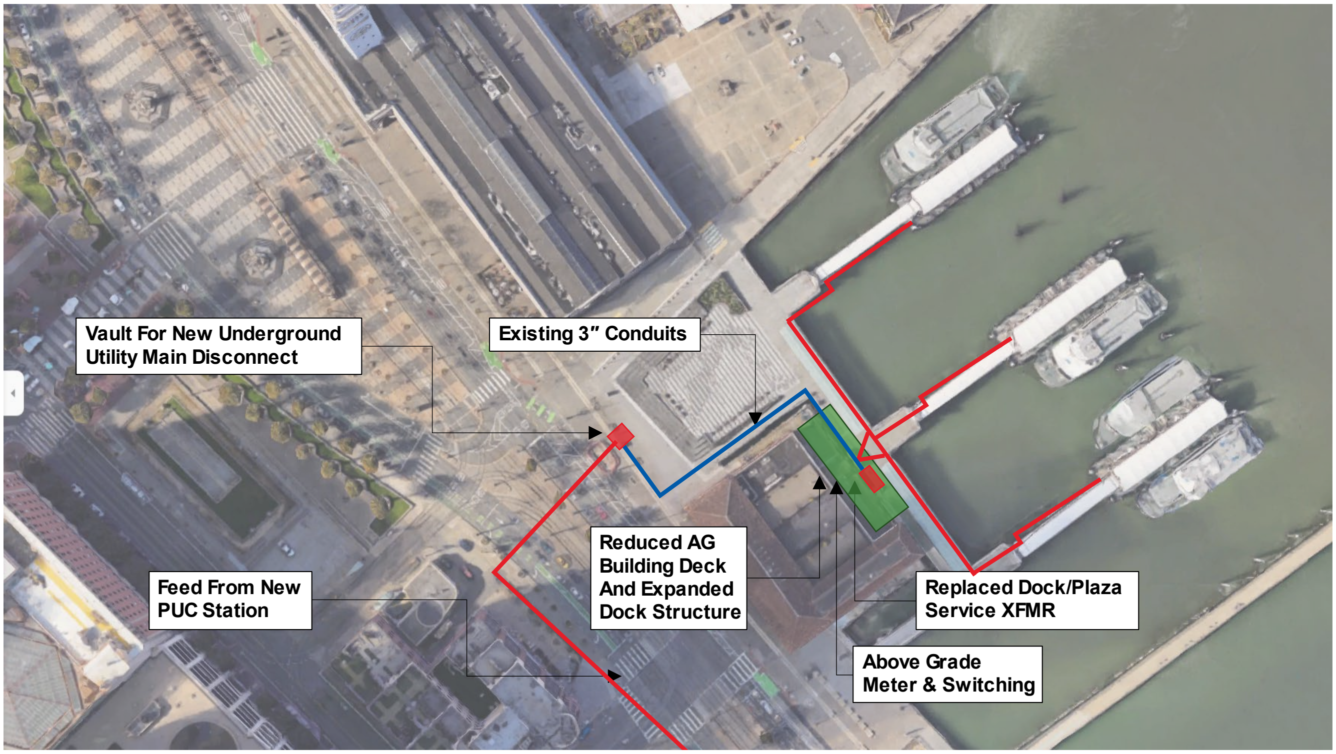

Figure 16: Utility Point of Connection and Switching at East of Embarcadero *Credit: Arup*

Coordination with SFPUC has offered unique solutions for locating utility meters and main disconnects remote from each other. In Scenario 2 (Figure 16), SFPUC would serve power directly to the Ferry Plaza via an underground disconnect switch, marking the point at which electrical distribution becomes privately owned by the WETA terminal. From the sidewalk, existing conduit pathways may be used to route service feeders to the rear deck area of the Agriculture Building, where above grade metering and switching will occur. The rear deck area provides ample space for equipment clearances but would require a structural enhancement, optimally shortening the existing Agriculture Building deck and expanding the new ferry deck in its place to accommodate the new equipment. Alteration of the existing deck structure, however, poses a significant design risk which may ultimately trigger replacement of the entire Agriculture Building support structure, and consequently, substantial differences in the costs for this scenario.

Scenario 3: Remote Utility Point of Connection and Underground Switching at East of Embarcadero

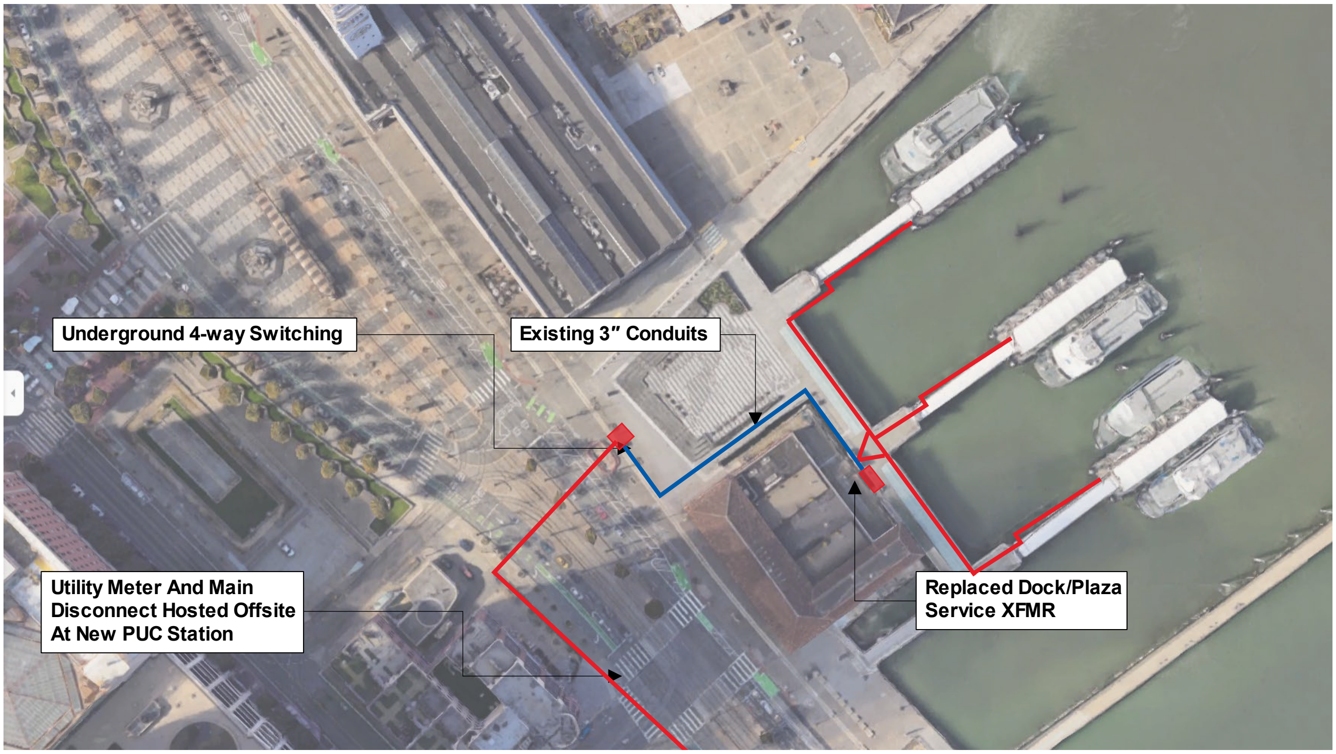

Figure 17: Utility Hosted Metering and Disconnect at Substation and Switching at East of Embarcadero *Credit: Arup*

The least intrusive installation is Scenario 3, which proposes private ownership of the medium voltage feed from the new SFPUC substation, eliminating the need for any additional above grade equipment at Downtown S.F. (Figure 17). The primary feeder would arrive at an underground 4-way submersible switch located at the Ferry Plaza sidewalk and attempt to utilize the existing conduits within the Plaza deck to route feeders to the dock floats and existing plaza transformer.

The major implication of this scenario is the private ownership of the electrical feeders underneath public roadways. Private ownership introduces additional logistics and costs such as maintenance, troubleshooting, and dig monitoring for the power feeder from the new SFPUC substation up to the terminal site. Typically, these responsibilities belong to the SFPUC, as they would in Scenarios 1 and 2.

Communication pathways would be provided alongside power such that the float charging infrastructure will be able to cross communicate with one another and ensure a cap on peak electrical demand at the utility service point of connection. Conversations with SFPUC stakeholders have established that an Uncompensated Export Service Agreement would allow the proposed scenarios to be implemented without remotely operable circuit breakers and the supervisory control and data acquisition equipment that would require additional space on site. This means there is no Net Energy Metering Agreement. If energy is exported from the site, WETA will not get paid for that energy but there is currently no planned export of energy.

Summary and Conclusions

For all service connection scenarios at the Downtown S.F. terminal, the intended concept for electrical distribution to the individual dock floats remains the same: a medium voltage electrical connection to each float, with battery storage located on the float. It should be noted that any distribution scenario without batteries in the float would require twice as many electrical feeders provided to each float.

The goal of this section is to present the feasibility of different methods of connecting and distributing new electrical services at the Downtown S.F. terminal to support electrical ferry charging operations. At a minimum, the result of this effort provides greater confidence that a properly sized electrical service connection and distribution to support ZEV ferry charging is possible, even at the Downtown S.F. terminal, where peak demand loads are the highest.

A conclusive recommendation for which scenario to implement at the Downtown S.F. is not within the scope of the Blueprint, and information provided here may be subject to change as requirements and new information evolves over time. The following matrix is provided comparing the three service connection scenarios under various aspects (Figure 18). Further coordination amongst stakeholders in consideration of this information, and in conjunction with site specific engineering design, will be required to arrive at a final design direction.

🟩 Minimal Impact
🟨 Moderate Impact
🟥 High Impact

	Planning Time Horizon	**Installation Cost**	**Maintenance Responsibilities**	**Operational Costs**	**Feasibility for Utility connections >10MW**
Scenario 1: *Utility POC and Switching @ West of Embarcadero*	🟨	🟨	🟨	🟨	🟥
Scenario 2: *Utility POC and Switching @ East of Embarcadero*	🟥	🟥	🟩	🟩	🟩
Scenario 3: *Remote Utility POC and Underground Switching @ East of Embarcadero*	🟩	🟩	🟥	🟥	🟨

Figure 18: Electrical Service Connection Routing Matrix

4.2. Treasure Island Terminal

Stakeholder Engagement

The project team had ongoing discussions with Treasure Island stakeholders to accommodate the anticipated power requirements of the new terminal. In addition to those identified in Table 7, the project team also met with Treasure Island Mobility Management Agency (TIMMA) and Treasure Island Development Group (TIDG), who are leading efforts on the redevelopment of Treasure Island.

Implementation Plan: Requirements

The Treasure Island Ferry Terminal has not yet been fully developed and is undergoing upgrades, including a new terminal building and dock. An electrical distribution concept to support vessel charging has been proposed to TIMMA, TIDG, and SFPUC, which entails putting underground conduits in place now for future electrification needs to mitigate future site disruption. Discussions with the Treasure Island stakeholders provided assurance that the utility distribution at the vicinity has adequate spare capacity for our electric vessel charging needs. With an estimated peak demand for vessel charging at 1.3MW, this terminal represents the low end of infrastructure needed to support electric vessel charging.

Due to the low anticipated peak demands, and available capacity from the local electrical utility, there does not appear to be any immediate reason to implement energy storage batteries at the dock float. However, a nominal amount of battery storage may be recommended to provide charging resiliency in the event of a power outage, or to reduce the peak demand on the local grid if it is deemed necessary at the time of design.

Implementation Plan: Execution

As noted above, the planned installation is to provide a low voltage service connection to the dock float. There is a utility switch nearby and space on shore (~300ft away from the dock to the West) that has been allocated for a utility-provided pad mounted transformer and owner-provided service switchboard. Conduit for parallel feeders from the switchboard location to an in-grade box near the dock float are installed for future use/connection. There will be a significant amount of conduit to coordinate with the dock design, which has been discussed with Treasure Island stakeholders. The project team's preliminary site plan is included below (Figure 19).

Figure 19: Aerial Image of Treasure Island Terminal

4.3. Mission Bay

The Port of San Francisco and WETA are building out a new ferry landing in Mission Bay to expand regional public transportation and provide resiliency in emergency situations. Phase 1 of the Mission Bay Ferry Landing project consisted of site preparation and was completed in November 2020. Construction of the terminal is anticipated to take place in 2024 [10].

Stakeholder Engagement

Because this terminal is not yet built, there is an opportunity to ensure the new terminal can accommodate electric ferries. The key stakeholders that were engaged regarding the Mission Bay terminal are detailed in Table 7, above.

Implementation Plan: Requirements

The planned future ferry terminal at Mission Bay has an estimated peak power demand of 1.8MW for charging electric vessels. This includes future scenarios in which full-size WETA vessels continue to the Mission Bay terminal from regional routes and require charging. Early coordination with the Port of San Francisco and

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[10] Mission Bay Ferry Landing Project Fact Sheet: https://sfport.com/files/2022-07/2022%2002%2015%20SFPortMBFL%20Fact%20Sheet.pdf

SFPUC has enabled the project team to proactively address potential constraints. A basic approach was employed for Mission Bay terminal, which doesn't have the same observed constraints as the other Phase 1 terminals, given its development stage.

It is anticipated that both ample space to locate above ground equipment and existing spare electrical service capacity, is available in the vicinity of the planned future terminal location.

Implementation Plan: Execution

Similar to the Treasure Island site, the peak electrical demand at Mission Bay is on the lower end. With minimal short-range vessels and a single dock float, the electrical distribution can be provided via a low voltage approach (Figure 20). However, depending on distance from the service equipment to the float and if there is space on the float for a transformer, a medium voltage service may provide best value.

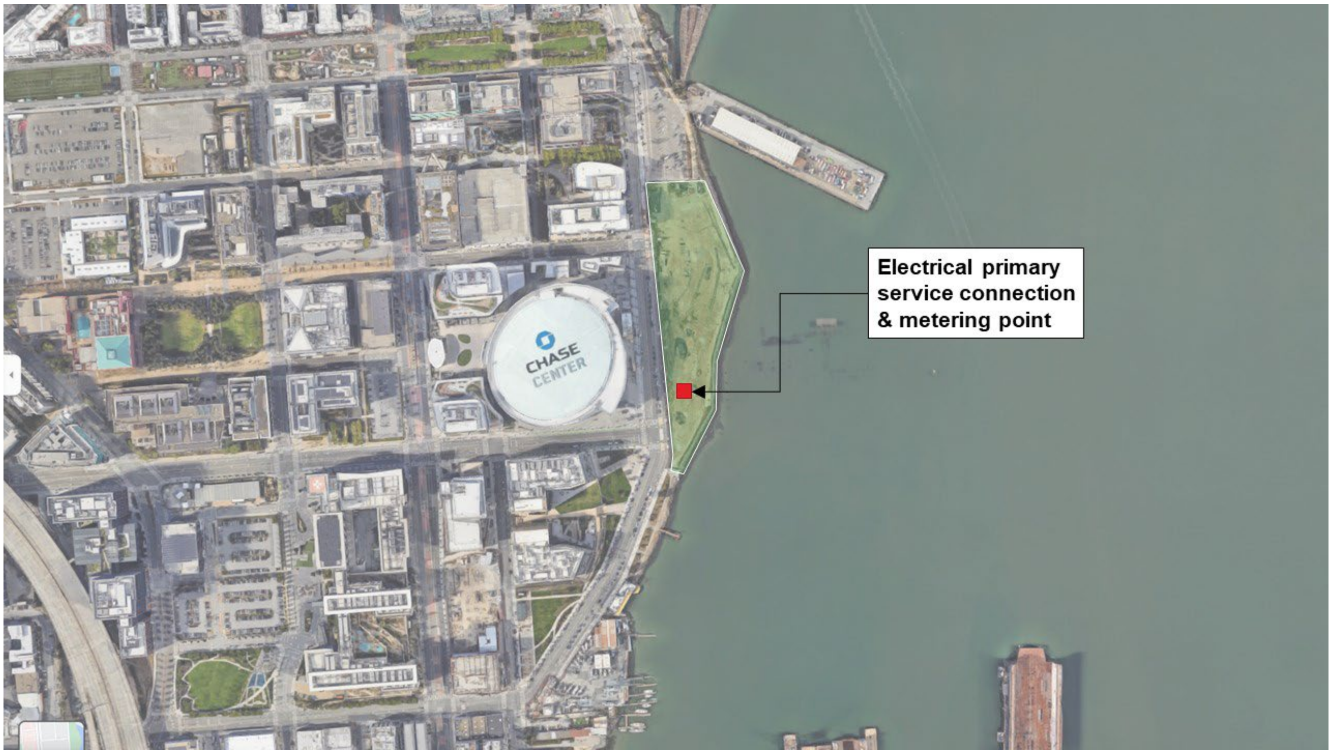

Figure 20: Aerial Image of Mission Bay Terminal

At 1.8MW peak demand, and available capacity from the local electrical utility, there again does not appear to be any immediate reason to implement energy storage batteries at the dock float. However, a nominal amount of battery storage may be recommended to provide charging resiliency in the event of a power outage, or to reduce the peak demand on the local grid if it is deemed necessary.

5. Phase 2 Terminal Implementation

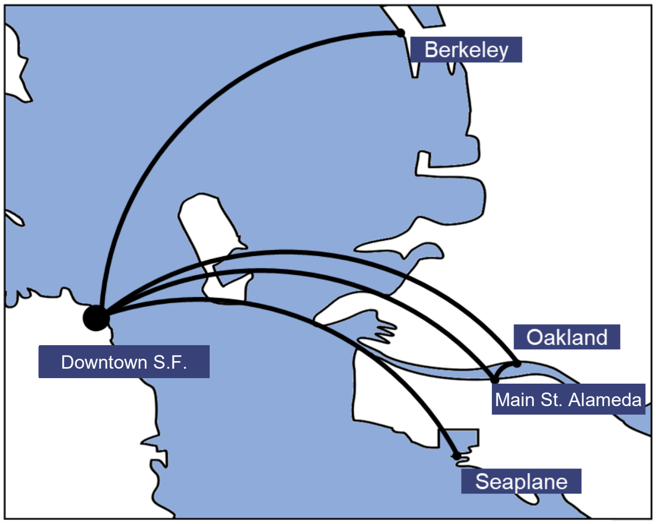

Figure 21: Map of Phase 2 Terminals & Routes

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). 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. A summary of the phase 2 vessel implementation is shown below. Figure 22 and Figure 23 show preliminary specifications for the 400-passenger and 250-passenger battery electric vessel, respectively.

Table 11: Phase 2 Terminal Stakeholders & Infrastructure Costs

Phase 2 Terminals	Utility Provider	Distribution Network Operator	Anticipated Stakeholders	Terminal Electrical Infrastructure Costs *(Million $)*	
				Low End	*High End*
Oakland[11]	PG&E	PG&E	Port of Oakland	*$2.50*	*$4.40*
Main St. Alameda	AMP	AMP	City of Alameda	$2.60	$3.80
Alameda Seaplane	AMP	AMP	City of Alameda	$2.80	$4.30
Central Bay Maintenance Facility	AMP	AMP	City of Alameda	$6.40	$9.50
Berkeley[12]	PG&E	PG&E	City of Berkeley	*$2.50*	*$4.40*

Table 12: Phase 2 Vessel Implementation

Vessel	Primary Service	Completion Year	Estimated Cost *(Million $)*	Funding Source
400E #1	Seaplane	2025	$19.00	FTA Replacement Funds- Intintolli
400E #2	Seaplane	2027	$19.00	FTA Replacement Funds- Mare Island
250E #1	Berkeley	2027	$15.50	TBD
Hydrus Repower	Oakland/Alameda	2027	$ 6.00	TBD

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[11] Oakland terminals are still in development. These costs are estimates based on other representative terminals and will be updated through ongoing stakeholder engagement.

[12] Berkeley terminals are still in development. These costs are estimates based on other representative terminals and will be updated through ongoing stakeholder engagement.

Vessel	Primary Service	Completion Year	Estimated Cost *(Million $)*	Funding Source
250E #2	Berkeley	2028	$15.50	TBD
Cetus Repower	Oakland/Alameda	2028	$ 6.00	TBD
Argo Repower	Oakland/Alameda	2029	$ 6.00	TBD
Carina Repower	Seaplane	2030	$ 6.00	TBD

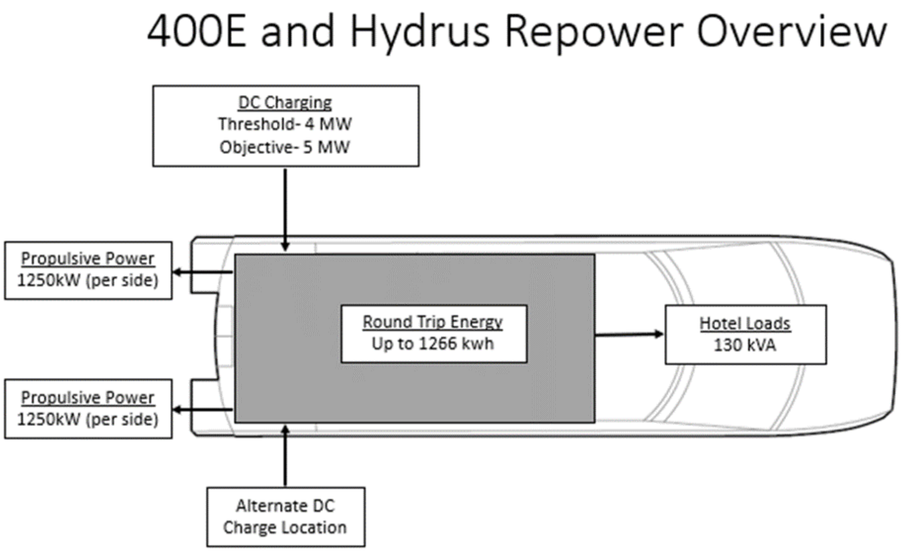

Figure 22: 400E and Hydrus-class repower conceptual energy and power specification *Credit: AMD*

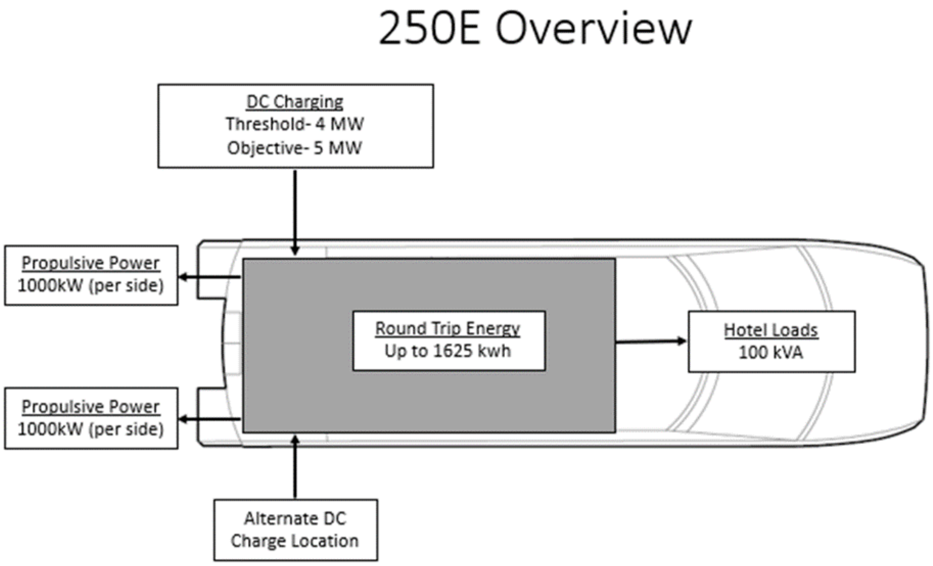

Figure 23: 250E conceptual energy and power specification *Credit: AMD*

5.1. Phase 2 Terminal Site Details

The project team has had preliminary discussions and information-gathering with AMP but is earlier in the process for Phase 2 terminals than Phase 1 terminals. The stakeholder engagement process will begin with PG&E at the Oakland terminal once a utility service application has been submitted. Below are the aerial site images for each of the Phase 2 terminals (Figure 24, Figure 25, Figure 26, and Figure 27), apart from the Berkeley terminal, whose design is still being discussed between WETA and the City of Berkeley. A conceptual design for the future terminal is included below (Figure 28). These site images were used in facilitating discussions with the relevant stakeholders and will continue to be iterated on as additional information is gathered for each terminal.

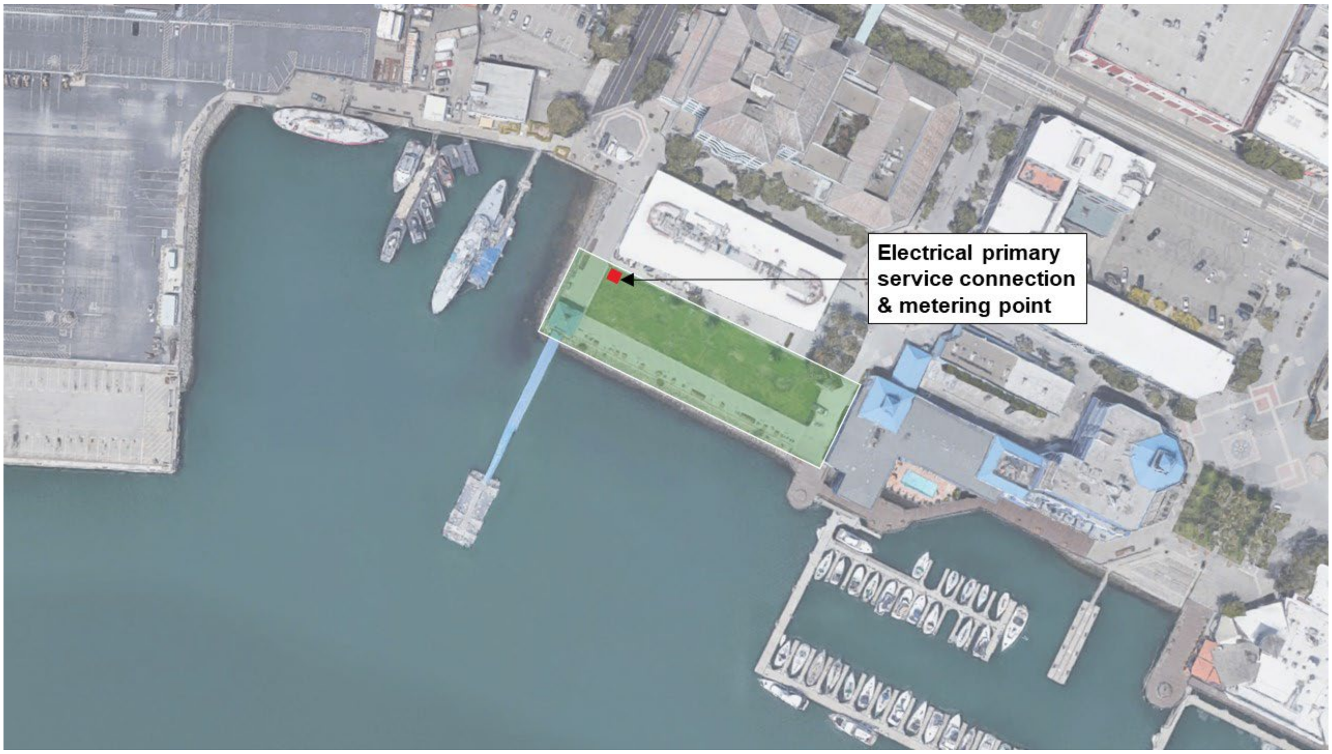

Figure 24: Aerial Image of Oakland Site *Credit: Arup*

Figure 25: Aerial Image of Main St. Alameda *Credit: Arup*

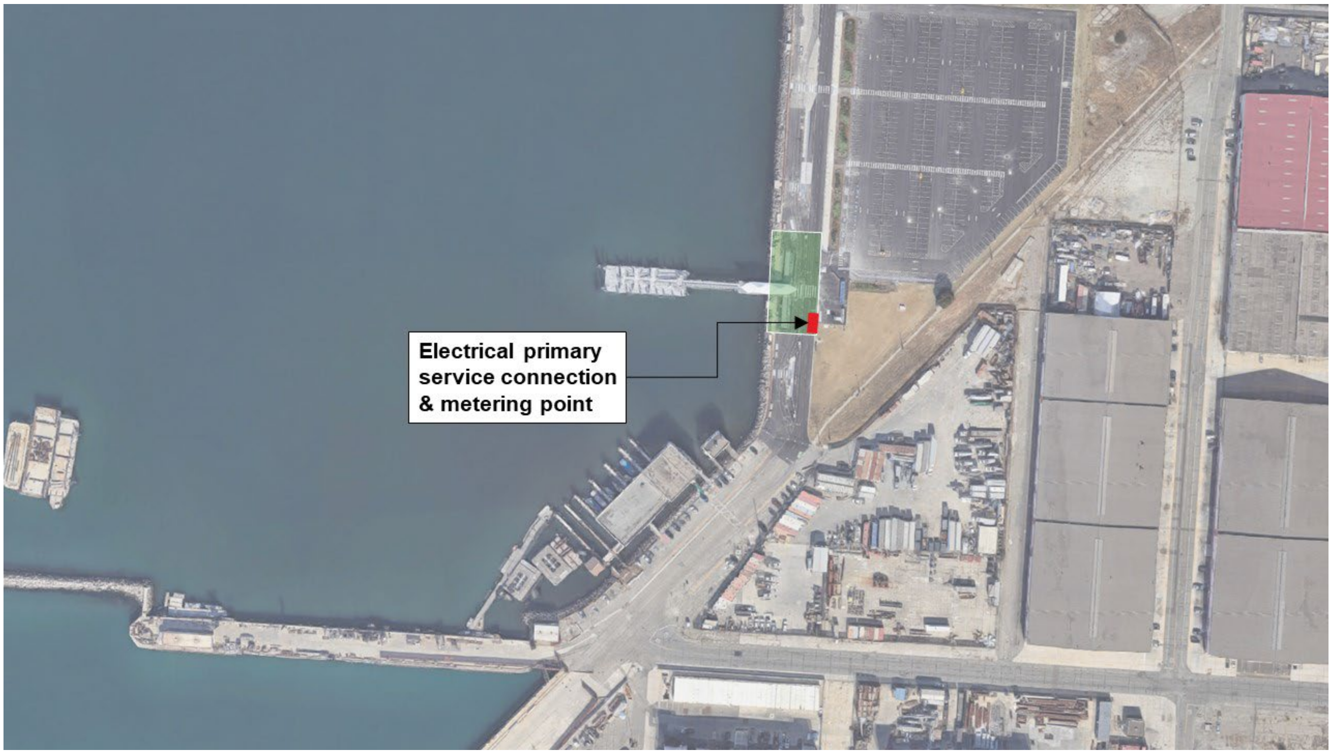

Figure 26: Aerial Image of Seaplane Site *Credit: Arup*

Figure 27: Aerial Image of Central Bay Maintenance Facility *Credit: Arup*

Figure 28: Rendering of Proposed Berkeley Terminal *Credit: City of Berkeley*

6. Phase 3 Terminal Implementation

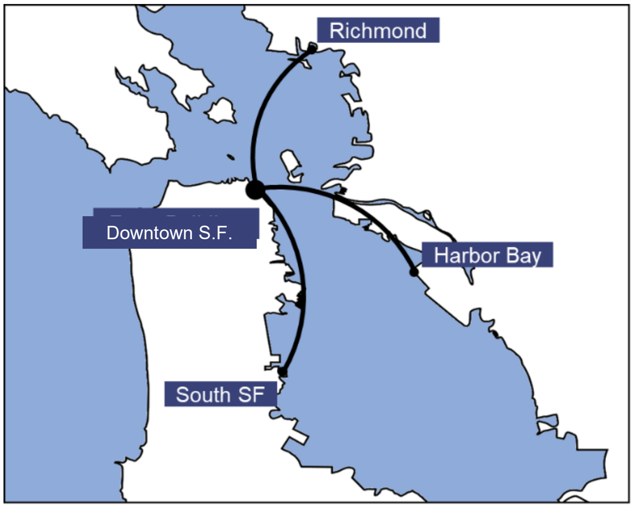

Figure 29: Map of Phase 3 Terminals & Routes

The terminals in Phase 3 include Richmond, Harbor Bay, and South SF (Table 13). 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. Operational changes are not yet defined but could include modifications to WETA's schedules and refueling protocols. 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. Section 8, Alternative Fuels Considerations, discusses zero-emission fuel options that could support the greater power requirements for longer routes.

Table 13: Phase 3 Terminal

Phase 3 Terminals	Utility Provider	Distribution Network Operator	Anticipated Stakeholders	Terminal Electrical Infrastructure Costs *(Million $)*	
				Low End	*High End*
Richmond[13]	PG&E	PG&E	City of Richmond	*$ 2.00*	*$ 4.00*
Harbor Bay	AMP	AMP	City of Alameda	$ 3.68	$ 5.50
South SF[14]	PG&E	PG&E	City of South SF	*$ 2.00*	*$ 4.00*

6.1. Phase 3 Terminal Site Detail

The project team has had preliminary discussions and information-gathering with AMP but is earlier in the process than Phase 1 and 2 terminals. The stakeholder engagement process has not started with PG&E for the Richmond or South San Francisco terminals, but will once utility service applications have been submitted. Site plans have not yet been developed for Richmond or South San Francisco because conversations with PG&E have not commenced. Aerial images of the terminals are included below (Figure 30 and Figure 31).

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[13] The costs for the Richmond terminal are still in development. These costs are estimates based on other representative terminals and will be updated through ongoing stakeholder engagement.

[14] The costs for the South San Francisco terminal are still in development. These costs are estimates based on other representative terminals and will be updated through ongoing stakeholder engagement.

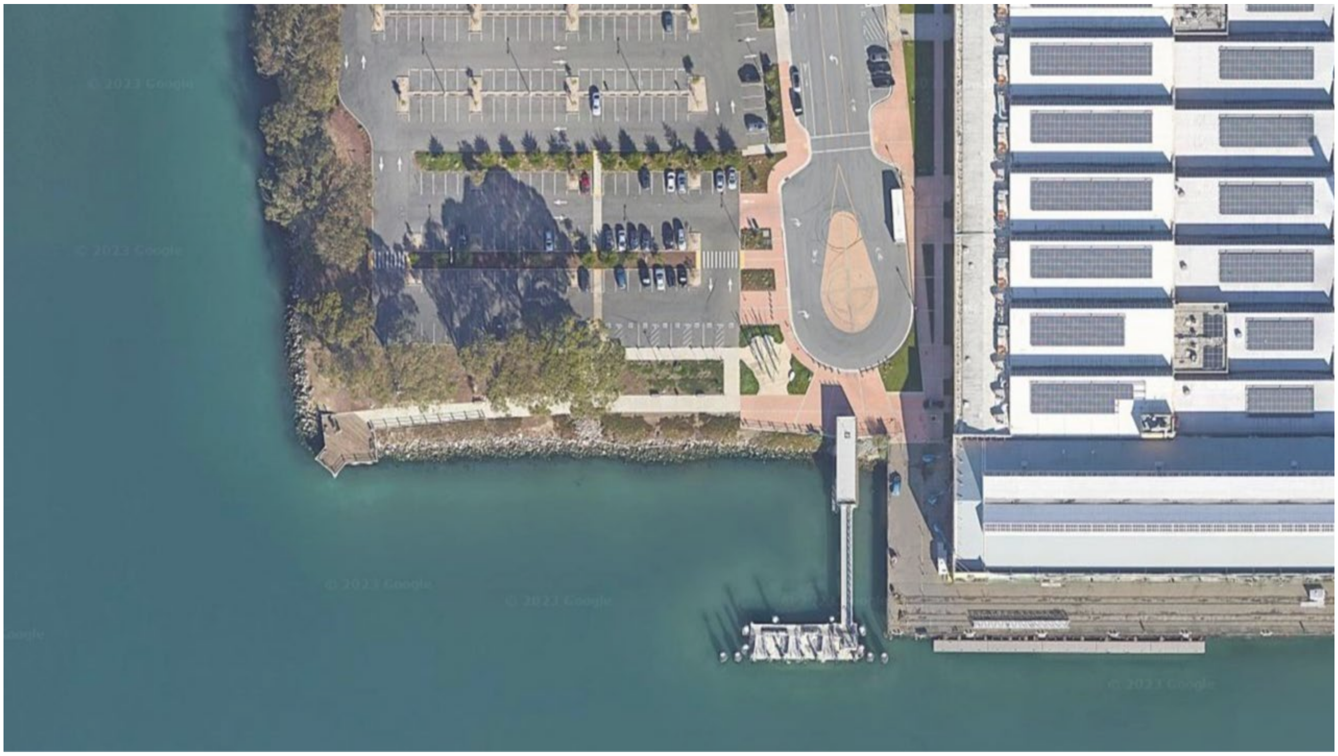

Figure 30: Aerial Image of Richmond Terminal *Credit: Arup*

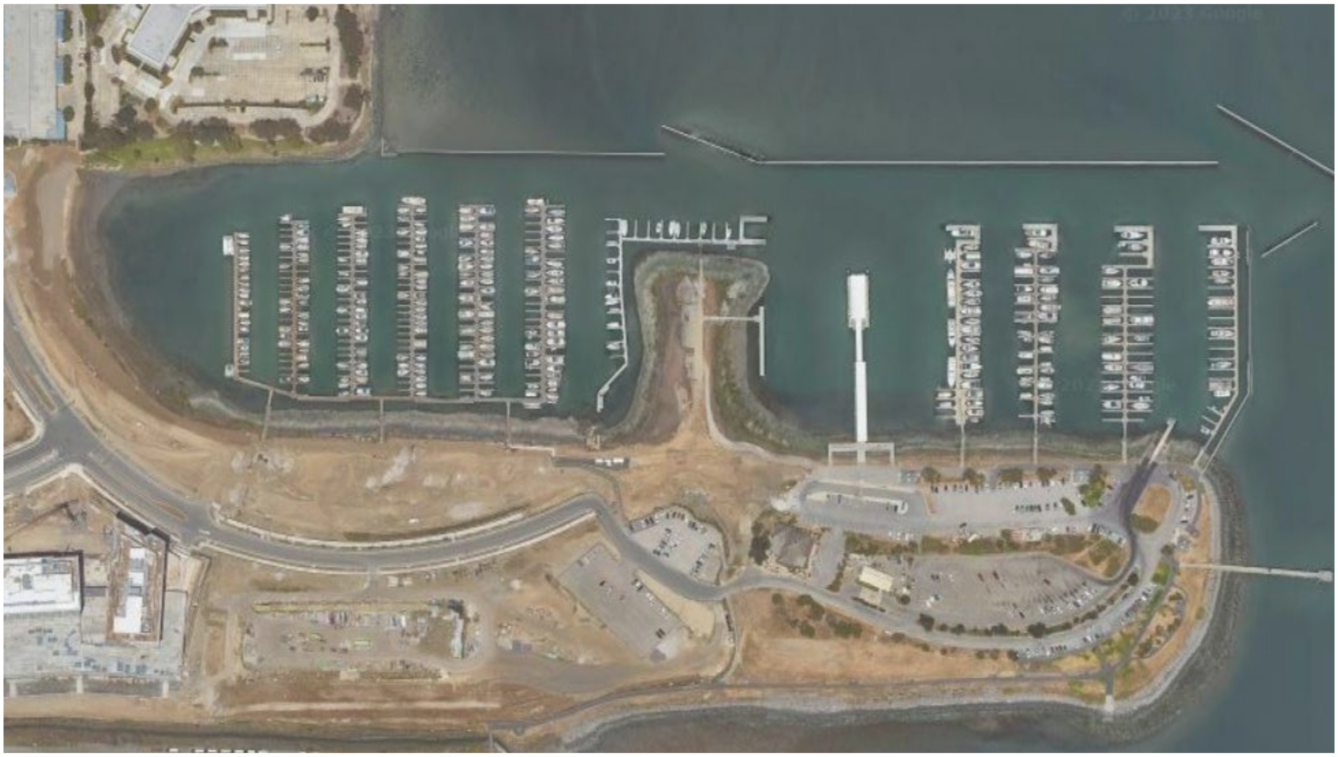

Figure 31: Aerial Image of South S.F. Terminal *Credit: Arup*

Below is the preliminary site plan for Harbor Bay (Figure 32). This site plan will be used in facilitating discussions with AMP and will continue to be iterated on as additional information is gathered for each terminal.

Figure 32: Aerial Image of Harbor Bay Terminal *Credit: Arup*

7. Phase 4 Terminal Implementation

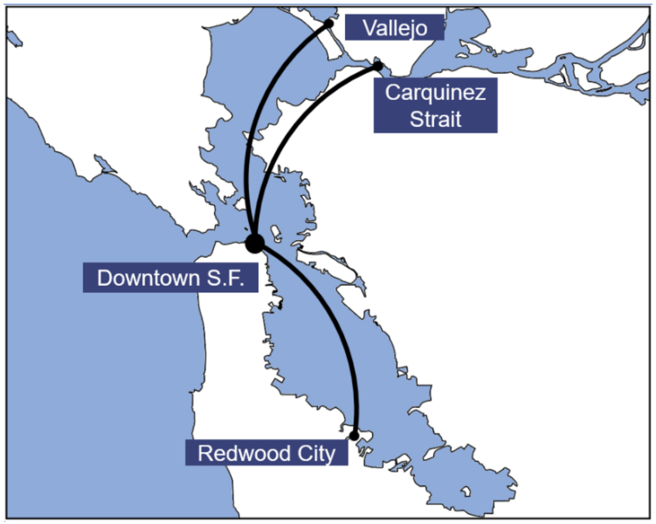

Figure 33: Phase 4 Long Routes

Phase 4 is not considered feasible with current battery electric technology, so 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. The Phase 4 terminals include Redwood City, Carquinez, and Vallejo (Figure 33).

8. Alternative Fuels Considerations

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, Phase 3 routes (with WETA's vessels and operational requirements) are at the edge of what is feasible with battery electric vessels, while Phase 4 routes are not feasible. For Phase 3, 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 Phase 3 routes. For Phase 4, zero-emission alternative fuel (non-battery electric) technologies are considered the only feasible zero-emissions option for the foreseeable future.

The two primary alternative zero-emission fuels being explored by industry are hydrogen and methanol, which are described briefly below.

Liquid Hydrogen

The use of hydrogen offers multiple benefits over battery electric ferries and was also considered as part of this study. Hydrogen has a very high energy density and quick refueling. When paired with a fuel cell, it produces zero emissions and can be sustainably sourced from renewable energy. The quick refueling and low weight are particularly big advantages over battery electric that make it appealing as a solution, especially for the long-distance ferry journeys. The safe storage of hydrogen onboard small, passenger-only vessels like WETA's is still in development, and the space and weight required for hydrogen storage still create several challenges when compared to diesel-vessels for medium and high-speed service. The fuel cost, and overall energy efficiency of hydrogen as a fuel, are significant current disadvantages when compared to battery electric that are expected to improve in the future.

Methanol

The marine sector has also been implementing the use of green methanol as a zero-emission fuel. Methanol has an energy density twice as high as liquid hydrogen and has a smaller space requirement, making it advantageous to liquid hydrogen. Further, it has proven to be easy to manage and meets marine operational safety standards. Methanol production differs depending on the technology and the feedstock used. The different production processes are detailed in Figure 34, below. WETA has not determined which fuel source will be used to support the future Phase 3 routes, but the benefits and drawbacks of multiple zero-emission fuels are being evaluated.

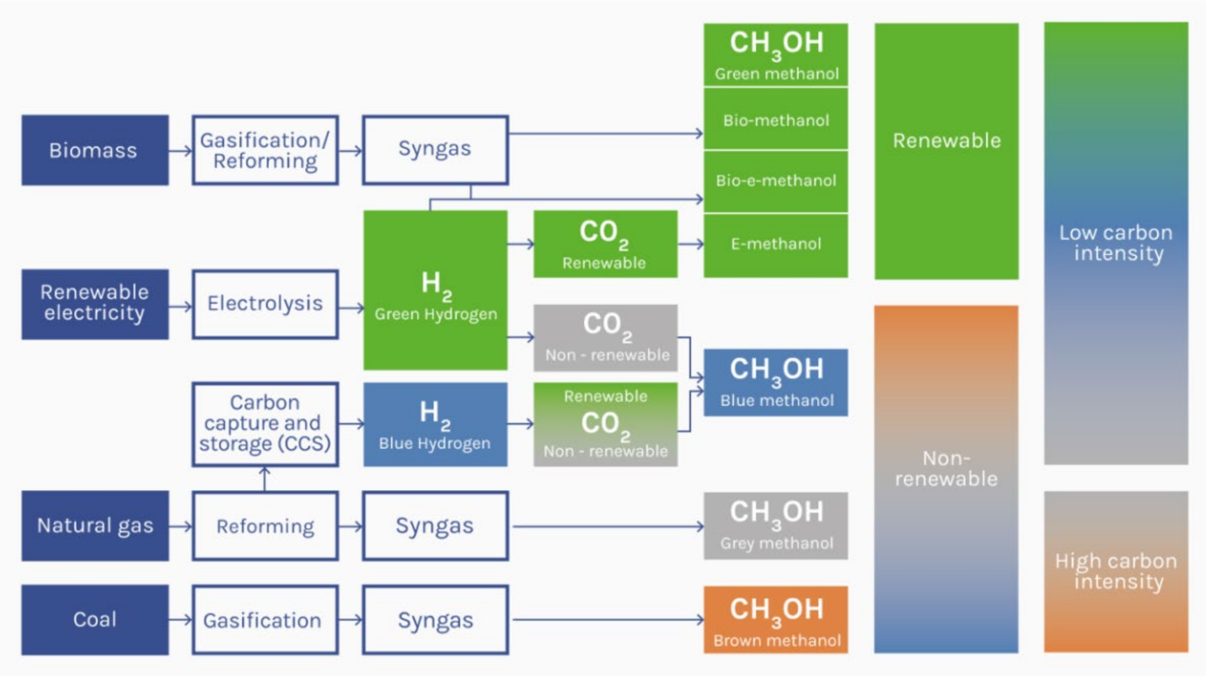

Figure 34: Methanol Production Process. *Credit: Global Maritime Forum*

9. Best Available Technology Assessment

Over the past decade, commercially viable zero emission ferry service has expanded rapidly worldwide. The growth in hybrid and battery electric vessels has created an equally impressive expansion in marine-specific battery and charging equipment manufacturing. According to DNV, (Det Norske Veritas) as of 2021 there are 333 vessels in operation worldwide using battery technology (hybrid and pure-electric), with 81 pure electric vessels.

As a nascent sector of the marine industry, zero-emission technologies have so far focused on the most technically feasible projects. In general, battery electric service is most viable for:

- Slow vessels
- Short routes (under ~3nm)
- Long periods of time at dock for charging
- Vessels with low sensitivity to weight
- Regions with strong political will for climate measures (e.g., Norway)

Most battery electric ferries in service today are car ferries, particularly vessels with short routes or long dwell times in port. Car ferries additionally have available space for equipment that is not typical in passenger ferries. WETA's operating profile consists of a high-speed route service with relatively short time periods at dock for passenger transfer, making them substantially harder to electrify than car ferries. As the technology improves and reduces in size and weight, more passenger-only, medium-speed vessels are being constructed. These vessels have similar service speeds, passenger capacities, and route distances to WETA's Phase 1 and 2 routes, providing a high degree of confidence the in ability for WETA to implement battery electric technology. A summary of key recent vessel projects globally is shown below (Figure 14).

Table 14: Key recent battery-electric passenger-only fast ferry projects globally

Vessel	Operator	Passengers	Service Speed (kts)	Charge Power (MW)	Charging Technology	Year Entered Service
Ika Rere	East by West Ferries (New Zealand)	132	20	1	Manual DC Fast Charging	2022
Medstraum	Kolumbus (Norway)	150	25	2.3	Manual DC Fast Charging	2022
Unnamed (10 Vessels)	Transtejo and Soflusa (Portugal)	540	17	4	Automated DC Fast Charging	2023
Electric Dream	Penguin International Limited (Singapore)	200	20	4	Automated DC Fast Charging	2023

Marine Charging Equipment

Three primary charging solution categories exist for the marine commercial market: Traditional manual marine shore-power plug solutions, Automotive-derived solutions, and Automated ship fast charging solutions. Low voltage AC, low voltage DC, and high voltage AC electricity can be used for each charging solution. For WETA's fleet, Low voltage DC is the optimal voltage, both for its vessel-side weight advantages, and for similarity with the automotive-derived DC fast charging solutions that are seeing the most development.

WETA's vessels exist in the middle of the two extremes; the charge power required to maintain service is larger than many automotive-derived solutions, but the ferries are smaller than the vessels that most automated chargers are designed to accommodate. Both options, however, are starting to be implemented successfully in WETA-sized vessels:

- Several small vessels are using multiple automotive-style DC fast charging cables in parallel to accomplish high charge power. Most notably, the Kolumbus's ferry Medstraum utilizes 6 combined charging system (CCS) plugs in parallel to achieve 2.3MW charging. Port of Auckland's tug Sparky similarly utilizes 4 CCS plugs to achieve 1.5MW charging.
- Newer automated connectors have more tolerance for movement, making them easier to implement on small vessels. Notably, Transtejo and Soflusa's 10-vessel fleet under construction and Penguin International Ltd.'s 3-vessel fleet under construction will use automated plugs for charging up to 4 MW on passenger-only catamarans of comparable size to WETA vessels.

There are currently no automotive-style charge solutions implemented with the 4-5 MW charging power desired for WETA's large vessels. By 2024, however, the automotive industry is expecting the release of higher-powered automotive chargers designed for trucks and buses. The Megawatt Charging System (MCS) is currently in development by an industry consortium that includes 280 member companies. MCS will be capable of 3000A at 1250 VDC (3.75 MW).

Both automated ship fast charging and automotive-derived solutions have merit and should be considered for WETA's implementation. There are several potential benefits to automotive-derived solutions that make it a better choice long-term if MCS becomes widespread. The economies of scale with automotive solutions create lower equipment prices, easier sourcing of spares, and higher levels of standardization between manufacturers and systems. For WETA's fleet, automotive-derived solutions also provide substantially more flexibility to account for the variations between vessels and docks than the current automated systems.

As charging expands to more energy-intensive services, the inability of grid infrastructure to handle the high loads at wharfs has become a significant bottleneck to adoption. It is becoming increasingly common in the European market to install shore-side battery systems to reduce the level of utility-side modifications required. Several additional benefits to shore-side battery storage include reductions in demand charges and increased resiliency during power outages. Shore-side battery storage has been successfully installed both onshore and in floating docks. For WETA's case, as discussed in earlier sections, battery energy storage is desirable at all "large vessel" docks, due to the high utility demand charges in the San Francisco area and due to the existing grid constraints.

Batteries

Lithium Ion is the primary battery technology for electric vessels. Three subcategories of lithium ion have been deployed by marine battery manufacturers: Nickel Manganese Cobalt (NMC), Lithium Iron Phosphate (LFP), and Lithium Titanate (LTO). Further, battery modules can be configured to favor either higher total energy (energy batteries) or higher available power (power batteries). Many experimental battery technologies exist that promise to improve or replace lithium ion; the most promising technology in the near term is solid-state batteries.

It is important to note that there is a noteworthy difference between marine batteries and those used in electric vehicles and other terrestrial uses. The manufacturing of the batteries is specialist and bespoke necessary to cater for the maritime environment and intensity of operations. This has big implications for multiple attributes, in particular price.

Of the current commercially available marine battery chemistries and configurations, most of the vessels in the passenger ferry market so far use NMC, high energy configurations. However, all the battery technologies listed continue to be somewhat competitive with each other due to their respective advantages and disadvantages. A study was performed in 2022 by UC Berkeley's student-run consulting group Bay Area Environmentally Aware Consulting Network (BEACN) to specifically assess current and future battery technologies for WETA's vessel fleet [15]. BEACN's primary conclusions were that currently and into the foreseeable future, NMC and LTO are the most competitive technologies. NMC is advantageous with respect to energy density and cost, while LTO is advantageous with respect to charge rate and sustainability. BEACN's final recommendation overall was to use LTO technology, but the report emphasized that both technologies are extremely competitive with each other for WETA's use-case. The two technologies should continue to be weighed against each other for both the ferries and the terminal energy storage systems as the electric fleet expands and as the battery technologies continue to mature.

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[15] Azhan, Billaut, et. al, (2022) *WETA Fleet Electrification Study: Future Battery Technology, Cost Projection, Environmental Impact, and End-of-Life.* Bay Area Environmentally Aware Consulting Network (BEACN).

10. Alignment with Climate Goals

While WETA currently operates a sustainable fleet, there is opportunity to further reduce emissions. WETA's ferry vessels are currently equipped with either EPA standard Tier 3 or Tier 4 engines and use two diesel types: ultra-low sulfur diesel (ULSD) or renewable 99 diesel (R99).

The project team employed a bottom-up emission calculation methodology to assess CO2 equivalent (CO2e) for Scope 1 and Scope 2 emissions generated from an all-electric fleet of ferries. Scope 1 emissions are defined as direct greenhouse (GHG) emissions that occur from sources that are controlled or owned by an organization. This means all fuel (i.e., diesel) purchased by WETA. Scope 2 emissions are defined as indirect GHG emissions associated with the purchase of, in the case of WETA, electricity. [16]

To calculate emissions from ULSD, R99, and gasoline, CARB's CA-GREET 3.0 data for carbon intensities was used. Table 15, below, outlines the emission factors used for these diesel fuels. Note that the well-to-wheel gCO2 per MJ are similar between ULSD and Gasoline. Because the heating value is slightly lower per gallon of gasoline, the CO2 per gallon is also lower. However, since diesel combustion is typically higher efficiency (in mpg or kwh per gallon), then diesel has a lower CO2 per kwh useful energy.

Table 15: Diesel Emissions Factors

Diesel Fuel Type	Emission Factor (gCO2e/MJ) [17]	Emission Factor (lbs. CO2e/ Gallon)
ULSD	100.5	30.0
R99	36.6	10.5
Gasoline	100.8	27.0

The emissions associated with an all-electric fleet scenario are not from fuel consumption, but a result of charging the ferries from the electric grid (i.e., Scope 2 emissions). California's grid emissions factor varies greatly, depending on the precise location and generation mix of the power suppliers. The California Energy Commission (CEC) requires retail energy providers to report details on the sources of energy that they supply to consumers. The 2020 figures that were published in the CEC's most recent power source disclosure are listed in Table 16. Also included in the table is the 100% carbon-free energy goal for each CCA.

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[16] Scope 3 emissions (supply chain) are assumed to remain constant under both emissions scenarios and have therefore been excluded from this analysis.

[17] Emissions factors sourced from the California Air Resources Board (CARB), *Substitute Pathways and Default Blend Levels for LCFS Reporting for Specific Fuel Transaction Types*

Table 16: CCA or Utility Provider for Each Terminal

Route	CCA	Emissions Factor lbs. CO2e / MWh	100% Renewable Energy Date
Treasure Island	Clean Power SF	40	2025
Mission Bay	Clean Power SF	40	2025
Oakland/ Alameda	Easy Bay Community Energy	591[18]	2030
Seaplane	Alameda Municipal Power	95	2045
Berkeley	Easy Bay Community Energy	591	2030[19]
Harbor Bay	Alameda Municipal Power	95	2030
Richmond	Marin Clean Energy	77	2025
South San Francisco	Peninsula Clean Power	13	2025
SF Downtown	Clean Power SF	40	2025

For consistency with this analysis and because PG&E owns the distribution infrastructure in the San Francisco Bay Area, PG&E emissions factors were utilized. PG&E's emissions factor is significantly lower than California's average grid emission factor, as compared below (Table 17). Emissions factors for 2021 through 2035 were then projected using linear regression based on California's and PG&E's 100% carbon-free energy goals.

Table 17: Emissions Factors for PG&E vs. Average California Utility

Provider	lbs. CO2e/ MWh[20]	100 % Renewable Energy Date
PG&E	160	2040
Average CA Utility	466	2045

Figure 35, below, illustrates the emissions for each fuel type for representative short- and medium-length routes. The representative routes focus on the Treasure Island route and Oakland/Alameda route. As depicted, the services provided by WETA emit significantly fewer GHGs when operating as electric vessels vs. diesel vessels. Electric ferries charging from PG&E's power mix are projected to reduce emissions by over 90% from standard diesel ferries. By 2035, when all the vessels on the Treasure Island and Oakland/Alameda routes are electrified, the electric vessels would emit 93.3% less emissions than R99 ferries. As California's grid mix strives to reach 100% renewable energy, these emissions will only continue to decrease.

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[18] *EBCE 2020 Power Content Label*

[19] *EBCE Integrated Resource Plan Results*

[20] Emissions factor provided as part of the California Energy Commission Power Content Labels for 2020 *https://www.energy.ca.gov/programs-and-topics/programs/power-source-disclosure/power-content-label*

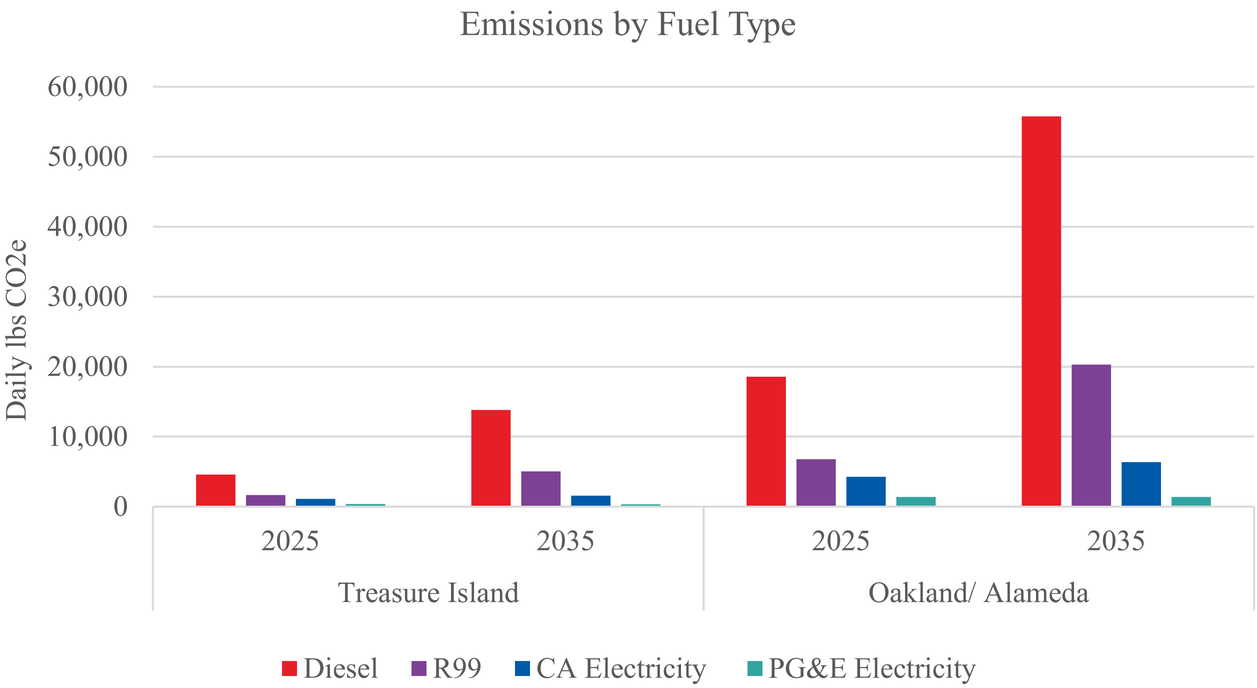

Figure 35: Treasure Island vs Oakland/Alameda Route Emissions by Fuel Type

10.1. Benefits to Disadvantaged Communities

Disadvantaged communities (DAC) are areas that experience disproportionately high adversity from economic, environmental, and health burdens. The Office of Environmental Health Hazard Assessment (OEHHA) developed CalEnviroScreen—a mapping tool that displays pollution data impacting communities—to demonstrate the environmental impacts of varying communities.

Figure 36 is the CalEnviroScreen 4.0 map of the San Francisco Bay area. As depicted, Treasure Island is in the 89th percentile, indicating that the community endures a disproportionate amount of pollution. The largest contributing exposure is traffic which could be considerably alleviated by commuters riding zero-emission ferries instead of driving single-rider vehicles. Further, CalEnviroScreen identifies asthma in the 94th percentile of sensitive populations. Asthma is a chronic disease that impacts the lungs, causing coughing and difficulty breathing. It is well known that that long-term exposure to air pollution, such as GHG emissions and particulate matter from traffic, can worsen asthma symptoms and increase the chances of developing asthma.

The Oakland terminal is in the 55th percentile overall, as indicated in Figure 36, and is most impacted by exposure to diesel particulate matter, placing in the 99th percentile. This community also identifies asthma in the 99th percentile for sensitive populations.

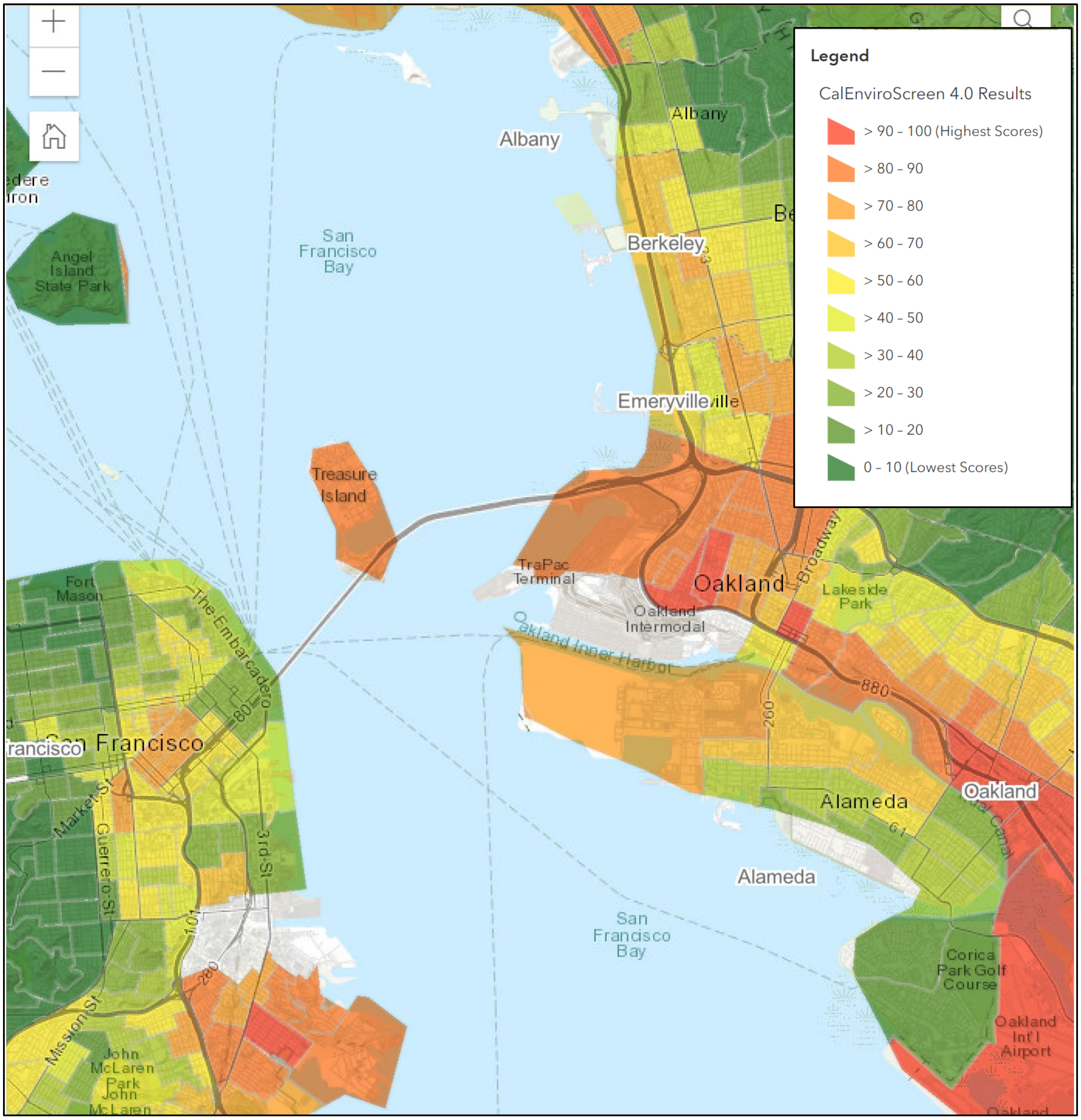

Figure 36: CalEnviroScreen 4.0 Bay Area Pollution Map

Though CARB has enacted strict emissions standards on traffic in California, vehicles are still a major contributor to GHG emissions, particularly in urban areas such as the San Francisco Bay Area.

11. Alignment with WETA Business Plan

A transition to zero-emission vessels has implications on WETA's operations, including a shift in operating costs and workforce development. This section discusses the projected operating costs for a zero-emission vessel fleet and opportunities for developing WETA's workforce.

11.1 Operating Costs

The electrical infrastructure that will be interconnected at each terminal is behind-the-meter, so it is subject to an electric tariff to purchase the electricity. Operational costs of purchasing electricity were calculated using Xendee, a techno-economic decision-making platform that was developed using scientific models of microgrid power and energy behavior modeling. Xendee' s intelligent modeling considered the tariff structure at each terminal, which can vary greatly depending on the utility and customer tariff. Electric tariffs encompass three key elements:

1. Price to purchase energy ($/kWh)
2. Charge based on the peak demand ($/kW of monthly peak demand)
3. Administrative fees ($/month)

The project team input the operational profiles of four representative terminals and their peak demands into Xendee (Table 18). The operational costs and tariffs used for each representative terminal were calculated based on a full fleet buildout in 2035 and do not consider any battery optimizations. Discharging BESS such that it reduces peak demands could allow WETA to realize electricity costs savings.

Table 18: Terminal & Electric Tariff

Terminal	Utility	Tariff	GWh / yr.	Consumption & Fees	Demand Charge	Total
				Thousand $	*Thousand $*	*Thousand $*
S.F. Downtown	SFPUC	SFPUC l-1P	27.6	$ 2,500	$ 7,700	$ 10,200
Treasure Island	SFPUC	SFPUC l-1S	3.1	$ 309	$ 570	$ 879
Oakland	PG&E	PG&E B-20	8.7	$ 1,600	$ 2,900	$ 4,500
Alameda Seaplane	AMP	Amp A-3	7.1	$ 940	$ 680	$ 1,620

As shown in Table 18, the estimated demand charges make up a substantial portion of the total yearly electrical cost. The demand charges shown are the worst case, assuming that no shore-side battery buffering is utilized at each terminal. BESS integration at terminals, which is discussed in previous sections, can substantially decrease the electricity cost at each terminal. BESS integration at terminals will reduce demand charges proportionally to the reduction in peak demand. The reduction is most evident at terminals where the peak energy demands are significantly higher than the average hourly demand (Oakland, S.F. Downtown). Reductions of demand charges of 30-50% are achievable with appropriately sized BESS systems.

For comparative purposes, the terminal electricity consumption was converted to equivalent diesel fuel use in Table 19**.** For example, the downtown terminal energy use of 27.6 GWh reduces the amount of diesel fuel burned by WETA's ferry fleet by 1.84 million gallons per year. The cost of electricity for this fuel savings, based on the worst-case electrical tariffs from Xendee, is the equivalent to paying 5.54 $/gal. The equivalent prices vary based on each terminal's utility tariff scheme. Again, the equivalent fuel price can be reduced further using on-site BESS; an additional diesel-fuel equivalent cost is shown based on a 30% reduction of demand charges at each terminal through BESS. Additional consideration should be given to utility tariff options and incentives to reduce electricity pricing.

In addition to the financial operating cost consideration, it is important to note that the transition to zero-emission vessels will reduce GHG emissions, and thus benefit disadvantaged communities. A more detailed analysis of the deduction in GHG emissions associated with a conversation to an all-electric fleet of ferries can be found in Section 10 (Alignment with Climate Goals).

Table 19: Terminal energy equivalent fuel cost (Annual, 2035)

Terminal	GWh / yr.	Diesel Fuel Use Abated	Equivalent Cost of Fuel, using worst case electricity tariffs	Equivalent Cost of Fuel, 30% demand charge reduction through BESS
		Thousands of Gallons	*$/gal Equivalent*	*$/gal Equivalent*
S.F. Downtown	27.6	1840	5.54	4.29
Treasure Island	3.1	210	4.25	3.43
Oakland	8.7	580	7.76	6.26
Alameda Seaplane	7.1	470	3.42	2.99

Maintenance Cost

ZEV vessels changes only the propulsion system on the vessels; all other components still require the same skills and expertise to maintain. Maintenance of battery-electric propulsion systems is generally considered to be less than for diesel systems. Modern 100% battery electric commercial vessels are a relatively new development, therefore historical long-term maintenance cost comparisons are not available; however, available data suggests propulsion maintenance cost savings of between 40% and 80% compared to diesel vessels, depending on the type of vessel and service. Analyses for light duty trucks comparing diesel and electric maintenance costs show similar savings. The reason that battery-electric propulsion systems have lower maintenance costs is simply due to the reduced number of moving parts. Maintenance tasks that are fully eliminated with a battery-electric vessel include fuel filter changes, injector maintenance, oil and oil filter changes, valve clearances and belts.

11.2 Workforce Development

Current Workforce

WETA fleet of 16 vessels and 8 facilities is currently supported by an operations subcontractor and their workforce. The WETA operations workforce generally includes the following roles:

- **Vessel Maintenance:** The fleet has an engineering support staff that tend to the day-to-day maintenance of the ferry fleet and facilities. This includes engineers and engine specialists.
- **Vessel Operations:** The vessels have on board operations staff that are certified by the United States Coast Guard (USCG) for vessel operations. This includes captains and deckhands.

The existing support staff is multidisciplinary to support the maintenance and operations of these vessels. New skillsets are required for ZEV vessels, but the training procedures currently used for existing vessels can be leveraged for training in these new skillsets.

New Workforce Roles

The following potential new roles have been identified for the operations and maintenance of the zero-emissions ferry fleet:

- **Charging Infrastructure Maintenance and Repair:** Maintenance of shore-side equipment will increase with the addition of charging equipment. Shore-side equipment infrastructure may require different skillsets and certifications than new vessel-side ZEV equipment. Although electrical equipment is generally low-maintenance, it necessitates frequent inspections by qualified personnel. Qualified personnel can complete maintenance work directly or through subcontracting.

- **Energy Management Experts:** Energy Management experts would monitor and manage energy storage systems on the vessels as well as any shore-side deployment of energy storage. The energy management experts would monitor the health of battery systems, as well as monitor and optimize battery interaction with the grid to minimize electricity costs. WETA staff or subcontracted expertise could meet the needs of an energy management expert role.

On a per-vessel basis, there is no expected change in the number of full-time employees (FTE) with electric vs. diesel vessels. The land-side charging equipment will require a similar level of FTE as the vessels, per-vessel.

Changed Workforce Roles

Currently, diesel engine maintenance requires a significant portion of vessel maintenance manpower. This maintenance is performed both by engineers (who are multidisciplinary) and engine specialists. Engine specialists are internal combustion experts that are factory trained and certified to work on the specific internal combustion engines in the ferry fleet and terminals.

Engine specialists, and diesel engine maintenance skills for other maintenance staff members, are expected to be modified, but not eliminated, in the transition to ZEVs. This is due to the following two factors:

- Diesel vessels will remain in the fleet during the transition period, and potentially for the foreseeable future for routes that are less feasible for ZEV.
- There is a need for emergency backup power in the case of power outages at shore-side facilities so that battery electric vessels can still be charged. Emergency backup power will likely be accomplished by diesel generators, which will need to be maintained.

New Training Requirements

The vessels ZEV 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.

Typically, all new vessels and machinery systems suppliers are mandated (by contract) to provide vessel specific training to the operating and maintenance crews upon delivery. The USCG will review training programs to ensure the vessels crews are sufficiently trained to operate the technology on an inspected vessel for passenger operations. Training programs are often specialized and tailored to the specific vessel, terminal and/or operator. The training programs outlined below represent adaptations of the standard training programs that are used today.

Commissioning Training - Operations

As new ZET equipment arrives at the terminals and on vessels, there will be a training program for the captains and deckhands for the operation of the equipment upon initial commissioning. This is the standard program that WETA follows with the installation or delivery of any new equipment. WETA will work with equipment suppliers and engineering consultants to determine the best team to administer this training. The operations training program will cover the following subjects:

- Vessel or terminal general overview
- Vessel or terminal operating instructions refencing the USCG approved operations manual.
- Individual detailed system review including the location, function, and operation of all system components. This also includes startup, shut down and emergency procedures.
- Specific vessel or terminal operating scenarios, docking, underway, charging or fueling (H^2), firefighting, man overboard drills, emergency bilge pumping, emergency override equipment operation and anchoring.

- Standard Operating Procedures (SOP) as it relates to fire, equipment failure and USCG reporting.
- Hands on training with vessel and/or terminal for scenarios covered in classroom portion of training.
- Safety hazards and SOP for all new and existing hazards.

Commissioning Training – Maintenance

As new ZET equipment arrives at the terminals and vessels, there will be a training program for the engineers for the operation, maintenance, and repair of the equipment. These programs are typically conducted by the equipment suppliers and engineering consultants. This is the standard program that WETA follows with the installation or delivery of any new equipment. The operations training program will cover the following subjects:

- Vessel or terminal general overview
- Vessel or terminal operating instructions refencing the USCG approved operations manual.
- Individual detailed system training including the location, function, operation, maintenance, and repair of all system components. This also includes startup, shut down, emergency procedures, all maintenance echelons, USCG and/or classification society requirements, troubleshooting, communications link software training and standard repair activities such as component replacement and overload device reset/replacement.
- Detailed review of electrical safety and specific ZET equipment safety related issues. USCG and classification society safety requirements.
- Detailed review of USCG Certificate of Inspection (COI) commissioning and annual testing requirements including Design Verification Test Procedures (DVTP), Qualitative Failure Analysis (QFA) and Periodic Safety Test Procedures (PSTP).
- Presentations from major equipment suppliers providing additional equipment specific information and manufacturer contacts for maintenance and repair points of contact.
- Hands on training with vessel and/or terminal equipment covering operation and component maintenance, repair, and replacement activities. Where applicable engineering staff will be sent to factory training centers for specific equipment certification.

Refresher or New Hire Training – Operations

After the ZET equipment has been placed into service, existing or new hire operations staff will require a refresher training course. The purpose of this course is to reinforce all items covered in the commissioning training programs at a classroom level. Where existing operation staff are taking the course, it will ensure their training has stayed current. The periodicity of training courses for existing staff will be determined through routine inspections and testing.

Refresher or New Hire Training – Maintenance

After the ZET equipment has been placed into service, existing or new hire engineering staff will require a training course. The purpose of this course is to reinforce all items covered in the commissioning training programs at a classroom level. Where existing engineering staff are taking the course, it will ensure their training has stayed current. The periodicity training courses for existing staff will be determined through routine inspections and testing.

Specific Equipment Training or Certification – Maintenance

WETA management will have to review engineering staff activities and competency, closely working with subcontractors to approve equipment supplier classes as needed. There are two scenarios that these training classes fall into:

- A factory certification program where members of the engineering staff obtain certificates to complete maintenance and repair activities that require special training and tooling to complete.
- There are specific pieces of equipment that have provided reliable and near maintenance free operation. In these cases, a large refresher course is organized with the equipment supplier.

New Training Programs and Certifications

Additional training could utilize the applicable national certifications programs and specialized training programs in conjunction with regional institutions. Regional institutions that could play a role in workforce development and training include:

- Maritime workforce training institutions such as the local maritime academy, California State University Maritime Academy (Cal Maritime)
- Vocational schools that have electrical certification programs
- Schools or certification programs that specialize in automation systems and information technology

New training programs will have to be developed in conjunction with the equipment suppliers and appropriate regional institutions or engineering consultants to support WETA and the industry. The training program should be tailored to provide the maintenance and operation personnel education in the following areas related to Energy Storage Systems (ESS), charging and propulsion equipment and any other ZEV that are implemented:

- ESS operation, maintenance, chemistry, failure modes and safety
- Equipment supplier training of system equipment, maintenance, and troubleshooting
- High Power Propulsion Inverter Properties
- PPE Selection
- Hazard & Arc Fault Risk Assessment
- USCG regulatory and or classification society requirements for ESS and Propulsion Systems
- Fire Fighting requirements for ESS

The training required for WETA personnel will be dependent on the final system architecture and associated equipment. As mentioned previously, the training scope for vessel systems is usually focused on on-the-job training, and training from equipment manufacturers and engineering consultants. At this stage, the scope for regional institutions is not well defined; further input will be solicited from institutions as to potential applicable existing training programs, as well as potential modifications to existing training programs that could improve workforce readiness in ZET equipment.

12. Key Conclusions

Ambitious climate goals from the State of California are driving the shift to clean transportation. Converting WETA's ferry operations to zero-emissions, however, requires long-term planning and close coordination with stakeholders. This Blueprint provides a four-phased approach over the next 20 years to transition WETA's fleet of vessels to zero-emission and were determined primarily 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 ZEVs 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. 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 S.F. Terminal. Many of the local grids are already constrained and have other entities competing for additional service requests. A combination of BESS, 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.