APPENDIX A:
Task 3 – Technology Assessment

Washington State Ferries

System Electrification Plan

WSDOT

Washington State Ferries

Table of Contents

Section 1:

Introduction

This memorandum summarizes the findings of an industry technology assessment to document the current and future state of hybrid and electric propulsion systems and supporting infrastructure. The industry has progressed significantly since the initial 2018 Jumbo Mark II Hybrid Electric Conversion Feasibility Studies. This memorandum discusses the following subjects:

- Delivered and on-order hybrid and electric RO-RO/PAX ferries
- Commercial marine battery manufacturers
- Current and projected marine battery performance parameters
- Commercially available rapid charging systems
- Technology developments related to vessel automation and equipment monitoring

Section 2:

Comparable Vessels

The list of comparable vessels was limited to RO-RO/PAX ferries between 15 and 550 cars. The majority are double-ended car ferries comparable to Washington State Ferries (WSF) vessels. As the number of hybrid ferries is rapidly expanding, this list is not exhaustive and will soon be out of date. The Norwegian Public Roads Administration predicts that "by 2022… there will be more than 70 battery-powered ferries operating on Norwegian fjords – either all-electric or hybrid-powered."[1] A recent article about WSF's conversion to battery hybrid states "there are currently 101 battery-operated car and passenger ferries in operation worldwide, with a further 76 under construction."[2]

The propulsion system type for each vessel is noted in the table with the following definitions:

- Hybrid: Operates on both engines and batteries utilizing the engines to charge the batteries.
- Plug-in: Typically operates solely on batteries utilizing shore power to charge the batteries. Engines are installed on the vessel, but typically not in use.
- All-electric: Operates solely on batteries utilizing shore power to charge the batteries. Engines are not installed on the vessel.

The In-Service Year for vessels on order or not yet in operation is bolded. Some cells remain blank where information was not readily available.

Additional information including operational parameters and hybrid system descriptions were

1 Tekna – The Norwegian Society of Graduate Technical and Scientific Professional, "Electric Ferries – a Success for the Climate and for Norwegian Battery Production," 4 February 2019. [Online]. Available: https://www.tekna.no/en/news/newsletter-february-2019/electric-ferries

2 J. Deign, "World's Second-Largest Ferry Operator Switching From Diesel to Batteries," Greentech Media, 29 November 2019. [Online]. Available: https://www.greentechmedia.com/articles/read/worlds-second-largest-ferry-operator-switching-from-diesel-to-batteries.

compiled for each vessel when available. An expanded table with this information is included in Appendix A.

Table 1: List of Comparable Vessels in Scandinavia

Vessel Name	Operator	Capacity		New / Retrofit	Propulsion Type	In Service Year
		Cars	Pax			
SCANDINAVIA						
AMPERE	Norled	120	360	New	All-Electric	2015
ELEKTRA	FinnFerries	90	375	New	Plug-in	2017
TYCHO BRAHE	ForSea	238	1100	Retrofit	Plug-in	2017
AURORA	ForSea	240	1250	Retrofit	Plug-in	2017
FOLGEFONN	Norled	76	300	Retrofit	Plug-in	2017
EIDSFJORD	Fjord1	120	345	New	Plug-in	2018
GLOPPEFJORD	Fjord1	120	345	New	Plug-in	2018
MOKSTRAFJORD	Fjord1	130	399	New	Plug-in	2018
HORGEFJORD	Fjord1	130	399	New	Plug-in	2018
HUSAVIK	Fjord1	50	195	New	Plug-in	2018
AUSTRÅTT	Fjord1	50	199	New		
VESTRÅTT	Fjord1	50	199	New		
HADARØY	Fjord1	120	399	New	Plug-in	2019
SULØY	Fjord1	120	399	New	Plug-in	2019
GISKØY	Fjord1	120	399	New	Plug-in	2019
LAGATUN	FosenNamsos Sjø	130	399	New	Plug-in	2019
MUNKEN	FosenNamsos Sjø	130	399	New	Plug-in	2019
NORANGSFJORD	Fjord1	120	350	Retrofit	Plug-in	2019
ROVDEHORN	Fjord1	120	199	New	Plug-in	2019
SKOPPHORN	Fjord1	120	199	New	Plug-in	2019
ELLEN	Ærøfærgerne	30	200	New	All-Electric	2019
COLOR HYBRID	Color Line	500	2000	New	Plug-in/Hybrid	**2019**
KOMMANDØREN	Fjord1	120	350	New		**2020**
TBN	Bastø Fosen	200	600	New		**2020**
FESTØYA	Norled	120	296	New	Plug-in	**2019**
TBN (2)	Norled	120	296	New	Plug-in	**2019**
MANNHELLER	Norled	120	296	New	Plug-in	**2020**
SOLVÅGEN	Norled	120	296	New	Plug-in	**2020**
TBN	Norled	80	299	New		**2021**
TBN - Havyard 141	Fjord1	50	199	New	Plug-in	**2020**
TBN - Havyard 142	Fjord1	50	199	New	Plug-in	**2020**
TBN - Havyard 143	Fjord1	50	199	New	Plug-in	**2020**
TBN - Havyard 144	Fjord1	50	199	New	Plug-in	**2020**
TBN - Havyard 145	Fjord1	50	199	New	Plug-in	**2020**
TBN	Fjord1	80	399	New	Plug-in	**2020**
TBN	Fjord1	80	399			
TIDEFJORD	Norled	120	350	Retrofit		
HEILHORN	Torghatten	60	199	New		
TBN	Norled	16		New		
STENA JUTLANDICA	Stena Line	550	1500	Retrofit	Hybrid	2018
HILLEFJORD	Fjord1	83	299	New	Plug-in	**2019**
TBN	Fjord1	83	299	New	Plug-in	**2019**
TBN	Fjord1	83	299	New	Plug-in	**2019**
TBN - MM111FE EL	Fjord1			New	Plug-in	**2020**
TBN - MM70FE EL	Boreal Sjø	60	199	New	Plug-in	**2019**

Table 2: List of Comparable Vessels in North America and Europe

Vessel Name	Operator	Capacity Cars	Capacity Pax	New / Retrofit	Propulsion Type	In Service Year
NORTH AMERICA						
MV PETER-FRASER	STQ	12	70	New	Hybrid	2013
SEASPAN RELIANT	Seaspan	59 trailer		New	Hybrid	2017
SEASPAN SWIFT	Seaspan	59 trailer		New	Hybrid	2017
GEES BEND	HMS Ferries	15	132	Retrofit	Plug-in	2019
AMHERST ISLANDER II	MTO	42	300	New	Plug-in	**2020**
WOLFE ISLANDER IV	MTO	75	399	New	Plug-in	**2020**
TBN (2)	Seaspan			New	Hybrid	
TBN - ISLAND CLASS	BC Ferries	47	300	New	Hybrid	**2020**
TBN - ISLAND CLASS	BC Ferries	47	300	New	Hybrid	**2020**
TBN (2) - ISLAND CLASS	BC Ferries	47	450	New	Hybrid	**2022**
TBN (2) - ISLAND CLASS	BC Ferries	47	450	New	Hybrid	**2022**
TBN	TxDOT	70	495	New	Hybrid	**2021**
EUROPE - OTHER						
HALLAIG	CMAL	23	150	New		
LOCHINVAR	CMAL	23	150	New		
CATRIONA	CMAL	23	150	New		
TÕLL	TS Laevad			Retrofit	Hybrid	**2020**
BEN WOOLLACOTT	Transport for London	45	150			
DAME VERA LYNN	Transport for London	45	150	New		2018
CRUISE BARCELONA	Grimaldi	300	3660	Retrofit	Hybrid	2019
CRUISE ROMA	Grimaldi	300	3660	Retrofit	Hybrid	2019
VICTORIA OF WIGHT	Wightlink	178	1170	New	Hybrid	2018

2.1 ForSea Ferries

ForSea Ferries, previously HH Ferries, operates the TYCHO BRAHE and AURORA between Helsingør, Denmark and Helsingborg, Sweden. These vessels were converted to hybrid propulsion in mid-2017. As discussed in Section 4.3.3, the charging systems were not fully operation until the end of 2018. These vessels are 111m long by 28m in breadth by 5.5m in draft and are approximately the same size as an Olympic Class vessel. Their crossing is 2.5 nautical miles long, very similar to the Mukilteo-Crossing, with charging on both sides. On the Denmark side the vessels dwell time runs as short as 5.5 minutes which requires a 10 MW charging rate with 10.4 kV connections.

Reportedly once designed to carry railroad cars, the vessels had a significant stability margin. Batteries and conversion equipment were placed on the upper deck in four large containers. See Figure 1 through Figure 34. Two contain the 4.16 MWh of batteries and the other two contain the shore conversion and battery charging equipment. Two 5,700 kVA shore power isolation transformers have four secondary windings each, are water-cooled, operate at an IEC noncontinuous S3 rating (connected 40% of the time) and convert the shore-side 10.4 kV down to 750V.

Figure 1: TYCHO BRAHE Battery Containers

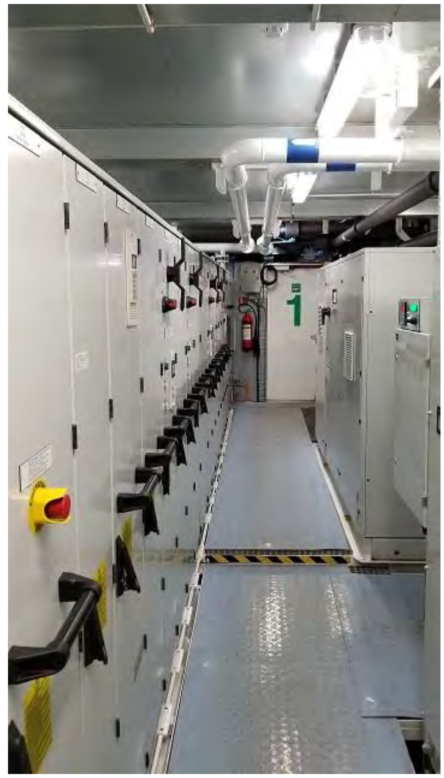


Figure 2: Interior of Converter Container

Figure 3: TYCHO BRAHE Shore Power Inverters

Figure 4: Sterling PBES (SPBES) Battery Racks

Section 3:

Commercial Marine Batteries

The below sections document battery industry developments since the initial 2018 feasibility studies were performed by Elliott Bay Design Group (EBDG) for WSF. Section 4.1 in the Jumbo Mark II Class Hybrid System Integration Study[3] and Section 3.3 in the Olympic Class Hybrid Feasibility Study[4] provide a more general background of battery technologies.

3.1 Battery Manufacturers

Several commercial marine battery manufacturers were researched for this market survey. Type approvals and location of manufacture are noted in Table 3. Buy America compliance was not confirmed, however only those systems manufactured in the United States would be eligible.

Table 3: Marine Energy Storage Systems

Manufacturer	Product Line	Location of Manufacture	Type Approval	Chemistry
Corvus Energy	Orca Energy	BC, NOR	ABS, DNV GL, BV,	NMC
Spear Power Systems	SMAR-11N	**USA**	DNV GL, BV	NMC
Siemens	BlueVault	NOR	DNV GL	NMC
SPBES	Power 65	CAN, DEU	DNV GL	NMC
Leclanché	MRS.9	DEU	DNV GL	NMC
XALT Energy	XRS142	**USA**	DNV GL	NMC
Saft	Seanergy	France	BV, LR	LFP

The above list is almost entirely composed of lithium-ion batteries with Lithium Nickel Manganese Cobalt Oxide (NMC) cells. NMC cells are used in most installations in the marine industry.

Lithium Titanium Oxide (LTO) batteries were discussed in the Jumbo Mark II Hybrid Feasibility Study as a potential alternative to NMC. However, the cost of LTO cells has not dropped at the originally anticipated rate. LTO cells are not widely used and have seen only limited use in vessel propulsion applications.

Lithium iron phosphate (LFP) is another chemistry that has been installed on a few hybrid vessels. LFP can approach the energy density of NMC, especially at the module or rack level. It has a perceived safety advantage over that of NMC as higher internal temperatures are required to initiate a thermal event and it releases less energy when it does. Unfortunately, LFP does not appear to offer any cost advantage in terms of dollar per kilowatt hour ($/kWh). With a considerably lower life cycle than the NMC alternative, LFP would have a more expensive life

[3] Elliott Bay Design Group (EBDG), "Jumbo Mark II Class Hybrid System Integration Study Appendices," 2018. [Online]. Available: https://www.wsdot.wa.gov/NR/rdonlyres/6C78A08B-19A1-4919-B6E6-E9EF83E6376D/123053/HybridSystemIntegrationStudyAppendixes.pdf.

[4] Elliott Bay Design Group, "Olympic Class Hybrid Feasibility Study, 18091-001-070-1," Elliott Bay Design Group, Seattle, WA, 2018.

cycle cost in terms of dollar per kilowatt hour cycle ($/kWh cycle).

With the overwhelming market share, lower cost, and greater energy density of NMC batteries, NMC chemistries are considered the most applicable solution for the near future. Each marine battery manufacturer and product line are discussed in further detail in the following sections.

3.1.1 Corvus Energy

Corvus Energy (Corvus) holds a majority share of lithium-ion battery installations on vessels. Originally founded in Richmond, BC in 2009, Corvus is now headquartered in Nesttun, Norway with a new fully automated factory in Norway. Corvus's product line has expanded since 2018 and now includes:

- Orca Energy for typical ferry applications
- Blue Whale for large installations
- Dolphin Energy/Power for weight-sensitive applications
- Moray Energy/Power for subsea applications
- Blue Marlin for high power applications

Of the Corvus offerings, the Orca Energy rack-based ESS is still the most well-suited for WSF applications. The Orca Energy can use either forced air or liquid cooling, but most supplied systems are forced air cooled. The Orca Energy has been installed on over 50 ferries worldwide.

Corvus manufactures the Orca Energy in Canada and Norway and holds a multitude of Type approvals including ABS, DNV GL, BV, and RINA.

3.1.2 Spear Power Systems

Spear Power Systems (Spear) designs and manufactures lithium-ion battery systems in Grandview, Missouri. Spear’s leading marine product line is still the Trident SMAR-11N rack-based ESS. The SMAR-11N can be either forced air or liquid cooled, but most supplied systems are liquid cooled. With no blind connectors of bus bars on the rear of the rack, Spear's system is modular and able to provide maximum flexibility for installation. Recent installations of the SMAR-11N include the Gee's Bend ferry in Alabama and the Maid of the Mist vessels operating at Niagara Falls.

Spear manufactures the SMAR-11N in Missouri and holds DNV GL and BV type approvals.

3.1.3 Siemens

Siemens is a German multinational company headquartered in Germany. Siemens acted as propulsion system integrators for years prior to the development of their own lithium-ion ESS. The BlueVault rack-based ESS was introduced in 2018 as the marine product line. Siemens offers only liquid-cooling and offers integral cooling skids in the rack line-up. Future US installations include the new Texas Department of Transportation Galveston ferries and the WSF Jumbo Mark II retrofit.

Siemens manufactures the BlueVault in Norway and holds a DNV GL type approval.

3.1.4 Sterling PBES Energy Solutions

In 2019, Plan B Energy Solutions (PBES) partnered with Sterling and Wilson, a power generation company, to form Sterling PBES Energy Solutions (SPBES). While SPBES headquarters are in Vancouver, BC, the company has a large European presence. The main product line is still the

Power 65 rack-based, liquid-cooled ESS. Prior to the creation of SPBES, PBES installed the Power 65 on the HH Ferries (now ForSea Ferries) vessel retrofits. Unfortunately, the Danish and Norwegian PBES holding companies went bankrupt before the project achieved its ultimate success in November of 2018. EBDG understands from HH Ferries/ForSea that there were delivery and operational issues during this period.

SPBES contracts the manufacture of the Power 65 ESS to a company in Germany and holds a type approval from DNV GL.

3.1.5 Leclanché

Leclanché is a Swiss battery manufacturer founded in 1909. Leclanché's marine product line is the scalable liquid-cooled Marine Rack System (MRS) available in rack heights of 3, 6, or 9-module variants. While the other systems require only external fire suppression, the MRS ESS requires a foam type fire suppression to be injected directly into the module. The all-electric ferry ELLEN, delivered August 2019, operates on the Leclanché MRS. Note the vessel recently required a three-week shipyard stay to replace 20% of all battery modules onboard. More detailed information is not publicly available; however, the ELLEN was not able to fully charge prior to the change out.

Leclanché manufactures the MRS in Germany and holds a DNV GL type approval.

3.1.6 XALT Energy

XALT Energy (XALT) designs and manufactures lithium-ion cells and battery systems in Midland, Michigan. XALT's product line adapted for the marine industry is the scalable XPAND Rack System (XRS) comprised of liquid-cooled XPAND Modular Packs (XMP). The first marine installation of the XALT XPAND ESS was in 2019 on the Kitsap Transit hybrid ferry, M/V WATERMAN. XALT has supplied cells to both Corvus for the AT6500 battery modules and SPBES (formerly PBES) for the Power 65 modules. As a result, their cells are installed on the six Scandlines hybrid vessels and the two ForSea Ferries (formerly HH Ferries) plug-in vessels.

XALT manufactures in Michigan and holds a DNV GL type approval for their XMP71P and XMP76P subpacks within their XPAND Battery System.

3.1.7 Saft

Saft offers its Li-ion Super-Iron Phosphate® cell chemistry in its Seanergy® battery modules for the marine industry.[5] [6] A battery system typically is composed of 14 modules per rack.[7] The modules come in either an energy or power battery type. As can be seen in Table 4, the energy density of the energy type of module is in the range of the lower half of NMC competitors. Unfortunately, the charge rates for the energy module are limited compared to all the others at about 1C. The cycle life is lower than its competitors at about 2000 cycles at 80% discharge. These batteries, then, may not be well suited for the high cycle count routes at Washington State Ferries.

[5] Seanergy® modules, Doc. No. 35016-2-0617, June 2017

[6] Seanergy® modules, Doc. No. 35016-2-0515, May 2015

[7] Saft, Seanergy® battery system, Doc. No. 35002-2-0515, May 2015

3.2 Performance Parameters

Performance parameters (energy density and specific energy), life cycle, and cost information is summarized in the following sections.

3.2.1 Energy Density and Specific Energy

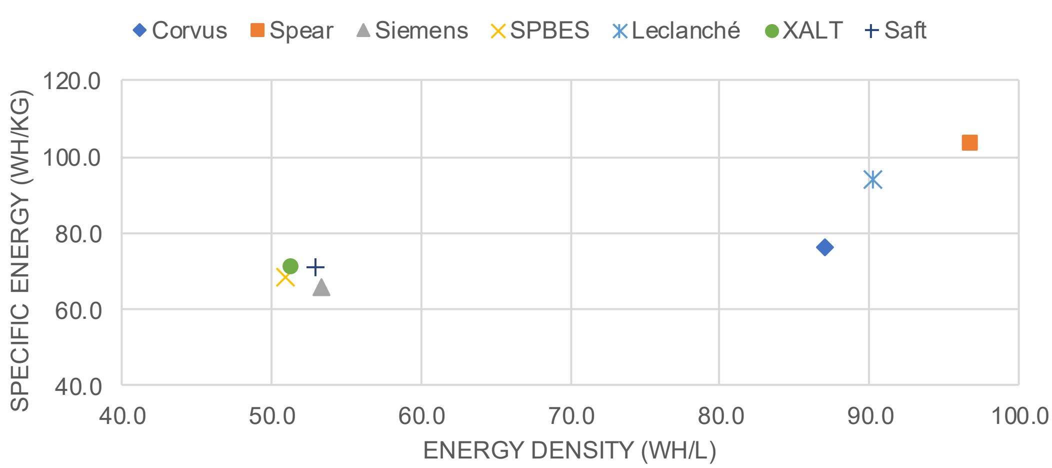
Energy density and specific energy are important parameters for marine energy storage systems. The first is energy per unit volume (Wh/L; watt-hour per liter), the latter energy per unit mass (Wh/kg; watt-hour per kilogram). Industry press announcements on new technology advances often quote specific energy at the cell level. Marine lithium-ion battery manufacturers often quote these parameters at the module level. EBDG finds it is often most helpful to determine these parameters at the rack level to ensure the weight or volume of all rack components are included.

Table 4 and Figure 5 provide comparisons of these parameters at the standard rack level for the six marine ESS manufacturers. XALT, SPBES, and Siemens are clustered together with relatively low energy density and specific energy. Corvus improves only on the energy density while the specific energy remains relatively low. At the opposite end of the spectrum, Leclanché and Spear offer significantly higher energy density and specific energy.

Table 4: Marine Energy Storage System Data at the Rack Level

Manufacturer	Product Line	Capacity (kWh)	Weight (kg)	Volume (m^3)	Energy Density (Wh/L)	Specific Energy (Wh/kg)	Nominal Voltage (V)
Corvus	Orca Energy	124	1628	1.4	87.1	76.4	980
Spear	SMAR-11N	124	1200	1.3	96.9	103.6	972
Siemens	BlueVault	59	900	1.1	53.3	65.9	900
SPBES	Power 65	65	950	1.3	50.9	68.4	888
Leclanché	MRS.9	58	616	0.6	90.2	93.8	969
XALT	XRS142	142	2000	2.8	51.4	71.0	884
Saft	Seanergy	53	560	1.0	53	71	647

Figure 5: Energy Density vs Specific Energy for Marine ESS



3.2.2 Life Cycle and Cost

Marine battery manufacturers have shifted away from publishing stated cycle life at a fixed depth of discharge (typically 80% DOD) since 2018. As discussed in the 2018 Jumbo Mark II Hybrid Feasibility Study, Corvus and PBES (now SPEBS) had previously included such information on their product spec sheets. XALT, as the cell manufacturer for PBES, has removed all references to cycle life on their publicly available spec sheets. Neither Spear nor Siemens have offered public information on cycle life. LG Chem, the cell manufacturer for Corvus, Spear, and Siemens, has not released any publicly available cycle life estimates.

The recent shift has been to estimations based on specific performance and operational criteria, not generic statements of cycle life based on somewhat artificial fixed and relatively high levels of depth of discharge. Companies such as Corvus, Spear, and Siemens have been forthcoming in providing battery sizing and cycle life estimates for notional applications. Cycle count, depth of discharge, temperature, and C-rate all contribute to aging of the cell.

With the increased number hybrid vessels in operation, these companies now have a much larger installed base of battery systems to track. Most of these are on high cycle count ferries, comparable to WSF. For instance, the first all-electric car ferry, MF AMPERE, entered battery-only service at Lavik-Oppedal in early 2015. With an initial 34 cycle per day operation from 2015 to 2017 and an increase to 48 cycles per day in 2017, the vessel is estimated to have completed at least 60,000 cycles in the first five years of service[8]. This installation of the first generation Corvus AT6500 ESS may provide some confidence that marine lithium-ion batteries can rack up impressive cycle life counts at reduced depth of discharge.

Recycling at end of life is an issue that continues to be raised. In the waste management hierarchy, reuse is almost always preferable to recycling. Marinized batteries in rack format may prove an ideal form factor for reuse over automotive batteries in customized and often odd shapes. For instance, a Tesla battery is one large battery pack almost extending fully from bumper to bumper and side to side, but not much taller than the 65mm height of the cells.

Marine batteries are typically sized for an “end of life” at 80% of original storage capacity. Outside the marine industry, lithium-ion batteries can offer considerably extended cycle life in reuse applications such as solar. The batteries on a WSF ferry would typically operate in a fairly demanding 1-2C range. Even a fairly rapid four-hour time shift of solar, ignoring lower levels of depth of discharge, would go no higher than 0.25C. Reused batteries coming off a single WSF vessel would have a storage capacity already sized for commercial or even grid solar applications.

Still, efforts at recycling are expanding. In January of this year, the US Department of Energy invested $15 million in their first Li-ion battery recycling R&D location at the ReCell Center in Illinois. Its goals include making Li-ion recycling competitive, profitable, and reducing US dependence on foreign sources of cobalt and other battery materials. It includes 50 researchers, six national laboratories and universities, manufacturers, suppliers, and other industry partners.

---

[8] T. Stenvold, " (Energy consumption on the electric ferry)," Teknisk Ukeblad (TU), 14 August 2017. [Online]. Available: https://www.tu.no/artikler/energibruken-pa-el-fergen-okte-med-20-prosent-pa-grunn-av-groe/398661.

The DOE also created the $5.5 million Battery Recycling Prize with the goal to incentivize entrepreneurs to find innovative solutions to collect, store and transport batteries to recycling centers[9].

EBDG has found lithium-ion pricing to continue a downward trend. When WSF began exploring marine lithium-ion batteries in 2011, NMC prices were in the $1100-1200 per kilowatt hour (/kWh) range. Current prices for marine are at roughly $650/kWh for a volume of 1MWh or above. Corvus appears to be leading in this regard, it has garnered a majority of the growing marine market. It may have begun achieving the economies of scale necessary to push prices further down.

3.3 Safety

Safety of lithium ion batteries is an important issue with instances of thermal runaways on marine vessels, aircraft, and with consumer electronics. A detailed discussion of previous events and some of the safety improvements added in the last few years can be found in Section 4.1.3 in the Jumbo Mark II Class Hybrid System Integration Study. The main safety improvements have been:

- Prevention of cell-to-cell propagation with testing and marine type approvals to IEC 62619
- Testing per the Norwegian Maritime Authority (NMA) RSV 12-2016 circular including module-to-module propagation tests and gas and explosion analyses
- Dedicated exhaust channels on many manufacturer's systems from inside each module to the back of each rack and out to a safe release point on the vessel
- Increasing transition to water-based fire suppression such as water deluge and water mist, either supplementing or replacing the earlier and exclusive use of gas-based fire suppression systems

As a way to assess the internal temperature of cells and detect a developing thermal runaway, thermal imaging was explored. Thermal imaging cameras employing thermography or even a standard heat gun might both allow for monitoring of peak temperatures experienced during maximum charge or discharge periods for enhanced safety. Found in countless research technical papers, thermography is used extensively in analyzing how accurate heat transfer models are in both normal peak temperature ranges and during thermal runaway at the cell level.

In the research papers, a single cell was exposed on all sides. In modern marine battery modules, the cells are usually stacked like slices of bread in a loaf from the front of the rack to the back. Further, manufacturers continue to develop thin thermal barriers between each cell to prevent cell-to-cell propagation. Some modules have 24-32 cells stacked from front to back. One technical source[10] describes it as follows:

> *"The distribution of temperature at the surface of batteries is easy to acquire with common temperature measurement approaches, such as the use of thermocouples and thermal imaging systems. It is, however, challenging to use these approaches in monitoring the internal temperature of LIBs [Lithium-ion batteries]. The self-*

[9] M. Jacoby, "It's time to get serious about recycling lithium-ion batteries," C&EN, Chemical and Engineering News, 14 July 2019. [Online]. Available: https://cen.acs.org/materials/energy-storage/time-serious-recycling-lithium/97/i28.

[10] Ma, et al., Temperature Effect and Thermal Impact in Lithium-Ion Batteries: A Review, Progress in Natural Science: Materials International, Nov. 28, 2018

production of heat during operation can elevate the temperature of LIBs from inside. The transfer of heat from interior to exterior of batteries is difficult due to the multilayered structures and low coefficients of thermal conductivity of battery components. The spatial distribution of internal temperature is also uneven."

Many battery manufacturers offer modules that are designed to slide out of the front of a rack which might allow thermography to reach surfaces otherwise inaccessible. Yet, such removal, especially during any event where thermal runaway is a concern, would present considerable challenges of its own from a safety standpoint. Some battery racks require the disconnection of electrical connections from the front beforehand. Many systems also have dedicated exhaust channels, liquid cooling connections or other thermal management and safety design features that might be compromised by module removal. Battery manufacturers usually install multiple temperature detectors inside each module to allow remote monitoring as the primary means to ensure either efficient or safe operation.

3.3.1 MF Ytterøyningen Battery Fire and Explosion

The most recent incident, and first on a car ferry, occurred October 10, 2019 on the MF Ytterøyningen in Norway. This vessel was built in 2006 but converted to battery-hybrid in 2019, was in regular operation and running on its diesel engines when the fire started. The investigation is still ongoing but preliminary reporting including from the responding local fire departments[11] states the following:

- The batteries (water-cooled Corvus Orca Energy ESS) were undergoing maintenance and were not supplying propulsive power.
- A fire of unknown origin was reported at 6:42pm while the vessel was in service on October 10.
- Crew had detected the fire while making a landing at the Sydnes ferry dock on Halsnøy Island. All passengers were quickly evacuated without incident.
- The vessel had a manual saltwater sprinkler system, automatic gas (Novec) system, and a foam extinguisher system.
- Crew had verified that the gas system did discharge.
- Firefighters responded from local fire departments and did apply a limited amount of their own "CAFS" foam from the top of the battery room through its escape hatch.
- For various reasons, the firefighters were not able to enter either the battery room or adjoining switchboard room during the next 12 hours.
- An explosion occurred at 6:52am on October 11 causing structural damage to the vessel.
- While none of the firefighters or crew treated for possible effects had any significant problems, the batteries generated hydrogen fluoride (HF) gas during the fire which can be harmful to anyone sufficiently exposed.
- Three clear and distinct warnings were made by the initial investigators and Corvus Energy to other operators with lithium-ion battery banks. One of those strongly suggested that the BMS system had been disabled to some degree prior to the event.

---

[11] A. Josdal, Fire and Chief, "Evalueringsrapport, Brann i MF «Ytterøyningen» 10.10.2019 (Evaluation Report, Fire in the MF«Ytterøyningen» 10.10.2019)," Kvinnherad Brann og Redning (Kvinnherad Fire and Rescue), Kvinnherad Municipality, Norway, October 2019.

The warning stated:

> *"Do not sail without communication between EMS and the packs (BMS). Keeping the packs powered up will maintain this communication link. An unpowered pack cannot communicate important system data (faults, warnings, temperatures and voltages) to the EMS/bridge. Ensure that current ESS parameters are showing at the EMS interface. This is a verification of the communication link."*

Corvus Energy then released preliminary finding published on their website December 12, 2019.[12]
Based on the investigations aboard the vessel, supported by external experiments and analysis, the following preliminary conclusion were cited:

> *"The most probable cause of the fire was a leakage in the battery system's liquid cooling circuit. Findings indicate that a twisted gasket, intended to seal the cooling plate outside of a battery module, is the most probable cause of the leakage.*
>
> *It is too early to conclude whether the twisted gasket was a result of the recent service work on the cooling system or if it was caused by other reasons.*
>
> *The leakage created arcing between electrical components, at pack voltages of 1000Vdc, igniting a fire. The fire was fueled by ethylene glycol components from the coolant and caused external heating of battery modules.*
>
> *Due to the ongoing service work, no part of the battery system was connected to the shipside systems at the time of the incident. Consequently, no alarms from the battery system were sent through the ship's alarm system.*
>
> *Findings have shown that the patented and certified Corvus Passive Single Cell Thermal Runaway Isolation safety system worked as designed and intended, most likely limiting the damage from the fire.*
>
> *Both the vessel's Novec 1230 inert gas system and the vessel saltwater fire sprinkler system were deployed during the event. The saltwater sprinkler system was installed as an additional safety barrier. Indications are that the activation of the saltwater sprinkler system contributed to escalating the incident.*
>
> *The further investigation will focus on how the extent and severity of the following events were able to develop towards an explosion 12 hours later in the switchboard room adjacent to the battery room."*

Norwegian Maritime Authority issued a press release the same day supporting these preliminary findings[13].

While energy capacity, service life, and unit cost are important considerations and financial drivers, it is important to perform battery selection with a holistic perspective that considers safety and the safety system that will be required, including but not limited to battery management system programming, maintenance procedures, temperature regulation methods, and fire

---

[12] Corvus Energy, "Fire onboard the car-ferry Ytterøyningen: Preliminary investigation results", Published Dec. 12, 2019 at https://corvusenergy.com/fire-onboard-the-car-ferry-ytteroyningen-preliminary-investigation-results/

[13] Sjøfartsdirektoratet (Norwegian Maritime Authority), "Supporting preliminary findings after battery incident", Published Dec. 12, 2019 at https://www.sdir.no/en/news/news-from-the-nma/supporting-preliminary-report-after-battery-incident/

suppression systems.

3.4 Trends and Future Technologies

The next near-term advance in lithium-ion battery chemistries is expected to be NMC-811. The three-digit number indicates the ratio of nickel, cobalt and manganese used. NMC cathodes have trended from the original NMC-111 (33% of each) to the most recently used NMC-622 (60% nickel, 20% cobalt and 20% manganese). While cobalt adds stability to the chemistry, increased nickel improves the energy density.

Over 60% of the world's cobalt comes from the Democratic Republic of Congo (DRC).[14] Between 10-25% of the DRC's cobalt is produced in artisanal mining operations. Such mines employ hand tools, have very little safety or environmental safeguards, regularly violate human and child labor rights and are often in the control of violent militias. Cobalt has historically been approximately four times the price of either nickel or manganese and much more volatile.

NCM-811 would reduce the percentage of cobalt to 10%. It would also improve its capacity by another 20-50% with the relative increase of nickel. It would take some time for manufacturing to overcome new challenges posed by the chemistry, but it is expected to ultimately reduce prices by more than 20%.[15] This drop would be in addition to the still declining prices of the existing chemistries. SK Innovations is said to begin production of NCM-811 cells this year.[16]

Solid-state electrolyte, lithium-sulfur and lithium-air batteries would all be respectively further out on the horizon. Perhaps the soonest to be feasible for marine, solid-state electrolytes (SSE) eliminate the flammable liquid electrolyte and could also limit or even block dendrites that lead to short circuits. One of the biggest challenges has been to increase the ionic conductivity, the ease with which a positive lithium ion (Li+) moves through a lithium-ion battery's electrolyte. SSE of the types Li7La3Zr2O12 (LLZO) and Li10GeP2S12 (LGPS) have amazingly achieved ionic conductivities on par with standard liquid electrolytes.[17] Seattle-area LAVLE is developing a solid electrolyte battery for the marine market with claims to release the commercial version as early as next year.[18]

3.5 Regulatory Environment

The US Coast Guard recently published policy letter CG-ENG No. 02-19 with the subject "Design Guidance for Lithium-Ion Battery Installations Onboard Commercial Vessels".[19] It contains the expected references and recommendations regarding Qualitative Failure Analysis (QFA, i.e. FMEA), Design Verification Test Procedures (DVTP) and Periodic Safety Test Procedures (PSTP) as would already be expected for a Subchapter H vessel. The policy letter introduces an

---

[14] N. Sherman, "The precious metal sparking a new gold rush," BBC, 26 July 2018. [Online]. Available: https://www.bbc.com/news/business-44732847.

[15] Research Interface, "What do we know about next-generation NMC 811 cathode?," Research Interface, 27 February 2018. [Online]. Available: https://researchinterfaces.com/know-next-generation-nmc-811-cathode/

[16] J. Nisewnger, "Report: SK Innovation to begin making NMC 811 cells in Q3 2019," Electric Revs, 31 May 2019. [Online]. Available: https://electricrevs.com/2019/05/31/report-sk-innovation-to-begin-making-nmc-811-cells-in-q3-2019/.

[17] F. Han, Y. Zhu, X. He, Y. Mo and C. Wang, "Electrochemical Stability of Li10GeP2S12 and Li7La3Zr2O12," *Advanced Energy Materials,* vol. 6, no. 8, pp. 1-9, April 20 2016.

[18] LAVLE, "LAVLE at Work on Solid Electrolyte Battery ESS for Marine Market," LAVLE, 22 March 2019. [Online]. Available: https://lavle.com/lavle-at-work-on-solid-electrolyte-battery-ess-for-marine-market/.

[19] R. C. Compher, Captain and Commandant, "Design Guidance for Lithium-Ion Battery Installations Onboard Commercial Vessels, CG-ENG Policy Letter No. 02-19," United States Coast Guard (CG-ENG), Washington, DC, October 2, 2019.

official reference to the new ASTM F3353-19: Standard Guide for Shipboard Use of Lithium-Ion (Li-ion) Batteries.[20]

ASTM F3353-19 calls out four references:

- IEC 62619 (2017) Secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes — Safety Requirements for Secondary Lithium Cells and Batteries, for Use in Industrial Applications
- UL 1642 Standard for Safety: Lithium Batteries
- United States Code of Federal Regulations (CFR): Title 46 Shipping
- ABS Guide for Use of Lithium Batteries in the Marine and Offshore Industries

The ASTM standard allows for either UL 1642 or IEC 62619 to be used for lithium-ion battery testing. UL 1642 does not require internal short-circuit or propagation tests. As a result, the standard potentially allows the use of battery modules that have not been tested for internal short-circuit or propagation. EBDG strongly recommends that any battery modules used on vessels meet the IEC 62619 testing for internal short-circuit and propagation tests at the cell level, which aligns with the ABS Guide for Use of Lithium Batteries and the DNV GL type approval. Section 5.2.1 of the ASTM standard does recommend propagation testing from module to module. Marine battery modules often contain 24-32 battery cells and a battery module fully involved in thermal runaway certainly represents a greater danger than a single internal cell.

While other standards allow either water or gas-based fire suppression, the ASTM standard includes a clear preference for water-based fire suppression, stating in Section 7.7:

> *"A fixed fire-fighting system should be provided, capable of preventing a Li-ion battery fire from propagating to adjacent compartments. This system should be water-based or show an equivalent capacity to absorb heat from a Li-ion battery fire. Considerations should be made to ensure that appropriate water mist or deluge can suitably access battery modules as applicable. For liquid cooled batteries, the cooling liquid may serve as an additional heat removal mechanism, but should not be used as a substitute for a fixed fire-fighting system. Reference should be made to any battery manufacturer's recommendations with regard to proper fire extinguishing agent, in consideration of particular battery chemistry used."*

Classification societies continue to revise and add to available marine standards. The most recent list includes:

- ABS Guide for Use of Lithium Batteries in the Marine and Offshore Industries, dated August 2018
- DNV GL Rules for Classification, Part 6, Chapter 2, Section 1, Battery Power, amended July 2019
- Bureau Veritas, Rules for the Classification of Steel Ships, Part F, Chapter 11, Sections 21 & 22, Battery System and Electric Hybrid, amended January 2019
- Lloyd's Register Type Approval System Test Specification Number 5, Type Testing for Lithium Battery Systems, dated March 2019

[20] ASTM International, "ASTM F3353-19: Standard Guide for Shipboard Use of Lithium-Ion (Li-ion) Batteries," West Conshohocken, PA, March 25, 2019

3.6 Shoreside Battery System

Many of the electrified routes in the coastal regions of Norway are in rural areas without access to the required power levels from the local utilities. These routes have utilized a shoreside Lithium-ion battery system to act as a buffer for the weak utility infrastructure. The shoreside batteries can charge from the grid at a lower rate throughout the day. When the vessel comes into dock to charge, the battery bank can either supply the full charging power or supplement the charging power from the grid.

Such installations require a climate-controlled building with space requirements for the additional power conversion equipment (inverters, filters, transformers, etc). Figure 6 shows an example of a building housing a shoreside battery bank building in Flakk, Norway with 900 kWh of batteries to support a 4.5MW charging rate. The vessels on this route were integrated by Siemens Norway.

Figure 6: Shoreside Battery Bank in Flakk, Norway

Shoreside battery installations to date have typically utilized the same marine battery system as installed on the vessel. However, utilizing a non-marinized grid storage battery system may present a more cost-effective approach.

The first automotive, marine, and grid storage Lithium-ion battery installations are just starting to reach end of life. End of life does not mean that the battery system is no longer able to function but is a function of available capacity. Battery aging is fairly linear from the beginning of life capacity (100%) to end of life (70-80% of original capacity). The rate of aging significantly increases when the battery reaches end of life, but the batteries can still be utilized in less critical applications as second use batteries. While the second use battery industry is still speculative and developing, there is high potential for application in a shoreside battery bank.

Battery systems onboard WSF vessels will require frequent replacements likely every four to five years. This will result in megawatt-hours of battery banks at end of life, but still with plenty of capacity for a potential second life as a shoreside battery bank. This application may prove to be the most cost effective and could also help to answer the question as to what happens to the onboard batteries after they reach end of life. However, as marine lithium-ion battery installations are still a recent phenomenon, repurposing at the end of life is an unproven concept and has not yet been implemented in a shoreside charging installation. Norwegian-based Stena Recycling has recently created a subsidiary named Batteryloop to develop a solution to use recycled batteries in charging stations at ports[21].

Nevertheless, the economics of utility power in the Pacific Northwest may challenge the case for shore-side battery energy storage. Much research has been done on the economics of energy storage and a $15/kW break point in demand charges is often cited for economic viability.[22] As found in previous studies done by Elliott Bay[23, 24], demand charges in the Pacific Northwest for large volume utility rate schedules are often in the $3-4/kW range.

Section 4: Rapid Charging Systems

Rapid charging systems (RCS) transmit high volumes of electrical power from the shore to the vessel and make the connection quickly for ferry or other short-docking operations. Such charging systems are a rapidly evolving technology and there are many design solutions available and in development to overcome various challenges.

RCS have been aided by the significant progress made in more slowly connected systems referred to as “cold ironing”. There has been increasing pressure placed on large ocean-going vessels such as cruise and container ships that burn heavy bunker fuel to switch to cleaner shore power. Starting in 2005, all Princess Cruises and Holland America vessels now connect to shore power while in Seattle.

The leading standard for such systems is IEC/ISO/IEEE 80005-1, first published in 2012. ABS published their Guide for High Voltage Shore Connection first in 2011. DNV published their Rules for Classification of Ships, Part 6, Chapter 29, Electrical Shore Connections, in 2012.

The most significant challenge to overcome with an RCS is the ship's motion and position relative to the pier. The system needs to span a gap to connect to the vessel without interfering with vessel operations while maintaining the electrical connection in a safe manner. Most existing systems utilize positive restraint to minimize vessel motions while at the dock. Positive restraint is typically provided by an automated mooring device near midship, such as a vacuum mooring system. These are discussed in greater detail in Sections 4.2.2 and 5.1.4.

The many types of solutions developed to address the RCS challenge are loosely categorized below:

- Mounted on Auxiliary Side Dock or Pier vs Loading Ramp vs Vessel
- Inductive vs Plug-In

[21] Batteryloop, "Quayside Powerbanks – The Next Step in the Electrification of Shipping", 2020. [Online]. Available: https://www.batteryloop.com/quayside-powerbanks/

[22] National Renewable Energy Laboratories (NREL), "Identifying Potential Markets for Behind-the-Meter Battery Energy Storage: A Survey of U.S. Demand Charges", Doc No. NREL/BR-6A20-68963, August 2017, Golden, CO

[23] Elliott Bay Design Group (EBDG), "Jumbo Mark II Class Hybrid System Integration Study Appendices," 2018. [Online]. Available: https://www.wsdot.wa.gov/NR/rdonlyres/6C78A08B-19A1-4919-B6E6-E9EF83E6376D/123053/HybridSystemIntegrationStudyAppendixes.pdf.

[24] Elliott Bay Design Group, "Olympic Class Hybrid Feasibility Study, 18091-001-070-1," Elliott Bay Design Group, Seattle, WA, 2018.

- Vertical (Hook) vs Horizontal (Arm Extension) vs Davit (Crane)
- Automated vs Manual

Ultimately, the RCS challenge is largely dependent on the specific arrangement and infrastructure of the pier or terminal. WSF does not dock vessels alongside a pier or auxiliary side dock. Currently, the vessels push on the wingwalls surrounding the dock's loading ramp during loading. A long transfer span adjusts for the over 20 ft of tidal fluctuation. A pivoting apron component at the end of the transfer span comes down on and adjusts to the vessel's flat car deck. For the largest volume crossings in the central Puget Sound, a separate passenger loading bridge adjusts and connects at the vessel's passenger deck height.

The WSF arrangement is not readily adaptable to the many broadside automated mooring and charging systems currently operating in Europe. Broadside systems cannot be used for WSF vessels and terminals without significant terminal improvements, including dolphin installation or modification, tethered barges, or floating docks. Such a solution may prove to be cost prohibitive. If connections are to be made from the existing types of structures, the locations are limited to a dolphin, wingwall, overhead passenger bridge, or vehicle apron.

Bow charging is more suitable to the WSF docking configuration as infrastructure improvements would not be as substantial. Bow charging may either be mounted on a stationary structure or on the vehicle ramp. The systems may not require a positive restraint (a mooring system that works in conjunction with charging) and could mesh with WSF's current operations of pushing on the dock while loading vehicles.

While almost all concepts install the RCS active component on shore, an alternative concept is to install the active component onboard the vessel such as the NG3 system (see Section 4.2.4). For a typical WSF vessel, the candidate location would be on or below the pickle fork. This is a non-conventional solution that is currently a subject of further investigation by potential charging system manufacturers.

Another significant variation in design solutions is whether systems are automated or manual. Automated shore power charging is discussed further in Section 5.1.2. The power levels involved with charging a WSF vessel will likely result in medium voltage. A rapid connecting, medium voltage charger may necessitate an automated system for safety of the crew involved. While the many benefits offered by autonomous charging systems come at significant capital cost, automated charging is especially advantageous when there is limited time to charge the vessel.

4.1 Performance Requirements of Rapid Charging Systems

Several aspects of rapid charging systems are important to consider:

1. Charge power. This determines how much energy can be loaded aboard the vessel in a given time, or conversely, how much time is required to transfer a given amount of energy.
2. Operating voltage. The decision is essentially between low-voltage and medium-voltage systems
    a. Medium-voltage requires thicker cable and transformer insulation, more careful grounding and ground fault protection measures, insulated busbars and

additional design, construction, and testing safeguards.

   b. Low-voltage systems will require higher amperage to pass the same amount of power. They will therefore require larger copper conductors, busbars and transformer windings leading to added weight.

   c. The power levels of most WSF routes will almost certainly require medium-voltage, due to the high current requirements of the anticipated power flow in a low-voltage configuration.

3. Time to connect and disconnect. As charge duration has a significant effect on performance and costs, connecting quickly upon arrival and disconnecting immediately before departure maximizes charge duration.

4. Automation and Autonomy. Given the speed required to make the medium-voltage connection, robotics will likely be necessary including infrared, laser or other optical sensors for connection targeting and telemetry to prepare a charging system for an approaching vessel. Tension, torque, pressure or other sensors may be needed to continually verify the integrity of a connection once passing high levels of power. Automation may reduce the requirement for additional crew or training as would be required for a manual system.

5. Range of motion. A careful analysis of motions will be necessary to ensure the system is designed to accommodate:

   a. Puget Sound tidal range on the order of 20 ft.

   b. Freedom of vessel movement along all three axes due to weather and current, wash from adjacent ferries, and vehicle loading and unloading.

6. Dependability. The ability to connect under most foreseeable weather conditions and vessel motions will be a key driver in the long-term success of medium vessel electrification. Consistent operation will be necessary during:

   a. All types of precipitation, from drizzle to windblown rain to thunderstorm downpour to light snow and ice accumulation.

   b. A wide range of lighting conditions including all possible angles of sunlight and resulting shadows and glare and both direct and reflected artificial lighting such as fixed area lights, vessel floodlights and headlights from loading and unloading vehicles.

   c. The full range of vessel surface temperatures which may be experienced.

   d. Reasonable levels of deterioration and fouling. Between drydocking, coating degradation and rust streaking must be accommodated. Additionally, the accumulation of mildew, marine growth, air pollutants and bird droppings must be avoided.

7. Structural and mechanical robustness. The system will require excellent corrosion resistance, galvanic protection, and minor impact resistance to improve performance and increase service life. Shore power rapid charging systems consist of a variety of

mechanical elements, and stout construction will enable long life.

8. Serviceability. Accessibility to wearing parts, quick trouble shooting and repair, and intuitive operation are advantageous. Additionally, spare parts, documentation, technicians, and technical support will need to be available. The layout of the charging system components could affect overall vessel operations. Service work required at various locations could impede vehicle or passenger loading or vessel arrivals and departures.

9. Safety. Proximity of the public and crew to medium voltage without sufficient barriers and protections in place is simply unacceptable. Circuit protection must include not just short circuit and overload trip settings but also quick acting and sensitive ground fault trips. Medium-voltage connection equipment either on the vessel or pier-side may require supplementary earthing conductors back to power sources and insulating layers between the metal casings of connection equipment and pier-side or vessel metallic structures.

4.2 Descriptions of Vendor Systems

Notable characteristics of the commercially available rapid charging systems described in the following sections are summarized in Table 5 below.

Table 5: Rapid Charging Systems Overview

Company	RCS Description	Autonomous vs Manual	Land Mounted vs Vessel Mounted	Inductive vs Plugin	Vertical vs Horizontal vs Davit
Stemmann-Technik	Pantograph Robotic Arm Crane/Davit	Semi-Autonomous Autonomous TBD	Land Land Land	Plugin Plugin Plugin	Horizontal Horizontal Davit
Cavotec	Vertical APS (Hook) Horizontal APS RL2C	Semi-Autonomous Autonomous Manual	Land Land Land	Plugin Plugin Plugin	Vertical Horizontal Davit
Mobimar	NECTOR	Autonomous	Land	Plugin	Horizontal
NG3	PLUG	Semi-Autonomous	Vessel	Plugin	Vertical
ABB	Robotic Plug System	Autonomous	Land	Plugin	Davit
Wartsila	Inductive	Autonomous	Land	Inductive	N/A
LOS Gruppen	Zinus	Manual	Land	Plugin	Vertical
Cochran Marine	Shore Power System	Manual	Land	Plugin	Davit

Each system and its applicability to WSF is discussed in further detail in the following sections. A high-level summary of the applicability of each system is shown in Table 6 below. Each system is ranked from 1-5 (least to most applicable) on power throughput, connection time, and WSF applicability.

- Power Throughput: Ability of the RCS to supply adequate power for a typical WSF vessel (approximately 8MW-15MW)
- Connection Time: Ability of the RCS to rapidly connect and disconnect to the vessel in the one to two minutes that will be necessary for WSF vessels

- WSF Applicability: Overall applicability to a typical WSF terminal and vessel

Table 6: Rapid Charging System Applicability to WSF

Company	Rapid Charging System Name	Power Throughput (1-5)	Medium Voltage or Low Voltage	Connection Time (1-5)	Side-Dock Required	WSF Applicability (1-5)
Stemmann-Technik	Pantograph	2	LV	4	Yes	2
	Robotic Arm	4	LV or MV	4	Yes	3
	Crane/Davit	4	LV or MV	3	No	3
Cavotec	Vertical APS (Hook)	2	LV	3	Yes	2
	Horizontal APS	3	LV or MV	4	No	3
	RL2C	1	LV	2	Maybe	1
Mobimar	NECTOR	4	LV or MV	4	No	3
NG3	PLUG	3	LV or MV	3	Maybe	2
ABB	Robotic Plug System	5	MV	4	Yes	2
Wartsila	Inductive	2	LV	5	No	3
LOS Gruppen	Zinus	2	LV	2	Yes	1
Cochran Marine	Shore Power System	5	MV	1	Yes	1

Rankings from 1-5 with 1 as least applicable and 5 as most applicable

4.2.1 Stemmann-Technik

Figure 7: Stemmann-Technik First Generation Horizontal Pantograph RCS

Stemmann-Technik GmbH first developed a horizontal pantograph charging system for Norled's MF AMPERE, Figure 7. Along with a Cavotec system mounted next to it (Section 4.2.2), it was the first RCS applied to a car ferry application. A pantograph is the typical arrangement for rail applications where a vertically extending control arm makes contact with an overhead cable. In this case however, a row of horizontally extending carbon brushes on shore makes contact with vertical busbars mounted in the side of the vessel. Both sides have automatic doors that cover up when the connection is not made. The vessel-side vertical busbars are sized to accommodate the tidal fluctuation. This system requires access to the side of the vessel with a pier running some part of the length of the berth. Since the pantograph pushes against the vessel to maintain contact between the brushes and busbars, it clearly requires positive restraint from the side of the vessel.

Stemmann-Technik then quickly developed a second-generation system, Figure 8. This system placed a horizontally extending robotic arm on a vertically traveling platform that moved up and down inside a tower. An electric eye allows it to autonomously target a fixed receptacle on the vessel. The first system went in operation on the Anda-Lote route in Norway in January 2018. In roughly three years, the company had made a big leap with the technology. The system was completed on schedule and has operated successfully since. With both vessels plug-in hybrid, Anda-Lote became the first zero emissions ferry crossing in the world. The system does not push against the vessel but makes an interlocking connection with plug and receptacle. Nevertheless, the systems have been mounted on a significant auxiliary dock with a vacuum mooring system at the side of the vessel. At least 26 of these “Generation 2” systems from Stemmann-Technik have now been installed or put in operation in Norway with 6 more on order.

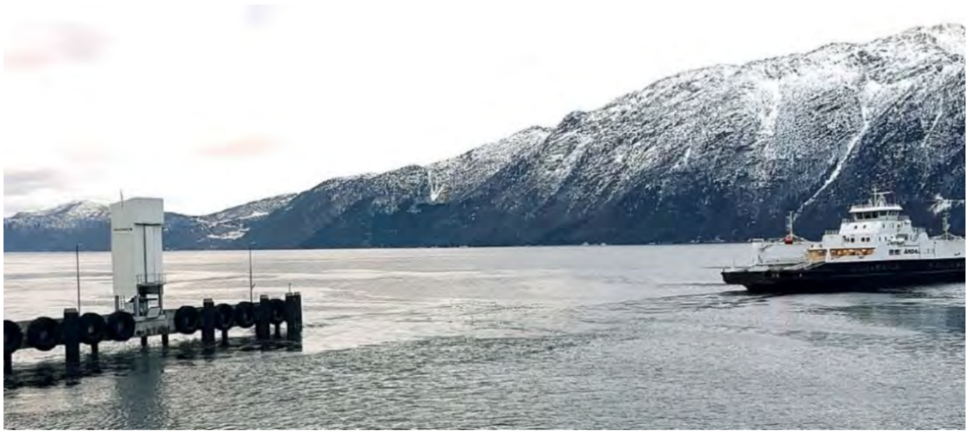


Figure 8: Stemmann-Technik Second Generation Tower RCS

Stemmann-Technik has just completed a detailed design and is currently manufacturing a new davit or crane-based system. Four of these units will be first used in Ontario, Canada at the Wolfe, and Amherst Island routes for the Ontario Ministry of Transportation. Each will be mounted at a location just to the side of the vehicle loading ramps and would be considered a bow charging solution. It is not known if these first systems will utilize or require positive restraint. Like all Stemmann-Technik RCS, they do retract into a safe position should the pilot contacts in the plug-receptacle connection be interrupted.

Figure 9: Stemmann-Technik Third Generation Crane Based RCS

4.2.2 Cavotec

Cavotec offers both manual and automatic e-charging technologies and automated vacuum mooring systems (positive restraint).

The automated plug-in system (APS) requires no human intervention and requires minimum modifications to vessels. Figure 10 below shows the APS Towers that establish connections in under 30 seconds when combined with an automated mooring system.

The Cavotec APS Tower is mounted on a pier alongside the vessel. It is an enclosed tower which features a plug assembly that lowers into a receptacle installed in the side of the vessel. The APS-vertical system is a proven technology with two active installations in Europe. It is currently employed for the MF AMPERE on the Lavik-Oppedal route in Norway and the ELEKTRA on the Parainen-Nauvo route in Finland. The existing APS vertical installations are mounted near the midship point of the ferry with a pier extending out a substantial portion of the vessel length. Both systems use a Cavotec MoorMaster automated vacuum mooring system to provide positive restraint for the connection, Figure 11.

Figure 10: Cavotec APS Tower RCS

Figure 11: Cavotec MoorMaster Automated Vacuum Mooring System

Cavotec has also developed a horizontal APS system as a bow charging solution. Initial concepts show this system mounted to an auxiliary side dock adjacent to the vehicle loading ramp. This system would require a much shorter auxiliary dock (or pier), extending no further than the ramp itself. There are or will soon be over 20 installations of the bow charging APS in Norway. Further discussed in Section 4.3.1, there may also soon be opportunities in Norway for this system to be mounted on the car ramp itself.

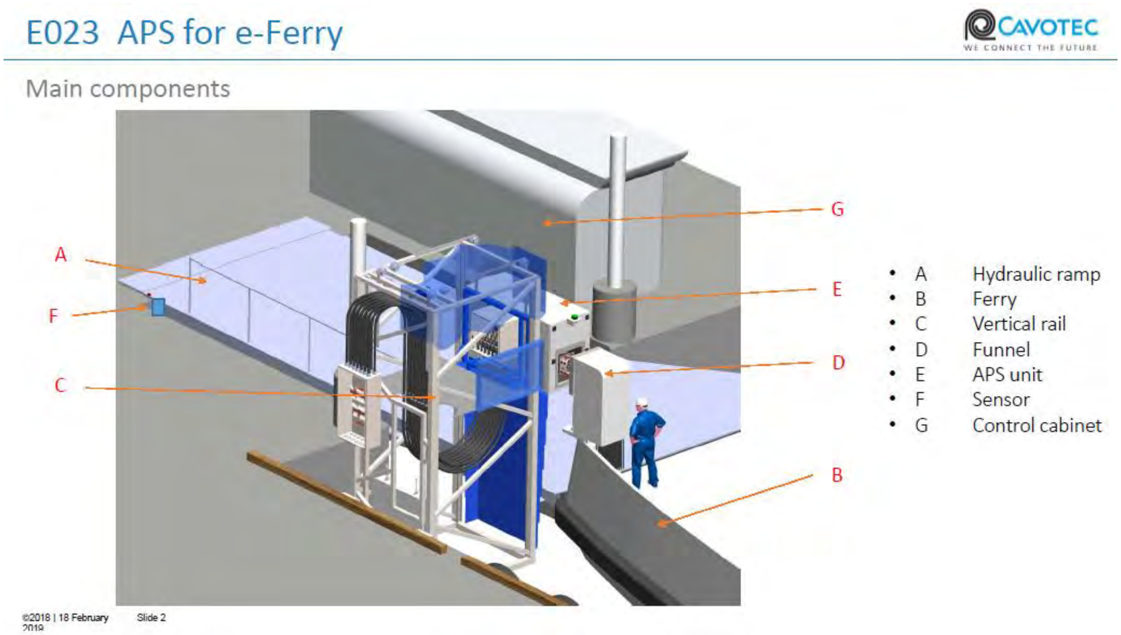


Figure 12: Cavotec Horizontal APS RCS

Cavotec has developed and deployed manually controlled davit systems for typically smaller vessel electrification. While these would likely not offer any practical feasibility for WSF operations, they demonstrate Cavotec's breadth of RCS offerings.

Figure 13: Cavotec Manual Davit

4.2.3 Mobimar

Mobimar offers a ramp-mounted bow charging system called NECTOR that can establish a rapid autonomous connection to the vessel, Figure 14 and Figure 15. The system can be easily activated with a push button from the bridge.

The greatest challenge facing Mobimar's system has been the lack of ramp-mounted charging systems implemented in Norway. As mentioned with the Cavotec horizontal system, there may soon be opportunities for ramp-mounted systems in Norway (see Section 4.3.1).

Currently the largest NECTOR model can transfer 4.2 MW at 750V DC, or 3.2 MW at 690V AC. Mobimar has developed a concept system for 11kV, which is comparable to expected WSF charging rates. The all-electric ferry ELLEN, serving the town of Søby, Denmark on Aeroe Island, uses the NECTOR to charge before its 22 nautical mile round-trip transit.

Figure 14: Mobimar NECTOR RCS

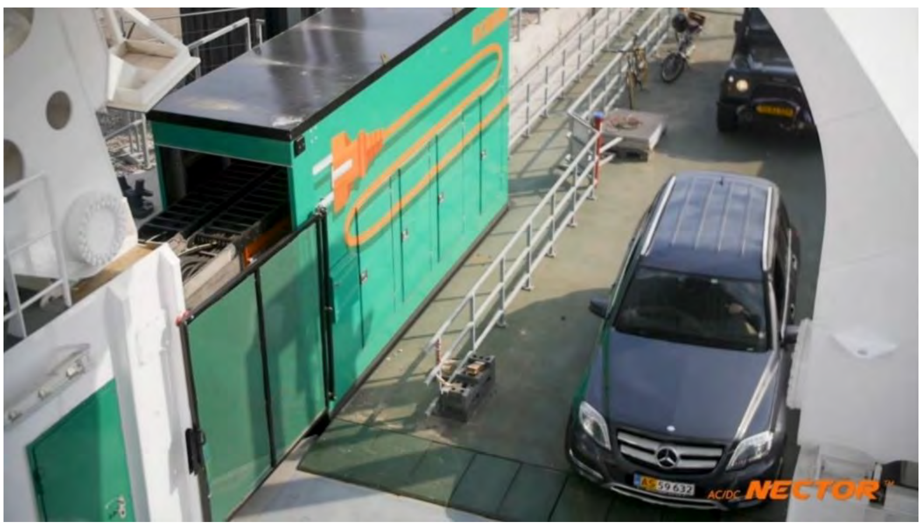


Figure 15: Mobimar NECTOR RCS

4.2.4 NG3

NG3 has supplied systems for large passenger ships operating in Scandinavia. The PLUG system has a vessel mounted arm that extends from the vessel, Figure 16. From this arm, it pays out a chain and hook that grabs a shoreside cable and pulls it up and into a receiving receptacle mounted to the extended arm. The system supports an 11kV and 4.5MVA connection and can connect in roughly one minute.

Since 2011, the system has been operating onboard five large ColorLine passenger vessels and at four terminals at which they operate. In 2016, a system was also piloted onboard Norled’s FOLGEFONN ferry and Jektevik terminal with a “baby” PLUG system modified for low voltage and high amperage. The company has patented the plug and receptacle connection system in the EU and US.

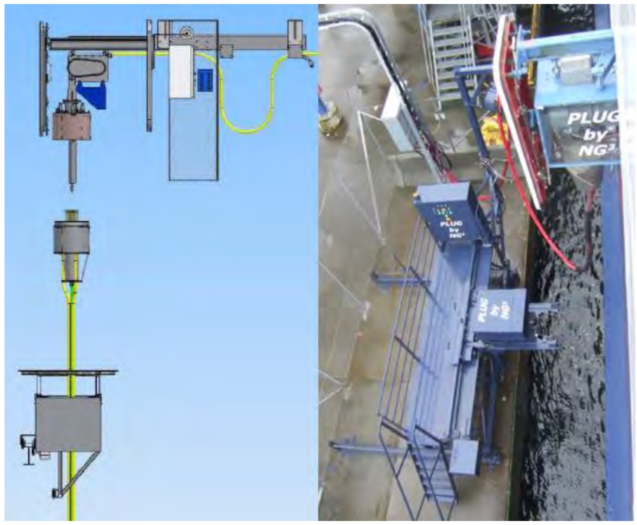


Figure 16: NG3 Plug RCS (left, engineering diagram; right, photo of installation)

4.2.5 ABB

After Siemens had succeeded with the groundbreaking electrification of MF AMPERE in 2015, ABB placed its considerable reputation on the line to take the technology to an even higher level in 2017. Whereas the AMPERE charged at low voltage and at around 1.5MW, ABB's ForSea Ferries (previously HH Ferries) retrofit project took this to a medium-voltage level of 10kV and 10MW, charging 4.2MWh battery packs in as little as 5 minutes.

The key RCS components were charging towers housing ABB factory robots, Figure 17. These towers were placed on already existing substantial side dock infrastructure with positive restraint. Despite challenges in making connections quickly enough, the system has finally achieved an approximately 95% success rate. The vessels now consistently make zero emissions crossings and have reduced the overall carbon emissions of their energy consumption by 65%.

The size and weight of the ABB towers is substantial and may be prohibitive for WSF. The towers are 8.67m high, 3.13m wide and 4.93m deep. Each weigh 20.9 metric tonnes. ABB made significant investments in this equipment and gained valuable know-how and insight while recognizing that this system was applied to an operator with unique existing infrastructure and operations.

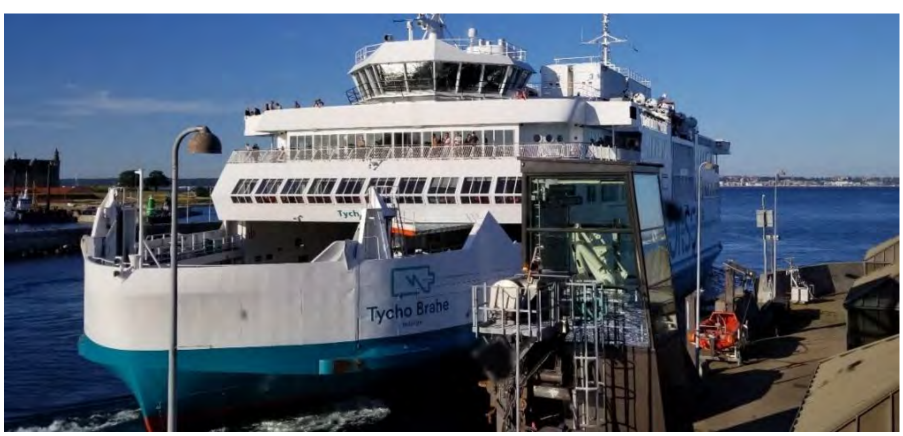


Figure 17: ABB Tower RCS

4.2.6 Wärtsilä

A wireless inductive charging system has been developed by Wärtsilä, Figure 18. The system has an advertised capacity of approximately 2MW and is integrated with an automatic vacuum mooring system. This system also connects along the midship portion of the vessel, requiring a pier or access alongside.

The system uses a transformer principle but without an iron core. It is able to obtain a 97% efficiency across the inductive air gap by creating a magnetic resonance at an elevated frequency in the 2-8kHz range. This frequency is optimized for the air gap distances and geometry of the shore-side and vessel mounted electrical windings.

As a result of the elevated and optimized resonant frequency, a complex rectifier-inverter arrangement is required up stream of the shore-side magnetic field with an expected added cost. Advantages of the novel approach are the ability to establish a galvanic isolation between shore and vessel right at the point of coupling, to allow the vessel mounted windings to have some relative motion to the shore-based winding and for the connection to be made almost immediately once the two plates come within range of each other. While this is an impressive technical solution, it is challenged to overcome cost, complexity, and efficiency drawbacks in becoming a widespread solution.

Figure 18: Wärtsilä Inductive RCS

4.2.7 LOS Gruppen

The LOS Gruppen Zinus RCS offering is a manually operated system and unlikely to be of benefit to WSF. It does represent a new entrant into this emerging field. The Zinus Port Power 850 offers four vertical plugs hanging from an extendible overhead arm, Figure 19. It is rated to supply 230-690VAC and up to 1400A for a power transfer of up to 1.6MW.

Figure 19: LOS Gruppen Zinus RCS

4.2.8 Cochran Marine

Cochran Marine is based in North Seattle and is a world leader in medium-voltage shore power systems for cruise ships. They have installed many systems in seven major ports across North America. They have also developed a 50 to 60Hz conversion system to target Europe and other parts of the world needing to provide power to such large vessel types.

Cochran Marine supplies an entire system: the utility intertie, transformers and any conversion equipment, switchgear, protective devices, control components, cable positioning and connection components. Figure 20 shows a representative offering from Cochran Marine. While their current systems would not be considered an RCS, Cochran Marine warrants mention as their systems regularly charge large cruise ships at medium voltage in Elliott Bay. Cochran Marine has also been exploring RCS solutions with key partners to help tackle the WSF type of challenges.

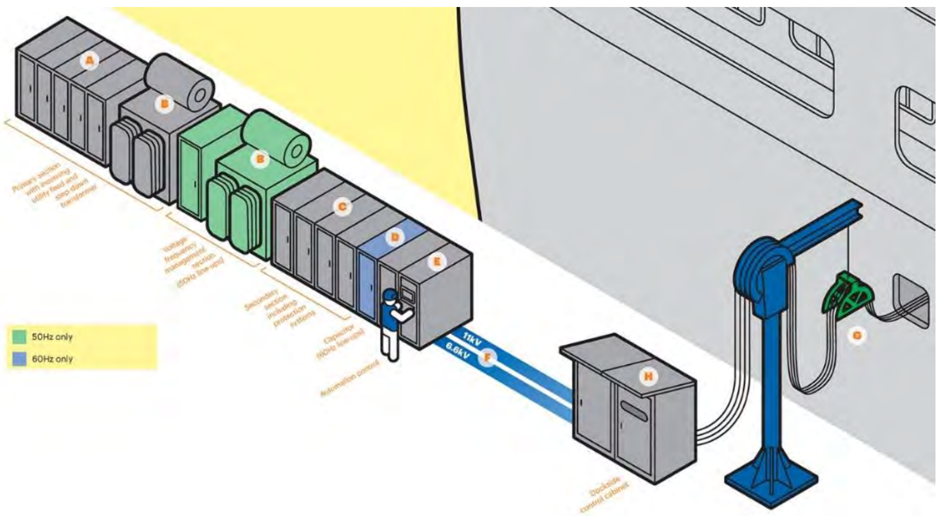


Figure 20: Cochran Marine Sample Charging System

4.3 Rapid Charging Systems Related Issues

4.3.1 Norwegian Road Administration Approach

The Norwegian Road Administration, or Staten Vegvesen (SVV), was a partner in developing the first car carrying all-electric ferry MF AMPERE. Like many significant transportation organizations, SVV publishes a large number of design, construction and installation standards.[25] Four of these handbooks relate to ferry docks: N400, V431, V432 and V433. These standards show that an auxiliary side dock is a well-defined item. Figure 21 below from the N400 Handbook[26] shows the auxiliary dock.

[25] Statens Vegvesen, "Håndbøker (Handbooks)," 15 October 2019 (last update). [Online]. Available: https://www.vegvesen.no/fag/publikasjoner/handboker/

[26] Statens Vegvesen, "Håndbok N400, Prosjektering av bruer, ferjekaier og andre bærende konstruksjoner (Handbook N400, Design of Bridges, Ferry Piers and Other Load-Bearing Constructions)," 2015. [Online]. Available: https://www.vegvesen.no/_attachment/865860/binary/1030718?fast_title=H%C3%A5ndbok+N400+Bruprosjektering.pdf.

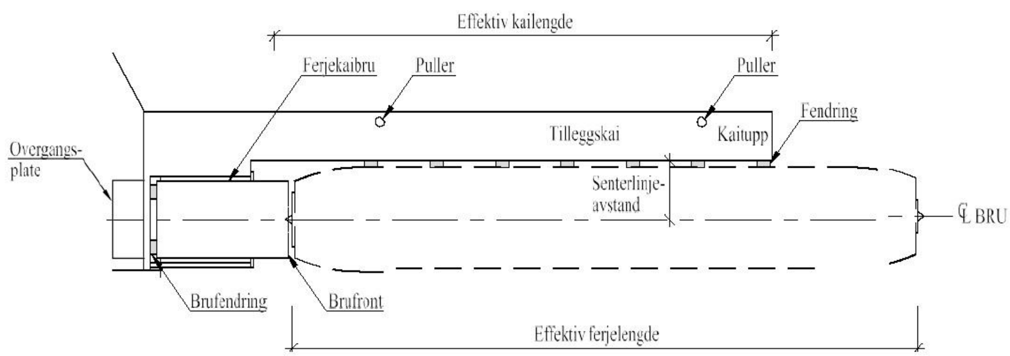


Figure 21: Typical Norwegian Auxiliary Side Dock Arrangement

From the view of Statens Vegvesen, the auxiliary side dock was a logical location for whatever charging, conversion or energy storage equipment was necessary for plug-in ferries. Since the ferry routes are contracted out to private ferry companies under a tender process, the location could accommodate such a variety of new systems provided by these private ferry companies, like the vessel itself. As the RCS technology is still in development, SVV did not try to standardize RCS systems.

Unfortunately, SVV views the ramp location as part of their domain rather than that of the private ferry operator. There is concern within SVV that ramp located equipment would obligate SVV to maintain it. These concerns and drivers may be why the ramp location has not been used for charging systems. Discussions with multiple RCS vendors have revealed how they either had to adapt such as with the Cavotec horizontal APS or Stemmann-Technik davit solutions or be effectively eliminated from consideration such as with the Mobimar devices in providing a bow located solution.

4.3.2 Patents

Various RCS companies have obtained patents related to their systems. For instance, NG3 patented its unique self-closing plug-receptacle combination under US and EU patents US2018151974A1[27] and EP3298661B1[28]. Blue Power Connect, a company not previously mentioned in this report due to an apparent lack of even a working prototype, patented a specific interlocking ramp-based system under WO2018052310A1.[29] Wärtsilä secured its patent rights to its magnetic resonance inductive charger under WO2017125153A1.[30] The NG3 and Blue Power Connect patents seem rather specialized to their unique solution.

Mobimar has a patent of perhaps more interest with a particular focus on the ramp location.[31] Its Z-shaped extension arm seems to have possible advantages for such a ramp-based location. While their application has not yet been approved, it may be a piece of intellectual property to

---

[27] D. Feger, "Compact Connector and Compact Socket for Electrically Powering a Portable Device from a Fixed Network". United States of America Patent US2018151974A1, 31 May 2018.

[28] D. Feger, "Compact Connector And Compact Socket For Electrically Powering A Portable Device From A Fixed Network". European Union Patent EP3298661B1, 28 March 2018.

[29] S. Gjerde, "Electrical Connector, Arrangement And Method". Worldwide Patent WO2018052310A1, 22 March 2018

[30] D. Lamperele, J. P. Hovland and F. Jenset, "A Charging Device, A Boat, A Ship, A Marine Vessel, A Dock, A Quay Or A Pontoon Utilizing The Charging Device And A Method Of Arranging The Charging Of Batteries Of A Boat, A Ship Or A Marine Vessel". Worldwide Patent WO2017125153A1, 27 July 2017

[31] A. Immonen and P. Immonen, "Charging Connection Device and Charging Arrangement Patent Application". European Union Patent EP3342626A1, 27 December 2016.

more closely watch in the near future.

4.3.3 Approaches to RCS Development

Typical ferry electrification projects in Norway have a private ferry company such as Norled or Fjord1 contracting an entire plug-in ferry project to a systems integrator such as Siemens or Norwegian Electric Systems (NES) as prime contractor. The systems integrator is then responsible for not only onboard systems but also the shore-side charging technology and any conversion or energy storage needs. This approach has served numerous Norwegian projects well. Such projects have all had a large auxiliary side dock infrastructure provided at the expense of Statens Vegvesen or local municipalities.

Countless reports in local media indicate that such projects were not under any specific pressure to become operational on or by a specific date. Vessels typically arrived from a shipyard to begin testing when they arrived. Charging systems typically starting charging when they were able to.

The ABB HH Ferries/ForSea Project at Helsingor-Helsingborg had a similar approach but a specific and more public date to begin operation. ABB was the prime contractor for the entire vessel retrofit and shore charging upgrades. On June 20, 2017, the first vessel was supposed to begin charging successfully and make battery-only crossings as the largest plug-in hybrid vessel in the world. Unfortunately, a large public event was cancelled just 24 hours before as the vessel was not yet charging successfully.[32] It was not until November 10, 2018 that the vessel was able to charge consistently enough to reschedule the event. The 16-month delay was regularly mentioned in the press and HH Ferries faced public scrutiny.[33]

Backtracking to the breakthrough MF Ampere project in 2014-2015, Norled and Siemens took an interesting approach to the shore charging technology. Rather than place “all their eggs in one basket”, they designed, manufactured and installed two competing system from both Stemmann-Technik and Cavotec. These were placed side-by-side on the auxiliary dock and either could be put into operation at the election of the onboard Captain. Both systems proved to be successful operationally and are still used in alternating fashion today. The approach ensured that at least one system and the project itself would prove to be successful.

Norled and Cavotec took another interesting approach with the Nesodden ferries that operate out of downtown Oslo. A mechanical-only pilot stage was used as a testing and proving grounds for the bow located Cavotec APS system. EBDG had the opportunity to see this system installed at Aker Brygge B Dock-5 in September of 2018, however the system was subsequently removed in July of 2019. A new installation is to be installed at Rådhusbrygge 4 just a couple piers to the east. The new Cavotec system will be fully operational and charge the relatively small vessels in 8 minutes and at 8MW.[34]

The real challenge with such systems is to mechanically connect in sufficient time, for control systems to target and track, and for tidal fluctuation and vessel motions to be accommodated.

[32] Y. Johansson, "Stor invigning inställd – batterifärjan laddar inte (Big Opening Set - The Battery Ferry Is Not Charging)," Helsingborgs Dagblad, 19 June 2017. [Online]. Available: https://www.hd.se/2017-06-19/stor-invigning-installd-batterifarjan-laddar-inte?redirected=1.

[33] U. Kristiansson, "Idag får alla åka gratis till Helsingör (Today Everyone Can Go to Helsingör for Free)," Helsingborgs Dagsblad, 10 November 2018. [Online]. Available: https://www.hd.se/2018-11-10/idag-far-alla-aka-gratis-till-helsingor.

[34] T. Stensvold, "Kongen har fått batterier – og hurtiglader på Aker Brygge (Kongen has got batteries - and quick chargers at Aker Brygge)," Technical Ukeblad Media AS, 6 September 2019. [Online]. Available: https://www.tu.no/artikler/kongen-har-fatt-batterier-og-hurtiglader-pa-aker-brygge/473155?key=GLgxGRu8

Once all that is overcome and a physical connection is made, the ability to pass electrical power is not really in much doubt. The mechanical only pilot stage provides the opportunity for a system to prove itself without requiring much of the shore-side infrastructure needed to supply the full electrical power or ensure structural longevity as would be required for permanent installation.

The Swedish Transport Administration's Ferry Division has taken an approach that combines elements of both the MF AMPERE and Nesodden Ferry projects. The Swedish ferry system has 70 ferries that do not currently have auxiliary side docks and, like WSF, sees adding such infrastructure as a major expense. They desire a bow system capable of transferring 3MW with a quick connection.[35]

Four systems were initially investigated for the Swedish system. The selected vendors were to supply and commission a mechanical-only pilot system for testing at Ljusteröleden. Estimated costs for each system were also reported as:

- Cavotec, SEK 2.5 million ($280,000)
- ABB, SEK 4.2 million ($470,000)
- Mobimar, no price stated
- Wärtsilä, 14 million ($1,560,000)

Cavotec and ABB were initially selected to commission such pilot systems. Wärtsilä was excluded due to price and Mobimar had not been able to prove their Danish system due to unrelated problems with battery deliveries. [25] EBDG now understands that Mobimar has installed their system at the Swedish system's test facility.

The Swedish Transport Administration's Ferry Division has just taken delivery of the TELLUS, a 100m, 80 car, 297 passenger plug-in hybrid car ferry. The vessel has four 460kW Volvo Penta diesel engines combined with almost 1MWh of onboard batteries. Until a solution is chosen and implemented for bow charging, the vessel will operate in hybrid mode.[36] Unlike the ABB HH Ferries project, no Swedish news reports can be found highlighting or questioning the current situation or approach.

Section 5:

Technology Developments

Vessel systems are experiencing unprecedented levels of technological advancement alongside the evolution of control electronics and computer systems. Vessel hybridization and electrification represents the forefront of vessel technological advancement with newer and newer generations of existing products entering the market place each year. It is probable that the evolution of vessel systems will outpace not only the long-range plan but the vessel's design life. Some of the

[35] J. Kristensson, "Så här kan Sveriges vägfärjor snabbladdas i framtiden (This Is How Sweden's Road Ferries Can Be Recharged in the Future)," Nyteknik, 8 October 2018. [Online]. Available: https://www.nyteknik.se/premium/sa-har-kan-sveriges-vagfarjor-snabbladdas-i-framtiden-6934040.

[36] S. Campanello, "Sveriges största elhybridfärja tas i drift – men saknar laddstationer (Sweden's Largest Electric Hybrid Ferry Comes Into Operation - But Lacks Charging Stations)," Nyteknik, 11 June 2019. [Online]. Available: https://www.nyteknik.se/premium/sveriges-storsta-elhybridfarja-tas-i-drift-men-saknar-laddstationer-6961659.

technological developments that might be incorporated in the next generation of vessels are outlined below.

5.1 Automated Engine Room Systems

While automation and remote control of mechanical systems is not new, the capabilities are growing. Most engine control functions are already automated and will only become more so as power management systems control multiple energy sources and loads.

Auxiliary equipment has some potential for automation. Ventilation control is a common choice; Delta T Systems offers an off the shelf system which can maintain an engine room at a set temperature, using modulation of fan speed to vary cooling. Other generic machinery functions, such as fuel day tank filling, and cycling of oily water separators and marine sanitation devices may also be automated.

5.2 Automated Crossing Systems

To optimize the energy consumption and consistency of vessel crossings, automatic crossing systems control the vessel's acceleration, deceleration, course, and speed. Similar to the new wave of self-driving cars, the vessel's captain will supervise the automatic system and, if necessary, take manual control of maneuvering.

These systems have been successfully deployed in Scandinavia, and several manufacturers purvey them. Kongsberg is one of the leading providers with their Autocrossing system. The Autocrossing system is currently employed on two ferries, the GLOPPEFJORD and EIDESFJORD, operating on the Anda-Lote route in Norway. The master manually operates the vessel from the terminal and engages the Autocrossing system. After the vessel autonomously makes its crossing under the master's supervision, the master takes control for final docking.

An American company named Sea Machines has brought an autonomous vessel control system to market. The system applies waypoint navigation, propulsion and steering control, obstacle and traffic avoidance, and remote control to navigate the vessel. While it is currently intended for small and simple work boats, it could conceivably be expanded to ferries in the future.

5.3 Automated Docking Systems

A step further than automated crossing systems, automated docking systems automate docking and departures from the terminals. The systems navigate the vessel relative to the pilings and wing walls, while the master observes and maintains overall situational awareness.

Overall improvement in vessel schedule can be translated into greater time at the terminal for loading and unloading, and shore power charging. This in turn will improve battery charging opportunity, potentially lower the required shore charging rate, and extended loading time will improve schedule reliability.

5.4 Automated Mooring Systems

Automated mooring systems are systems that secure a vessel to a pier without human intervention. Currently WSF vessels push the dock during loading and unloading by using the propeller to maintain vessel position relative to the vehicle transfer span. Shore power from the grid would supply this pushing power for vessels with shore charging capabilities; the electric power is converted to mechanical power to turn the propeller. An automated mooring system would maintain the position of the vessel without requiring vessel power, resulting in lower energy consumption and reducing the shore charging rate. A few systems have been developed within the industry.

As previously discussed, Cavotec offers the MoorMaster, an automated mooring system with vacuum pads. A robotic arm with the pads is mounted to a pier, and mates with a reinforced smooth section of the vessel side. Upon docking, the arm extends and connects to the vessel, holding it in place. Trelleborg also manufactures a similar product, known as AutoMoor.

An alternative system is the MacGregor auto-mooring unit. This device uses a tower with a hydraulic ram on a carriage, in an arrangement similar to an elevator. The hydraulic ram is equipped with a hook which engages a bollard aboard the vessel. Existing installations of this system are not automated but are remotely controlled by a crew member. However, this system is not intrinsically more complicated than automated high-power shore power charging systems on the market, so it is reasonable to assume that the auto-mooring unit can be automated.

MacGregor has been subcontracted by Kongsberg to provide automated mooring systems for the world's first autonomous unmanned container ship, the YARA BIRKELAND. This vessel will transport fertilizer along a 31 nautical mile inland waterway route between Porsgrunn, Larvik, and Brevik in Norway.

Each of these systems connects to the side of a vessel and is not well suited to an end-docking configuration. A pier along the length of the berth would be necessary to apply these systems to WSF vessels. One end connection system is at concept level development, the SmartLander by Momentum Marine. However, it appears suited for smaller vessels than WSF's and has no known installations.

5.5 Integrated Bridge Systems

Integrated bridge systems combine data from many sources into an array of display screens which can be interpreted and managed by the bridge crew. Instead of dedicated units for individual functions such as radar, chart plotting, and CCTV, an integrated bridge system allows display of any function on any screen and allows the operator to easily select what information is shown on which display. These systems are advantageous due to the volume of data and data sources which must be absorbed, processed, and acted upon by vessel crews. They streamline information flow and decision making and provide a more uniform and ergonomic system for vessel crews to train upon and operate.

Several manufacturers have developed integrated bridge systems, including Sperry Marine, Furuno, and Kongsberg.

5.6 Real Time Vessel Systems Monitoring

In recent years, several advancing data technologies have brought sophisticated remote machinery monitoring into economic feasibility. Data collection and processing, storage, wireless communications, and cloud access technologies have been combined to develop remote monitoring and condition assessment tools. Companies have developed systems which handle data acquisition from sensors on machinery, and the storage and transmission of the data to operators ashore. There it is processed and analyzed; and conclusions regarding machinery status and prognosis are drawn. The information is presented in a user-friendly graphical interface and uses a web-based portal which may be accessed anywhere an internet connection is available. These systems can be used to create a conditions-based maintenance program, which uses actual machinery status, to replace a time-based maintenance program, which uses simple operating hours or calendar time to determine when maintenance procedures are necessary.

A system called MarineInsight from Seattle based ioCurrents is just such a system and is deployed on vessels in the Pacific Northwest and around the world. Kongsberg's Health Management and Wärtsilä's Propulsion Condition Monitoring Service are similar systems.

5.7 Machine Learning

Advanced computing technologies are being developed and implemented throughout our society, and maritime systems cannot be far behind. While few systems are available in the maritime market today, and even fewer have applications to WSF, the situation will assuredly be different in a few years. Artificial Intelligence, Machine Learning, Big Data, Internet of Things (IoT), and Augmented Reality tools and solutions will become available.

Sea Machines is developing a situational awareness system which uses Light Detection and Ranging (LiDAR) and computer imaging to identify and track targets in the vicinity of the vessel. This system could be developed as an input to autonomous operation, or simply as a tool for crews to improve situational awareness.

APPENDIX B:
Task 4 – Vessel Functional Requirements

Washington State Ferries

System Electrification Plan

Table of Contents

Section 1:

Introduction

Puget Sound is an ideal location for adopting plug-in hybrid diesel-electric vessels because of the low cost and proximity to renewable zero carbon emission power sources including hydropower and wind. The Washington State Ferry (WSF) system is undertaking an ambitious initiative to leverage this situation for reduced environmental impact and operational costs. Marine electric propulsion systems have been employed in various passenger and ferry vessel service around the world and is a rapidly evolving frontier. WSF is leading the way with ground-breaking work in implementation of this technology on large vehicle passenger ferries.

This technical memorandum summarizes the preliminary vessel electrification functional requirements for the future WSF fleet as described in the Long Range Plan (LRP). The goal is to maximize the benefits of fleet electrification with the least impact, and desired improvement, to the system as a whole.

1.1 Approach

The LRP recommended hybrid retrofits to the existing Jumbo Mark II and Kwa-di Tabil (KDT) classes and new construction of hybrid vessels to create the Hybrid Electric Olympic (HEO) (5 vessels), New 124-Car (4 vessels), and New 144-Car classes (7 vessels). A summary of the final 2040 fleet composition and vessel class route assignments is included below to lay a foundation for the following discussions. The "Design Criteria Route" indicates the most arduous of the class' intended route assignments to which the class will be designed. By default, vessels will be capable of being assigned on less demanding routes. The class route assignments are informed by Task 6, Vessel and Terminal Improvement Schedule, which includes some updates from the LRP.

Table 1: 2040 Fleet Composition, Class and Route Assignments

Vessel Class	Hybrid or Diesel	Qty	Design Criteria Route	Route Assignment – 2040 Long Range Plan
Jumbo Mark II	H	3	Seattle / Bainbridge	Seattle - Bainbridge, Edmonds - Kingston
Olympic	D	4	N/A	SOLAS Route (for converted vessels), Relief
Hybrid Electric Olympic	H	5	Seattle / Bremerton	Seattle - Bremerton, Mukilteo - Clinton
New 144-Car	H	7	Seattle / Bremerton	Edmonds - Kingston, San Juan Islands
New 124-Car	H	4	Fauntleroy / Southworth	Fauntleroy - Southworth, Vashon - Fauntleroy, Vashon - Southworth
Kwa-di Tabil (KDT)	H	3	Port Townsend / Coupeville	Port Townsend - Coupeville, Point Defiance - Tahlequah

Any route within WSF can be served by a hybrid-electric vessel, however, the practicability and extent to which that vessel can take advantage of its electric propulsion technology and/or shore charging depends on a variety of elements including the route's length, frequency of service and corresponding dwell time, and power availability at the terminal.

The primary route assignments of the New 144-Car class vessels do not include Seattle-Bremerton in the LRP time horizon, however it is recommended to design the New 144-Car class vessels to the design criteria of the Seattle-Bremerton route for fleet commonality and interchangeability. Reducing the number of vessel classes is a strong focus of the LRP to support flexible and adaptable operations within WSF.

The SEP reviewed each WSF route in detail to develop recommendations for if, how, and when a route should be electrified. There were many trade-off decisions that were identified and considered for each route to balance the competing priorities of cost effectiveness, emission reductions, and schedule and service.

For each route the following was identified:

- Vessel Assignment over a 20-year time horizon
- Estimated Crossing Energy on a route (based on Vessel Class)
- Historical Dwell Time Distribution and Corresponding Theoretical Charging Rates
- Utility at each terminal, and corresponding Utility Cost Schedule (If available)
- Terminal Layout and Foot Print at each terminal to inform space availability and feasibility of incorporating charging infrastructure
- Possibility of one-sided charging vs two-sided charging

The above was used to generate the vessel functional requirements summarized in this memorandum. Some classes, such as Hybrid Electric Olympic and Jumbo Mark II, have also been the subject of more in-depth studies, which information was used to inform the functional requirement development process for other classes that have not yet been studied rigorously.

1.2 Memorandum Structure

This memorandum contains two sections, the first is the route analysis summary, the second is the preliminary vessel functional requirements.

The route analysis summary publishes the following:

- The fuel savings estimate for a no-shore charging scenario
- The mean and upper-end crossing energy, dwell time recommendations, charging rate estimates, and estimated fuel usage for each route excluding the San Juan Islands.
- An identification of assumptions made for the San Juan Island routes and recommendations for areas of further study.

The vessel functional requirements are organized in the following categories, which define the capabilities of a vessel to enable it to be assigned to appropriate routes of service:

- Propulsion plant configuration
    - Energy storage system: type of battery chemistry, capacity, cycle count, charge rate, service life
    - Charging: frequency and energy requirements
    - Number of diesel generators required
    - Automation: options for automatic operation of components (i.e. charging connection), information technology integration within the vessel and to shore, diagnostics and troubleshooting
    - Redundancy: highest standards for safety, regulatory compliance, and system reliability
- Operational requirements

  - Operating modes: battery, hybrid, and (for some classes) diesel boost
  - Service speeds
  - Fuel/energy endurance
- Rapid charging system requirements
  - Charge rate: energy required to sustain operations
  - Configuration for system-wide compatibility
  - Reliability

Section 2:

Definitions

Charging Rate	Power required to recoup the crossing energy and charge the batteries while at the terminal and supplying hotel and docking loads.
Crossing Energy	Amount of energy required to complete a single, one-way, transit on a route, including propulsion and hotel loads. The energy value will vary with vessel, speed, and encountered environmental conditions.
Cycle Count	Number of times the battery is discharged and charged. For most routes, this will be one-way transits. For routes with charging only on one end, one roundtrip will count as one cycle.
Design Dwell Time	The time between landing and departure required for the vessel to recharge the batteries to full capacity at the vessel and terminal designed charge rates.
Dwell Time	Length of time the vessels are at the terminals between transits for loading/unloading.
Design Criteria Route	The most arduous route that the vessel class will operate on that will determine vessel functional requirements.
Energy Storage System (ESS)	Collectively refers to battery rooms, racks, and management systems
Level of Service	Collective term for passenger and vehicular throughput capacity, trip frequency, crossing numbers, and service hours, and varies by service route.
Load Leveling	A form of hybrid operation where the diesel generators are operated constantly at their most efficient point. Batteries discharge during transit to supply additional propulsion power and are charged during the dwell time by the diesel generators.
Plug-in Hybrid Vessel	Vessel with a propulsion system consisting of diesel generators, batteries, and a plug-in connection to shore for charging from the power grid.
Rapid Charging System (RCS)	High power, automatic charging system for the onboard propulsion batteries. Makes the physical connection between the vessel equipment and the shoreside charging infrastructure.
Transit Time	Length of time the vessels are on a single, one-way, transit between terminals from departure to arrival.

Section 3:

Route Analysis Summary

3.1 No Shore Charging Scenario

The tasking of the SEP requires an analysis of and a comparison to a no-shore charging scenario. The fuel savings of a hybrid vessel without plug in charging that does not require shore side expenditure was estimated as follows.

Table 2: No Shore Charging Fuel Reductions

Route or Vessel Position		Class	Diesel Efficiency[1]	Hybrid Efficiency	Existing BSFC	Hybrid BSFC	Hybrid Fuel Savings
Seattle	Bainbridge	JMII	0.941	0.915	0.410	0.345	13.5%
Mukilteo	Clinton	HEO	0.960	0.913	0.375	0.309	13.3%
Seattle	Bremerton	HEO	0.960	0.913	0.375	0.309	13.3%
Port Townsend	Coupeville	KDT	0.960	0.913	0.375	0.309	13.3%
Point Defiance	Tahlequah	KDT	0.960	0.913	0.375	0.309	13.3%
Edmonds	Kingston	JMII	0.941	0.915	0.410	0.345	13.5%
Edmonds	Kingston	144	0.960	0.913	0.375	0.309	13.3%
FVS Routes		I24	0.960	0.913	0.355	0.309	8.4%
SJI Routes		144	0.960	0.913	0.375	0.309	13.3%

1 Diesel propulsion efficiency inclusive of coefficients for generators, motors, diode rectifiers, gears, and clutches as applicable for each vessel class.

2 Hybrid propulsion efficiency inclusive of coefficients for generators, motors, diode rectifiers, inverters, batteries.

Note that a significant contributor to the above fuel reductions results from improved brake specific fuel consumption (BSFC). While some of this improvement is a result of hybridizing a vessel, most of this improvement is a result of adopting new and different engines.

The above analysis is vessel class dependent rather than route dependent as a result of the large battery bank sizes that will be incorporated on the vessel to support a typical all-electric voyage. This battery bank size provides excess capacity compared to typical hybrid and load leveling operations and as a result, the operations of generators in the no shore charging scenario are unrelated to the routes crossing distance and dwell time.

The above values are also reflected in the scenario with shore charging for instances when hybrid vessels become available before terminal infrastructure upgrades are complete, and to estimate the fuel usage estimate of each vessel.

3.2 Shore Charging Scenario

The estimated mean crossing energy and resulting charge rates, and the estimated upper-end crossing energy and resulting charge rates for all routes (except the San Juan Islands) are published below in Table 3 and Table 4.

The mean crossing energy table is what is estimated to occur most of the time. This crossing energy is used to calculate the expected power charges from each utility.

The upper end crossing energy table includes margin of up to 10% compared to what is published in the mean crossing energy. This margin could be addressed through greater generator reliance if there is a desire to reduce terminal costs. This will have to be evaluated by route-specific trade off study. The charging rates listed are used to evaluate infrastructure needs at each terminal and RCS and is used to calculate demand charges from each utility. This is the margin identified in the Jumbo Mark II Class Hybrid System Integration Study.

The crossing energies represent the propulsion and hotel loads incurred during transit. For routes which are recommended for single-sided charging (RT = round trip), there is an additional column to include the energy expended while at the dock. The crossing energy or crossing energy + dock side load for round trips, is used to determine the charge rate of the batteries. The rapid charging system (RCS) and shore side infrastructure will need to deliver additional power to support dock pushing loads and hotel loads during battery charging operations. This total energy demand determines the charging rate of the RCS.

Table 3: Mean Energy and Mean Charging Rate Summary

Route	Class	Charging Time	Mean Crossing Energy	1xDock Side Energy for RT	Mean Battery Charge Rate	Total Energy Demand	Mean RCS Charge Rate
			kWh	kWh	kW	kWh	kW
Seattle / Bremerton	HEO	18	4,030		13,500	4,330	14,500
Seattle / Bainbridge	JM II	18	2,200		7,400	2,530	8,500
Vashon/ Fauntleroy	124	8	550		4,200	640	4,800
Vashon / Southworth		7	460		4,000	540	4,700
Southworth / Fauntleroy		7	820		7,100	900	7,800
Pt. Defiance / Tahlequah (RT)	KDT	12	600	100	3,500	800	4,000
Edmonds / Kingston (RT)	New 144	18	2,400	330	9,100	3,060	10,200
Edmonds / Kingston (RT)	JMII	18	3,370	385	12,600	4,140	13,800
Mukilteo / Clinton (RT)	New 144	12	1,540	200	8,700	1,940	9,700
Port Townsend/ Coupeville	KDT	13	950		4,400	1,060	4,900

Table 4: Upper-End Energy and Upper-End Charging Rate Summary

Route	Class	Charging Time	Upper-End Crossing Energy	1xDock Side Energy for RT	Upper-End Battery Charge Rate	Total Energy Demand	Upper-End RCS Charge Rate
			kWh	kWh	kW	kWh	kW
Seattle / Bremerton	HEO	18	4,250		14,200	4,550	15,200
Seattle / Bainbridge	JM II	18	2,400		8,000	2,730	9,100
Vashon / Fauntleroy	124	8	600		4,500	690	5,200
Vashon / Southworth		7	502		4,400	582	5,000
Southworth / Fauntleroy		7	895		7,700	975	8,400
Pt. Defiance / Tahlequah (RT)	KDT	12	655	100	3,800	855	4,300
Edmonds / Kingston (RT)	New 144	18	2,618	330	9,900	3,278	11,000
Edmonds / Kingston (RT)	JMII	18	3,676	385	13,600	4,446	14,900
Mukilteo / Clinton (RT)	New 144	12	1,680	200	9,400	2,080	10,400
Port Townsend / Coupeville	KDT	13	1,036		4,800	1,146	5,300

The recommended design criteria dwell time, median dwell time, and corresponding % of generator reliance and % of fuel consumption are presented below in Table 5. A % of generator reliance of 5% minimum is assumed for all routes to account for RCS connection reliability due to tides and for instances of shore side power interruption allowed for in the interruptible utility schedule. The % of generator reliance is increased based on perceived schedule risk (the difference between design criteria and median dwell time).

Table 5: Route Summary Dwell Time and % Generator Reliance

Route	Class	Design Criteria Dwell Time[1] *Minutes*	Median Dwell Time[2] *Minutes*	Charging Time[3] *Minutes*	% of Generator Reliance[4]	Hybrid Fuel Savings[5]	% Fuel Reduction[6]
Seattle / Bremerton*	HEO	20	16	18	18%	13.3%	84.5%
Seattle / Bainbridge*	JMII	20	19	18	11%	13.5%	90.5%
Vashon / Fauntleroy	124	n/a	10	8	5%	8.4%	95.4%
Vashon / Southworth	124	n/a	9	7	9%	8.4%	92.0%
Southworth / Fauntleroy*	124	9	9	7	13%	8.4%	88.4%
Pt. Defiance / Tahlequah	KDT	n/a	14	12	5%	13.3%	95.7%
Edmonds / Kingston	144	n/a	20	18	5%	13.3%	95.7%
Edmonds / Kingston	JMII	n/a	20	18	25%	13.5%	78.4%
Mukilteo / Clinton*	HEO	14	11	12	5%	13.3%	95.7%
Port Townsend / Coupeville*	KDT	15	14	13	5%	13.3%	95.7%

1 Recommended for design - criteria routes only, previously assumed dwell time for Mukilteo - Clinton included for reference

2 Based on historical data from May 2018 to November 2019

3 Design Criteria Dwell Time (or Median Dwell Time if unavailable) minus two minutes for connecting and disconnecting RCS

4 Assumed 5% Generator Reliance as minimum, increased percentage of reliance based on perceived difficulty of obtaining full charge using mean crossing energy.

5 As calculated for the applicable vessel class in the no-shore charging scenario

6 Applied to the existing fuel budget

The expected number of annual one way trips for each route is summarized below in Table 6.

Table 6: Route Summary Mean Crossing Energy and Annual Trip Counts

Route	Crossing Distance[1] *miles*	Vessel Class	Mean Crossing Energy[2] *kWh*	Total Annual Trips[3] *One-way trips*
Seattle / Bremerton*	15.5	Hybrid Electric Olympic	4030	10,980
Seattle / Bainbridge*	8.6	JMII	2200	16,604
Vashon / Fauntleroy	3.2	New 124-Car	550	24,458
Vashon / Southworth	1.8	New 124-Car	460	16,004
Southworth / Fauntleroy*	4.7	New 124-Car	820	4,674
Pt. Defiance / Tahlequah	1.7	KDT	300	14,244
Edmonds / Kingston	5.2	JMII	1685	17,985
		New 144-Car	1200	26,280
Mukilteo / Clinton*	2.5	Hybrid Electric Olympic	770	27,868
Port Townsend / Coupeville*	4.9	KDT	950	9,720

* **Design - Criteria routes**

1 One-Way

2 One-Way, including ship service loads for transit duration, does not include dock pushing energy or auxiliary loads at dock

3 Assuming 316 days, three boat schedule for Edmonds Kingston 144 Car assignment

The electrification of the San Juan Islands is scheduled in the second half of the LRP in the hopes that technological advancements and lessons learned from simpler route configurations will help make electric operations in the islands a more successful reality. **It is our recommendation that a focused study on the island routes, infrastructure, schedule, and demands be conducted when the future vessel class design requirements and technological advancements and limitations are better understood.** Note that, the international route in the San Juan Islands is currently undergoing a privatization study.

Unlike most WSF routes, vessel operations in the San Juan Islands involve four or more vessels operating in non-linear, non-repetitive route assignments and combinations to facilitate the transfer of passengers and goods, and to share the limited pier space while maximizing service to the communities. The schedule is complicated further by large service level changes depending on season, with the winter months being the highest energy months for the vessels because of the limited number of vessels available. Schedule adjustments for one vessel/route will have cascading impacts to every other vessel that operates in the islands. It is unclear if schedule adjustments are a realistic option for the San Juan Islands while maintaining appropriate service levels.

The route is further complicated by the need for a SOLAS vessel on the international route to Sidney BC, and an interisland vessel that can accommodate a complex vehicular loading arrangement inherent to the numerous embarkation/destination pairs that results from serving four terminals. Even on the remaining routes (San Juan vessel positions 2 and 3) the complicated operations results in nonstandard crossing, speed, times, energy, and dwell times. As a result, it was not possible to estimate crossing energy for all San Juan routes and route combinations based on historical fuel consumption. Crossing energies in the San Juan Island routes were sampled from engine operating data (also known as IBA data). These crossing energy samples were used to inform feasibility recommendations and are provided in rough-order-of-magnitude values below.

- A Super Class vessel from Anacortes to Lopez requires 3MWh of crossing energy. Assuming a dwell time of 20 minutes this crossing energy corresponds to a charging rate of 10MW.
- An Olympic Class vessel from Anacortes to Friday Harbor requires 5MWh of crossing energy. Assuming a dwell time of 25 minutes this crossing energy corresponds to a charging rate of 13MW.
- An Olympic Class vessel from Anacortes to Orcas requires 4MWh or crossing energy. Assuming a dwell time of 20 minutes this crossing energy corresponds to a charging rate of 14MW.
- A Super Class vessel from Friday Harbor to Lopez (without stops) requires 2MWh of crossing energy. Assuming a dwell time of 10 minutes this corresponds to a charging rate of 14MW.

These samples show that charging rates in the San Juan Islands can be as high as the Seattle-Bremerton route which is the most demanding route in terms of charge rate in the WSF system.

Further, with the exception of Anacortes, all terminals are served by a single utility provider OPALCO. As a result, the utility may experience additional demand when multiple vessels are charging simultaneously at different San Juan Island terminals.

However, there is indication that the planned improvements for the local utility infrastructure (OPALCO) will be able to support electrified ferry operations in the San Juan Islands in the future. While cost schedules for industry are not currently available through OPALCO, there is a clear desire to support environmentally sustainable ferry operations in the San Juan Island communities.

These sample energies show that hybridization is feasible but that further study is required to maximize fuel reductions. While the specifics of San Juan Island ferry electrifications cannot be determined without this further study, the System Electrification Plan makes the following conservative assumptions.

- The SOLAS route will not be a hybrid vessel.
- Vessel Positions #2 and #3 will be hybridized, but incur high crossing energies for the long crossings to and from Anacortes.
- The interisland vessel has frequent overlaps with Vessel Positions #2 and #3 at other OPALCO terminals and operates with shortened dwell times.
- The New-144 Car vessels hybrid systems will be sized to meet the requirements of the Seattle-Bremerton route.
- The shoreside infrastructure in the San Juan Islands will be sized to meet the requirements of the Seattle-Bremerton route Design Criteria vessels.

Table 7: Percent of Generator Reliance for San Juan Islands

San Juan Island Vessel Position	% of Generator Reliance	Hybrid Fuel Savings	Estimated Fuel Reductions
Position #1 SOLAS	100%	0%	0%
Position #2 & #3	40%	13.3%	65.3%
Position #4 Interisland	60%	13.3%	48.0%

Section 4:

Preliminary Vessel Electrification Functional Requirements

Preliminary vessel functional requirements, as they relate to vehicle and passenger capacities, dimensions, and construction material were identified in the 2040 LRP. This memo expands on the electrification functional requirements for each vessel class that has been identified.

All future vessels are encouraged to obtain a DNV GL Silent-E notation which certifies the vessels are acoustically sensitive. A benefit of electrifying the fleet is the greater ability to attain this notation, with compliant vessels exhibiting reduced impact on marine life.

4.1 Hybrid System General Requirements

The general requirements in this section are applicable to all vessel classes unless noted otherwise.

4.1.1 Energy Storage System (ESS)

The ESS shall be sized for the design criteria routes as previously discussed in Section 4 using the following inputs at minimum:

- Crossing energy
- Cycle count (trips or charges per day)
- Expected battery life in years

The crossing energy for each route was calculated as summarized in 3.2 based on data for existing vessels on the applicable routes. Annual crossing counts for each route were totaled and divided per vessel to determine the cycle count. Expected battery life is a manual input into the calculation. Longer battery life will require a larger battery bank. Shorter battery life will allow a smaller battery bank but will result in a higher frequency of battery replacements. The approach used in the ESS capacity calculations were to assume:

- A five-year battery life for the smaller installations to align with the typical drydocking schedule, or
- A four-year battery life for the larger installations to reduce the ESS to a more manageable size to fit within the vessel.

As the design criteria routes are the most demanding, the ESS for vessels operating on the design criteria routes will have the shortest battery life before a replacement is required. Operation on less demanding routes will extend the life of the ESS past the design life.

4.1.2 Rapid Charging System (RCS)

An RCS is required for each plug-in hybrid vessel class. As shown in Figure 1, the RCS provides a connection between the shore and vessel. An active component is required to bridge the gap between the vessel and shore, typically the active component includes a plug which is inserted into a stationary component with a receptacle. An RCS with the active component on or below the pickle fork on the port side of the vessel end (looking forward) is under development for the JMII conversion project.

To enhance fleet commonality, the RCS is to be compatible with each plug-in hybrid vessel class and electrified terminal, except as noted in the following sections. The RCS designed for the JMII conversion will serve as the fleet standard for future installations. Compatibility with the geometry of the Hybrid Electric Olympic class should be confirmed in conjunction with further development of the RCS as vessel design efforts are already underway. A standard charging voltage of 12.47kV is recommended to align with the goal of fleet RCS commonality.

Note that design effort for the RCS is underway. The current RCS design does not include a provision for sea level rise, and the most extreme tidal ranges were not accommodated based on a cost-benefit analysis.

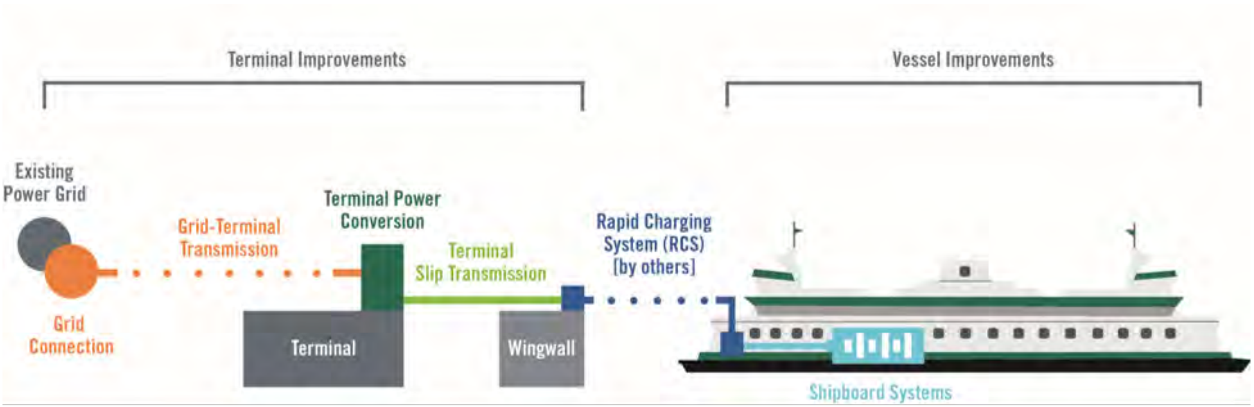


Figure 1: Electrification Components

4.1.3 Automation & IT Requirements

The following additional forms of automation are recommended for all vessels with plug-in hybrid propulsion:

- A power management system (PMS) to automate the distribution of power in each of the operating modes, including but not limited to automatic start/stop of the diesel generators when dictated by available battery charge.
- A battery management system (BMS) to monitor, manage, and protect the lithium-ion batteries by:
  - Monitoring the voltage, temperature, state of charge and state of health among other parameters.
  - Preventing the batteries from operating outside the safe operating envelope, such as over-charge situations.
  - Communicating with the vessel alarm and monitoring system to alert crew to potential issues.
- Automatic connection and disconnection of the RCS when the vessel enters the slip.

Appropriate safety mechanisms or interlocks shall be installed to manage the risk of the vessel departing while the charger is still connected.

As databases, cloud storage, network bandwidth and other information technologies (IT) expand, ship systems are no exception. Propulsion control, alarm and monitoring and automated safety systems have been computerized onboard WSF vessels for decades. WSF IT has greatly expanded the ship to shore networking system since 2000, especially with the transfer of security camera video and maintenance software databases. The well-defined operating region of WSF allows the vessels to use wireless rather than satellite to transfer from ship to shore.

US Coast Guard regulations require that no failure on the IT side of communications with vital systems can affect the vital systems. Any interconnects would require regulatory submittals such as failure modes and effects analyses (FMEA) and design verification test procedures (DVTP).

Major systems integrators such as Siemens, ABB, and Kongsberg offer products enabling remote diagnostics or troubleshooting of vessel automation. Such systems have improved over the years and become more widespread in offshore and ocean-going marine sectors. Even smaller firms such as Seattle-based ioCurrents have found a niche in the growing field of gathering, transmitting, and analyzing vessel equipment data. Continuous connectivity is not required, instead the vessel can upload the data when the wireless is connected. Remote diagnostic systems only upload when initiated by the customer for a fault-finding mission. Remote condition monitoring can provide continuous monitoring of equipment that is uploaded to the cloud for real-time analysis.

Remote diagnostic or monitoring programs could benefit WSF in the effort to track the health of the lithium-ion batteries and onboard power electronics. The number of onboard power electronics on a hybrid vessel is much larger than the diesel-electric propulsion system on the Jumbo Mark II class.

Auto-docking systems (if selected) require additional sensors and cameras onboard the vessel with an interface to the Propulsion Control System (PCS) to direct the thrust while entering the slip. Cameras will also be required on shore to interface with the onboard system. A wireless network will be required to establish real-time communications between the vessel and landside cameras.

Auto-crossing systems (if selected), such as that developed by Kongsberg, require additional sensors, cameras, and electronics onboard with interfaces to both the PCS and bridge electronics, including the radar, Automatic Identification System (AIS), and Electronic Chart Display and Information System (ECDIS). The system utilizes advanced maneuvering situational awareness to avoid other vessels or hazards while following the route as charted. No landside upgrades are required for auto-crossing systems. An auto-crossing system may be used to control or advise crossing speeds as a means of minimizing energy consumption and improving operational performance.

With the transition to electrified vessels with increased levels of automation onboard, the number of required communication links between the ship and shore will increase. An effort to minimize the number of different communications may be beneficial to WSF. Maintaining a wireless system as a standard is recommended. With onboard systems controlling vessel maneuvering or charging requiring wireless communications, it is recommended to ensure the security of the connection is reviewed.

4.1.4 Standards of Redundancy

Safety and reliability are two pillars of the WSF operation. To maintain both, standards of redundancy for the new, more complicated propulsion systems needs to be addressed.

This section organizes hybrid propulsion system failures into two categories:

1. Defined in the USCG required documentation or no affect to vessel maneuverability: Failure Mode and Effects Analysis (FMEA), Design Verification Test Procedures (DVTP), Periodic Safety Test Procedure (PSTP), etc.
2. Not defined in the documentation and affecting vessel maneuverability.

The vessel should be allowed to remain in service if failures of the first category occur. It is likely the USCG will remove the vessel from service for failures of the second category. Regardless of the failure category, no single failure shall affect take home capabilities of the vessel. USCG regulations (46 CFR 58.01-35) allow for a partial reduction of normal propulsion capability to 7-knots as a result of a failure.

The following failure scenarios assume a failure of the first category, defined in the USCG documentation, or that the equipment is simply out of service.

- Failure of a single motor may, at maximum, result in reduced operations at a slower service speed.
    - Tandem motors on a conventional shaft line provide greater redundancy than a single motor on each shaft line.
    - A four azimuth thruster arrangement (two on each end) provides greater redundancy than a two thruster arrangement.
- Failure of the ESS in a single battery room shall not impact operations. Diesel generators are assumed to supplement the remaining operational ESS to maintain service speeds.
- Failure of a single engine shall not impact operations when shore charging is available.
- Failure of a single engine may, at maximum, result in reduced operations at a slower speed while in hybrid operation without shore charging available.
- Failure of shore charging, whether caused by the RCS or utility, shall not impact operations.

4.2 Jumbo Mark II Class

In accordance with the Jumbo Mark II Hybrid System Integration Study[1], the three vessels of the Jumbo Mark II class shall be converted for plug-in hybrid operation. The vessels almost exclusively operate on the Seattle / Bainbridge and Edmonds / Kingston routes. To maintain flexibility between the two routes, the vessel hybrid propulsion system shall be designed for operation on the more demanding Seattle / Bainbridge route.

4.2.1 Propulsion Plant Configuration

The vessels shall be converted to plug-in hybrid operation as detailed in the Hybrid System Integration Study. Two diesel propulsion generators will be removed and replaced with lithium-ion batteries in tandem with a planned propulsion control system upgrade.

The ESS capacity shown in Table 8 is sized to achieve a four year battery life of operation on the Seattle / Bainbridge route with charging available on each end. Operations on the Edmonds / Kingston route currently assumes single sided charging. The currently recommended battery bank size is too small to maximize fuel reductions on this route in a single charging configuration, however, a JMII's assignment to the Edmonds / Kingston route is assumed to be temporary until a three boat schedule

[1] Elliott Bay Design Group, "Jumbo Mark II Class Hybrid System Integration Study", 17102-070-0, Rev.-, Seattle, WA, 2018.

can be incorporated as shown in Task 6. If implemented, double sided charging could result in increased fuel reductions. Given the reduced crossing energy, service on that route would extend battery life.

While the JMII RCS itself must be mechanically compatible with the higher charge rates required for the other vessel classes and routes, the charging system onboard the JMII need only be designed electrically to supply the 8.5MW of the Seattle / Bainbridge route. Note that the mean RCS charge rate on the single-sided charging Edmonds / Kingston route is greater. As noted previously, the JMII's assignment to Edmonds / Kingston route is temporary and the intention is for the vessel to take advantage of ad much shore charging as possible with the Seattle / Bainbridge sized hybrid equipment.

Table 8: Jumbo Mark II ESS Capacity[2]

Applicable Routes	ESS Capacity (kWh)	Expected ESS Life (Years)	Annual Cycle Count (cycles)	Mean RCS Charge Rate (MW) [3]
Seattle / Bainbridge	6,300	4	8,302	8.5
Edmonds / Kingston (RT)		5+	4,496	13.8

Automation and standards of redundancy shall comply with Sections 4.1.3 and 4.1.4.

4.2.2 Operational Requirements

To maintain the expected level of service, a hybrid Jumbo Mark II vessel needs to achieve the same operational requirements as the existing non-hybrid vessels. The two main operational modes are shown below in Table 9.

Table 9: Jumbo Mark II Class Operational Requirements

Mode	Description	Duration Required	Speed (knots)
Battery Only	Typical all-electric operation with shore charging	Seattle - Bainbridge and Edmonds / Kingston one-way transits	18
Hybrid	Typical operation when shore charging is not available with the generators and batteries operating in the "load leveling" mode described in Section 3.1.	Optimized for Seattle - Bainbridge and Edmonds / Kingston one-way transits	18

There are not specific requirements for diesel + battery boost or diesel only operational modes for the Jumbo Mark II, however high-level discussions of these modes are included below.

[2] Most recent JMII ESS capacity is 5,700kWH with a charging rate of 11.3MW for Edmonds/Kingston and 10.4MW for Seattle/Bainbridge.

[3] Vessel charge rate, includes ship service and dock pushing loads

A diesel-only mode of operation assumes that all propulsion batteries are out of service and not able to supply propulsion power. As described in the Hybrid System Integration Study, two propulsion diesel generators can supply adequate power for some transits, although the vessel may not be able to attain 18 knots in a fully loaded condition. The vessel would no longer have a source of energy to act as spinning reserve.

In a diesel + battery boost mode with shore charging operational, the vessel can surpass the 18-knot design speed. The current vessels can attain upwards of 20-knots as a maximum speed. Replacing two generators with batteries will not affect this requirement.

No tankage modifications will be made, but carriage of fuel should be reduced, after the installation and consistent operation of the RCS, to reduce vessel weight and power requirements.

4.2.3 Rapid Charging System Requirements

The Jumbo Mark II ferries on the Seattle / Bainbridge route will receive the first RCS of the fleet and will serve as the model for future installations. For fleet commonality, the RCS will need to be designed to be capable of suppling the higher charge rates required by the Hybrid Electric Olympic, further discussed in Section 4.4.3. However, the actual installation of the RCS on the JMII need only supply the 8.5MW required for the Seattle / Bainbridge route at the standard voltage of 12.47kV.

The RCS should be compatible with all electrified terminals.

The RCS should be capable of fully charging the vessels onboard battery banks within the allowed dwell time with an initial 90% minimum success rate. The prescribed dwell times in Table 5 include time for connection/disconnection and ramp up/down of charging power from the utility.

The RCS should automatically connect and begin charging when the vessel enters the slip. Connection and disconnection times shall be minimized, less than one minute each, to allow for maximum charging periods. Appropriate safety mechanisms or interlocks shall be installed to manage the risk of the vessel departing while the charger is still connected.

The active portion of the RCS shall be installed on or below the pickle fork on the port side of each vessel end (looking forward) for fleet and terminal commonality. This orientation will result in the charging connection on the opposite side of passenger loading at the Seattle, Bainbridge, Edmonds, and Kingston terminals, further discussed in the Task 5 memo, Terminal Functional Requirements. The RCS shall be capable of connecting from the vessel to the receptacle on shore over the design tidal range of the terminal and the full range of freeboard variations of the vessel while accounting for sea level rise predictions.

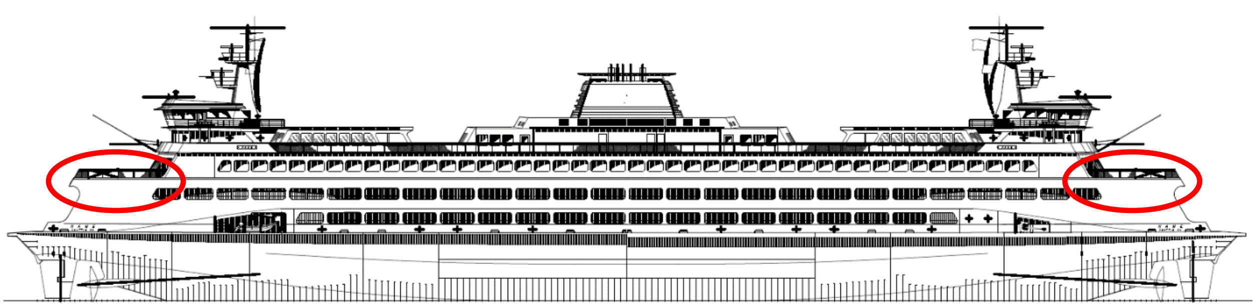


Figure 2: Jumbo Mark II RCS Location

4.3 Olympic Class

The four recently delivered diesel-mechanical Olympic Class vessels in the WSF fleet will not be converted to hybrid propulsion in this plan.

4.4 Hybrid Electric Olympic (HEO) Class

As discussed in the LRP, the Hybrid Electric Olympic Class is to consist of five vessels designed on the same platform as the existing Olympic Class. The first two vessels are intended to operate on Mukilteo / Clinton, the second two on Seattle / Bremerton, and the fifth in relief. The class design criteria route will be Seattle / Bremerton to maintain fleet flexibility.

4.4.1 Propulsion Plant Configuration

The vessels shall utilize a hybrid diesel-electric propulsion system consisting of lithium-ion batteries and marine diesel generator sets.

The ESS capacity shown in Table 10 shall be sized to achieve a four year life of operation on the Seattle / Bremerton route with charging on each end. While less demanding, the battery system must also be appropriately sized for operation on the Mukilteo / Clinton route with charging only on one end.

Table 10: HEO Class ESS Capacity

Applicable Routes	ESS Capacity (kWh)	Expected ESS Life (Years)	Annual Cycle Count (cycles)	Mean RCS Charge Rate (MW)[4]
Seattle / Bremerton	10	4	5,490	14.5
Mukilteo / Clinton RT		10	6,967	9.7

Automation and standards of redundancy shall comply with Sections 4.1.3 and 4.1.4.

4.4.2 Operational Requirements

The HEO Class is intended to have four modes of operation: battery only, hybrid, battery + diesel boost, and diesel only. A high-level discussion of each mode is shown below in Table 11.

[4] Vessel charge rate, includes ship service and dock pushing loads

Table 11: HEO Class Operational Requirements

Mode	Description	Duration Required	Speed (knots)
Battery Only	Typical all-electric operation with shore charging	Seattle / Bremerton one-way and Mukilteo / Clinton roundtrip	16
Hybrid	Typical operation when shore charging is not available with the batteries operating in "load leveling" mode described in Section 3.1.	Optimized for a Seattle / Bremerton one-way transit with a 7-day fuel endurance	16
Battery + Diesel Boost	Atypical operation with the diesels providing an extra boost to the battery-only mode	N/A	17
Diesel Only	Atypical operation with only diesels online assuming a complete loss of battery power	N/A	14.5

As the vessels are likely to be delivered prior to the installation of shore charging infrastructure, a hybrid mode of operation with only diesel generators and batteries shall be incorporated into the design. Once shore charging is available, the vessels are intended to typically operate in battery only mode. Both hybrid and battery only modes shall perform at the required transit speed of 16 knots to accommodate this transition period.

The battery + diesel boost mode is not intended for typical operations, but only when the vessel needs an extra boost of speed (i.e. making up schedule) by operating the diesel engines to supplement battery only mode. This mode will likely not drive the sizing of diesel generators or lithium-ion batteries but will affect the sizing of the propulsion train (motors, shafting, and propellers).

The diesel only mode assumes a complete loss of battery power and shall be considered an emergency operation. The vessel shall be able to achieve a reduced speed of 14.5 knots to either provide reduced service on a route or transit to a shipyard.

4.4.3 Rapid Charging System Requirements

To maintain flexibility within the fleet, the RCS for the Hybrid Electric Olympic class should be developed on the standard platform modeled by the Jumbo Mark II and shall be compatible with all electrified terminals except, possibly, Port Townsend, Coupeville, Point Defiance, and Tahlequah. The RCS should be capable of supplying 15MW at the standard voltage of 12.47kV.

The RCS should be capable of fully charging the vessels onboard battery banks within the prescribed dwell time with an initial 90% minimum success rate. The prescribed dwell times in Table 5 include time for connection/disconnection and ramp up/down of charging power from the utility.

The assumption of a 20 minute dwell time on the Seattle / Bremerton route was directed by WSF after the Dwell Time vs Transit Speed Analysis[5] and included as a requirement in the Part C Technical Specifications for the construction of the Hybrid Electric Olympic Class. Regularly achieving this dwell time may require operational adjustments to ensure adequate time to charge the batteries or the use of diesel generators to supplement the batteries on some crossings.

The RCS should automatically connect and begin charging when the vessel enters the slip. Connection and disconnection times shall be minimized, less than one minute each, to allow for maximum charging periods. Appropriate safety mechanisms or interlocks shall be installed to manage the risk of the vessel departing while the charger is still connected.

The active portion of the RCS shall be installed on or below the pickle fork on the port side of each vessel end, looking forward to the terminal interface, for fleet and terminal commonality. The RCS shall be capable of connecting from the vessel to the receptacle on shore over the full design tidal range of the terminal and the full range of freeboard variations of the vessel while accounting for sea level rise predictions.

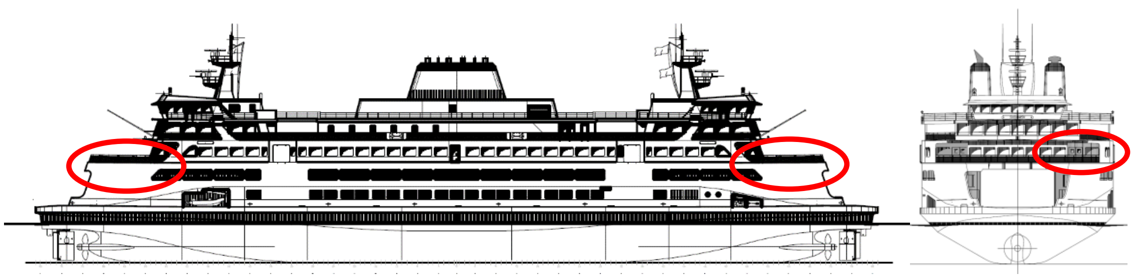


Figure 3: Hybrid Electric Olympic RCS Location

[5] EBDG, "Hybrid Dwell Time vs. Transit Speed Analysis, Seattle-Bremerton Route", 18091-003-070-4-, 10/28/19.

4.5 New 124-Car Class

The New 124-Car class of vessels will consist of four vessels to replace the Issaquah Class for operation primarily on the triangle route. Three vessels will typically operate on the route with one in relief.

The New 124-Car class will be designed to accommodate the most demanding vessel position on the triangle route, position 1, and the most demanding segment of the triangle route, Southworth / Fauntleroy.

As the first new vessel class designed specifically for a plug-in hybrid propulsion system, efficiency should be considered at every level in the design spiral. Standard WSF design and construction standards should be revisited to confirm applicability and relevance with a plug-in hybrid vessel design. Vessel design tradeoff decisions should be considered to minimize vessel weight and maximize energy efficiency while maintaining the 60-year service life, including construction materials, propulsor selection, diesel generator engine selection, HVAC plant design, superstructure arrangements, etc. As recommended in the LRP, a vessel design charrette should be convened to ensure all components of the vessel are evaluated for minimizing environmental effects. Ferry operators with operational hybrid vessels should be consulted for a transfer of knowledge, including lessons learned from vessel design, construction, and operation.

Note: There have been internal conversations between WSF and the planning team on the potential to proceed with a variation of a vessel design that already exists (144-Car or 136-Car variations) instead of pursuing a new 124-Car Class. This memorandum assumes a New 124-Car class will be designed per the LRP, as electrification itself does not require changing the vessel vehicle capacity.

As the first newly designed hybrid electric vessel, consideration should be given to azimuth thrusters. Azimuth thrusters may result in quieter vessels that can achieve a silent-E notation.

4.5.1 Propulsion Plant Configuration

The vessels shall utilize a hybrid diesel-electric propulsion system consisting of lithium-ion batteries and marine diesel generator sets.

The ESS capacity shown in Table 12 is sized to achieve a five year life of operation on the triangle route with charging at each terminal. A weighted average of vessel departures from each terminal was used in the calculations. Potential future weight and design improvements have not been incorporated in these calculations but would reduce the overall power requirements making this a conservative assumption.

While the RCS itself must be mechanically compatible with the higher charge rates required for other vessel classes and routes, the charging system onboard the New 124-Car vessels need only be designed electrically to supply the 8MW required for the Fauntleroy / Southworth segment of the route.

Table 12: New 124-Car Class ESS Capacity

Applicable Routes	ESS Capacity (MWh)	Expected ESS Life (Years)	Annual Cycle Count (cycles)	Mean RCS Charge Rate (MW)[6]
Fauntleroy / Vashon / Southworth	4,000	5	8,302	7.8

Automation and standards of redundancy shall comply with Sections 4.1.3 and 4.1.4. Additionally, it is recommended to consider implementation of auto-crossing and/or auto-docking and restraint systems to further improve the safety and efficiency of the vessels. The next step to implement these systems would be focused studies to determine the most appropriate propulsor and integration with steering and control systems, and infrastructure modifications.

4.5.2 Operational Requirements

The New 124-Car class is intended to have four modes of operation: battery only, hybrid, battery + diesel boost, and diesel only. A high-level discussion of each mode is shown below in Table 13.

Table 13: New 124-Class Operational Requirements

Mode	Description	Duration Required	Speed (knots)
Battery Only	Typical all-electric operation with shore charging	Southworth / Fauntleroy leg, Vessel Position 1 on the triangle route	16
Hybrid	Typical operation when shore charging is not available with the batteries operating in "load leveling" mode described in Section 3.1.	Southworth / Fauntleroy leg, Vessel Position 1 on the triangle route	16
Battery + Diesel Boost	Atypical operation with the diesels providing an extra boost to the battery-only mode	N/A	17
Diesel Only	Atypical operation with only diesels online assuming a complete loss of battery power	N/A	14.5

The typical transit modes of operation, battery only and hybrid, shall align with the 16-knot speed of the existing Issaquah class to ensure no service reductions are required.

Additional power throughput can be designed into the vessels to incorporate a battery + diesel boost mode to provide a higher sprint speed.

[6] Vessel charge rate, includes ship service and dock pushing loads

Reducing the required speed in the diesel only operation introduces additional flexibility in diesel generator selection and the possibility of smaller models.

4.5.3 Rapid Charging System Requirements

To maintain flexibility within the fleet, the RCS for the New 124-Car class should be developed on the standard platform modeled by the Jumbo Mark II and Hybrid Electric Olympic Class and compatible with all electrified terminals except, possibly, Port Townsend, Coupeville, Point Defiance, and Tahlequah. The RCS should be capable of supplying 7.8MW at the standard voltage of 12.47kV.

The rapid charging system shall be capable of fully charging the vessels onboard battery banks within the prescribed dwell time with a minimum 95% success rate. The success rate for the later vessel classes has a higher requirement because the technology should be further refined to ensure a higher success rate. The prescribed dwell time includes time for connection/disconnection and ramp up/down of utility power.

The RCS shall automatically connect and begin charging when the vessel enters the slip. Connection and disconnection times shall be minimized, less than one minute each, to allow for maximum charging periods. Appropriate safety mechanisms or interlocks shall be installed to manage the risk of the vessel departing while the charger is still connected.

The active portion of the RCS shall be installed on or below the pickle fork on the port side of each vessel end looking forward for fleet and terminal commonality. The RCS shall be capable of connecting from the vessel to the receptacle on shore over the full design tidal range of the terminal and the full range of freeboard variations of the vessel while accounting for sea level rise predictions.

4.5.4 General Requirements

The vessels shall also adhere to the following general functional requirements per the LRP:

- Double ended ferry
- 124 vehicles
- 750/1500 passengers[7]
- 2 lane vehicle loading and unloading
- Overhead passenger loading
- Compatible with all WSF terminals (except Coupeville)
- Meet USCG and EPA standards
- ADA compliant
- Minimal crewing
- 60 year service life

[7] Per the LRP, the vessels are to be designed to provide flexibility in passenger capacity so they could be expanded in the future to hold more passengers as demand increases, but keep costs down in the interim by providing less capacity and therefore requiring less crew.

4.6 New 144-Car Class

The New 144-Car class will consist of seven vessels to standardize and strengthen the fleet. The class will be designed to accommodate the most demanding central sound route: Seattle / Bremerton. Note that the New 144-Car Class vessels are intended to be assigned to the Edmonds / Kingston and San Juan Island routes per Task 6. However, it is recommended to design the New 144-Car class vessels to the design criteria of the Seattle / Bremerton route for fleet commonality and interchangeability. Reducing the number of vessel classes is a strong focus of the LRP to support flexible and adaptable operations within WSF.

While the overarching requirements of the New 144-Car class are the same as the Hybrid Electric Olympic class, this plan recommends a new vessel design that considers efficiency at every level in the design spiral. A process similar to that described above for the New 124-Car class should be undertaken for the New 144-Car class, including revisiting of standard WSF practices, tradeoff decisions, vessel design charrette, and lessons learned from operators with similar hybrid vessels.

As a newly designed hybrid electric vessel, consideration should be given to azimuth thrusters. Azimuth thrusters may result in quieter vessels that can achieve a silent-E notation.

4.6.1 Propulsion Plant Configuration

The vessels shall utilize a hybrid diesel-electric propulsion system consisting of lithium-ion batteries and marine diesel generator sets.

The ESS capacity shown in Table 14 is sized to achieve a four year life of operation on the Seattle / Bremerton route with charging on each end. Potential future weight and design improvements have not been incorporated in these calculations but would reduce the overall power requirements making this a conservative assumption. The charging system should be designed to supply 14.5MW as required for the Seattle / Bremerton route.

Table 14: New 144-Car Class ESS Capacity

Applicable Routes	ESS Capacity (MWh)	Expected ESS Life (Years)	Annual Cycle Count (cycles)	Mean RCS Charge Rate (MW)[8]
Seattle / Bremerton	10	4	5,490	14.5

Automation and standards of redundancy shall comply with Sections 4.1.3 and 4.1.4. Additionally, it is recommended to consider implementation of auto-crossing and/or auto-docking systems to further improve the safety and efficiency of the vessels.

A maneuvering study is recommended to determine the most appropriate propulsor. To incorporate an auto-crossing or auto-docking system, the propulsion control system will require an interface with the steering system.

[8] Vessel charge rate, includes ship service and dock pushing loads

4.6.2 Operational Requirements

The New 144-Car class shall have operational modes similar to those of the Hybrid Electric Olympic class as shown in Table 15.

Table 15: New 144-Car Class Operational Requirements

Mode	Description	Duration Required	Speed (knots)
Battery Only	Typical all-electric operation with shore charging	Seattle / Bremerton one-way and Mukilteo / Clinton roundtrip	16
Hybrid	Typical operation when shore charging is not available with the batteries operating in "load leveling" mode described in Section 3.1.	Optimized for a Seattle / Bremerton one-way transit with a 7-day fuel endurance	16
Battery + Diesel Boost	Atypical operation with the diesels providing an extra boost to the battery-only mode	N/A	17
Diesel Only	Atypical operation with only diesels online assuming a complete loss of battery power	N/A	14.5

4.6.3 Rapid Charging System Requirements

To maintain flexibility within the fleet, the RCS for the New 144-Car class should be developed on the standard platform modeled by the other vessel classes and shall be compatible with all electrified terminals except, possibly, Port Townsend, Coupeville, Point Defiance, and Tahlequah. The RCS should be capable of supplying 15MW at the standard voltage of 12.47kV.

To meet the design criteria of the Seattle / Bremerton route, the RCS should be capable of fully charging the vessels onboard battery banks within the prescribed dwell time with an initial 95% minimum success rate. The success rate for the later vessel classes has a higher requirement because the technology should be further refined to ensure a higher success rate. The prescribed dwell times in Table 5 include time for connection/disconnection and ramp up/down of charging power from the utility.

The design criteria should be reassessed after the focused San Juan Islands study. It is recommended that the Seattle / Bremerton route design criteria be kept even if the criteria for the San Juan Islands are lesser for fleet commonality and vessel interchangeability.

The RCS should automatically connect and begin charging when the vessel enters the slip. Connection and disconnection times shall be minimized, less than one minute each, to allow for maximum charging periods. Appropriate safety mechanisms or interlocks shall be installed to manage the risk of the vessel departing while the charger is still connected.

The active portion of the RCS shall be installed on or below the pickle fork on the port side of each vessel end, looking forward to the terminal interface, for fleet and terminal commonality. The RCS shall be capable of connecting from the vessel to the receptacle on shore over the full design tidal range of the terminal and the full range of freeboard variations of the vessel while accounting for sea level rise predictions.

4.6.4 General Requirements

The vessels shall also adhere to the following general functional requirements:

- Double ended ferry
- 144 vehicles
- 750/1500 passengers[9]
- 2 lane vehicle loading and unloading
- Overhead passenger loading
- Compatible with all WSF terminals (except Coupeville)
- Meet USCG and EPA standards
- ADA compliant
- Minimal crewing
- 60 year service life

[9] Per the LRP, the vessels are to be designed to provide flexibility in passenger capacity so they could be expanded in the future to hold more passengers as demand increases, but keep costs down in the interim by providing less capacity and therefore requiring less crew.

4.7 Kwa-di Tabil (KDT) Class

In accordance with the LRP recommendation, the three vessels of the Kwa-di Tabil (KDT) class should be converted for plug-in hybrid operation. The vessels operate almost exclusively on two routes: Point Defiance / Tahlequah and Port Townsend / Coupeville.

To maintain flexibility between the two routes, the vessels shall be designed for one-way operation on the Port Townsend / Coupeville route and roundtrip operation on the Point Defiance / Tahlequah route.

4.7.1 Propulsion Plant Configuration

In the LRP, this conversion was intended to align with the engine maintenance and overhaul that will be required at the first midlife refurbishment (2031-2033). The LRP also discusses potential propulsor conversions to improve maneuverability at the Coupeville terminal. A high-level feasibility check was performed to ensure that there was appropriate space and weight margin to accommodate batteries. Key findings from this analysis are listed below:

- There is adequate space to house batteries in the void spaces at either end. Batteries may be housed in the current tank rooms (with the tanks shifted to the void spaces) depending on the desired piping and machinery arrangement.
- There is adequate weight margin in the vessels to accommodate batteries. The KDT's currently carry more than 70 tons of permanent ballast for list correction. A weight shedding strategy should be incorporated into the modifications that minimizes the need for permanent ballast by optimizing the machinery arrangement.
- There may be opportunities to add buoyancy by extending the skeg if necessary. Skeg extensions may be helpful for directional stability and may be required to accommodate a propulsor change to azimuth thrusters or cycloidal drives. It is recommended that a maneuvering study be performed.

The vessels shall be converted to a plug-in hybrid propulsion plant with potential modification to azimuth thrusters or cycloidal drives (pending the above recommended maneuvering study). The direct drive diesel mechanical propulsion plant will be removed and replaced with diesel propulsion generators, lithium-ion batteries, and electric propulsion motors.

The lithium-ion battery banks shall be sized to achieve a five-year life of operation on the Port Townsend / Coupeville route with charging on each end. While less demanding, the battery system must also be appropriately sized for operation on the Point Defiance / Tahlequah route with charging only on one end.

Table 16: KDT Class ESS Capacity

Applicable Routes	ESS Capacity (MWh)	Expected ESS Life (Years)	Annual Cycle Count (cycles)	Mean RCS Charge Rate (MW)[10]
Port Townsend / Coupeville	3.5	5	4,860	4.9
Point Defiance / Tahlequah RT		6	7,122	4.0

[10] Vessel charge rate, includes ship service and dock pushing loads

Automation and standards of redundancy shall comply with Sections 4.1.3 and 4.1.4.

4.7.2 Operational Requirements

The hybrid KDT's will need to achieve the same speed as the diesel mechanical version to ensure no impacts to service.

Table 17: KDT Class Operational Requirements

Mode	Description	Duration Required	Speed (knots)
Battery Only	Typical all-electric operation with shore charging	Port Townsend / Coupeville one-way and Point Defiance / Tahlequah round trip transits	15
Hybrid	Typical operation when shore charging is not available with the batteries operating in "load leveling" mode described in Section 3.1.	Optimized for Port Townsend / Coupeville and Point Defiance / Tahlequah transits	15

4.7.3 Rapid Charging System Requirements

While general fleet standardization is a goal, the requirement for conformity with the charging systems in the rest of the fleet may not be as important for the KDT class. The three vessels of the fleet are rarely relocated to service other routes and almost exclusively operate on the Port Townsend / Coupeville and Point Defiance / Tahlequah routes. Similarly, other vessel classes rarely operate on these two routes. A unique (smaller and cheaper) RCS could be installed on the KDT vessels without negatively affecting the flexibility of the fleet. The RCS should be capable of supplying 6MW at the standard voltage of 12.47kV.

The RCS shall be capable of fully charging the vessels onboard battery banks within the allowed dwell time with a minimum 95% success rate. The prescribed dwell time includes time for connection/disconnection and ramp up/down of utility power.

The RCS shall automatically connect and begin charging when the vessel enters the slip. Connection and disconnection times shall be minimized, less than one minute each, to allow for maximum charging periods. Appropriate safety mechanisms or interlocks shall be installed to manage the risk of the vessel departing while the charger is still connected.

The active portion of the RCS shall be installed on or below the pickle fork on the port side of each vessel end looking forward for fleet and terminal commonality. The RCS shall be capable of connecting from vessel to shore over the design tidal range of the terminal and the draft variations of the vessel while accounting for sea level rise predictions.

4.8 Summary

The following tables summarize the ESS and RCS requirements for each vessel class and route where applicable. The design criteria route is bolded.

Table 18: Vessel ESS Capacity Summary

Vessel Class	Applicable Routes	ESS Capacity (MWh)	Expected ESS Life (Years)	Annual Cycle Count (cycles)
Jumbo Mark II	**Seattle / Bainbridge**	6.3	4	8,302
	Edmonds / Kingston RT		5+	4,496
Hybrid Electric Olympic	**Seattle / Bremerton**	10	4	5,490
	Mukilteo / Clinton RT		10	6,967
New 144-Car[1]	**Seattle / Bremerton**	10	4	5,490
	Edmonds / Kingston RT		9	4,380
New 124-Car	**Fauntleroy / Vashon / Southworth**	4	5	15,045
Kwa-di Tabil	**Port Townsend / Coupeville**	3.5	5	4,860
	Point Defiance / Tahlequah RT		6	7,122

[1] The New 144 car vessels will be assigned to the San Juan Islands and Edmonds / Kingston routes. Seattle / Bremerton is the design criteria route.

Table 19: Vessel RCS Summary

Vessel Class	Design Charge Rate (MW)	Charge Voltage (kV)
Jumbo Mark II	8.5	12.47
Hybrid Electric Olympic	14.5	12.47
New 144-Car	14.5	12.47
New 124-Car	7.8	12.47
Kwa-di Tabil	4.9	12.47

APPENDIX C:
Task 5 – Terminal Modifications

Washington State Ferries
System Electrification Plan

WSDOT

Washington State Ferries

Table of Contents

Section 1

Introduction

To achieve the goal of electrifying the WSF fleet, utility and terminal improvements are needed across the system to get electric power from the existing grid to the operating slips in order to charge the vessel batteries. These utility and terminal improvements will include:

- Grid connections and distribution lines to the terminal,
- Terminal power conversion equipment, switchgear, and batteries,
- Terminal to slip distribution,
- Connection to the Rapid Charging System (RCS)[1],
- Structural improvements to the terminal and wingwalls to support both the additional power conversion equipment, switchgear, and RCS.

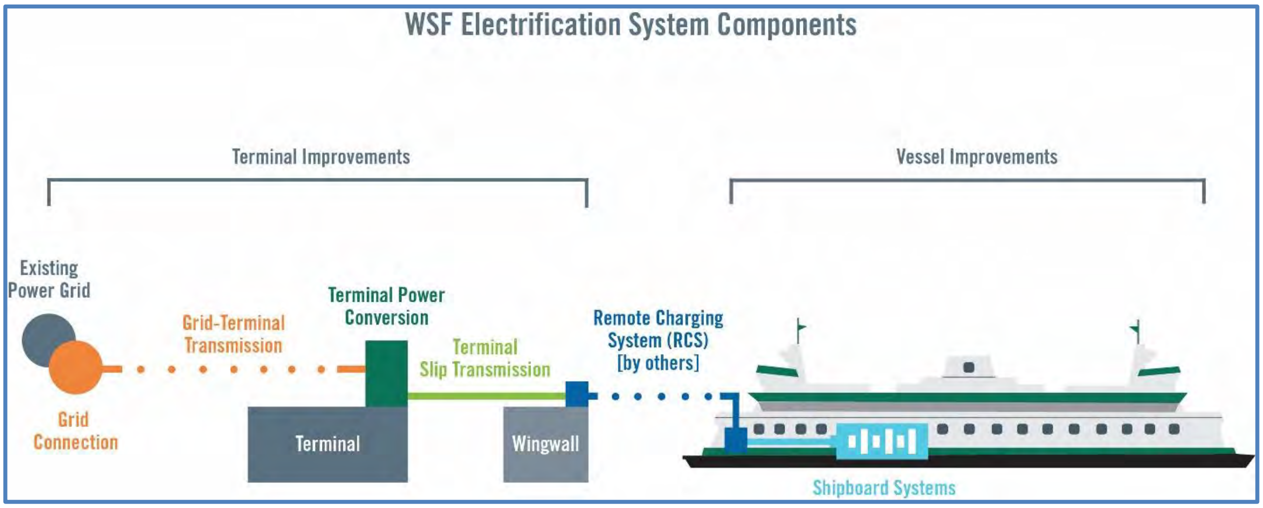


Figure 1: Terminal Electrification Components

The cost for each component will vary with each terminal and will be affected by factors such as distance to the nearest substation, distribution line routing, distance between the new electrical equipment and the operating slip, and the means of getting the power lines from the terminal trestle to the wingwall-mounted RCS.

This report starts with the power requirements determined previously (Section 2) then addresses the improvements needed from the existing electrical grid to the RCS at the operating slips (Section 3 through Section 7). The capital cost of the improvements at each terminal are addressed in Section 8.

This report focuses on the Central Puget Sound terminals that are likely to be electrified first. As the electrification program proceeds over the next 20 years, lessons learned from these initial efforts will be applied when developing site-specific plans for the remaining terminals.

[1] The Rapid Charging System is being designed by others.

Section 2

Power Requirements and Power Sources

2.1 Power Requirements

The energy requirements for each vessel class on each route within the system were developed and are discussed in the Task 4 report. The values in Table 1 represent the upper end of the annual range of energy demands and charge rates for each terminal. These values have been rounded up to ensure the infrastructure at each terminal has some margin above the design values. As the design of any particular terminal progresses, the margins can be reduced as uncertainties in energy demand or other costs are reduced.

Table 1: Route Power Requirements

Route	Vessel Class	Total Energy Demand kWh	RCS Charge Rate kW[2]
Colman Dock (Bremerton)	HEO	4,550	15,200
Bremerton		4,550	15,200
Colman Dock (Bainbridge Island)	JM II	2,730	9,100
Bainbridge Island		2,730	9,100
Vashon	New 124	690	5,200
Southworth		980	8,400
Fauntleroy		980	8,400
Pt. Defiance (RT)	KDT	860	4,300
Tahlequah		(no charging)	
Kingston (RT)[2]	New 144	3,280	11,000
Edmonds		(no charging)	
Clinton (RT)	HEO	2,080	10,400
Mukilteo		(no charging)	
Port Townsend	KDT	1,150	5,300
Coupeville		1,150	5,300

Given the complexity of the service in the San Juan Islands, additional study is needed to determine the power demands for the Anacortes, Friday Harbor, Orcas, Shaw, and Lopez Island terminals, which serve multi-stop routes. Electrification of the Sydney, BC, terminal is not recommended at this time.

[2] The Kingston design criteria were developed by the new 144 vehicle class ferries. When the hybrid Jumbo Mk II ferry is on that route, it will need to use the onboard generators to complete each round trip.

The new 144 Car Class and Hybrid Electric Olympic Class vessels will be designed with sufficient capacity to provide roundtrip service on the Edmonds-Kingston and Mukilteo-Clinton routes, respectively, thereby only needing an electrified slip at one terminal on each route. The west side terminals, Kingston and Clinton, were chosen for electrification based on the following:

- The west side terminals each have two operating slips, allowing one slip to be electrified without the need for service disruptions. The east side terminals only have a single slip each and significant operations, circulation, and schedule changes would be needed to accommodate the necessary construction effort.
- The availability of a second slip at the west side terminals also allows continued operation when the Rapid Charging System (RCS) receiver requires maintenance or repair.
- The west side terminal sites have more space available to accommodate the new electrical equipment necessary for charging the vessel batteries, resulting in fewer construction and terminal operations impacts.

2.2 Electrical Utilities

The following utilities provide electrical power to WSF terminals.

Table 2: Utilities and Available Power

Utility	Terminal	Voltage (kV)	Power (MW)
Orcas Power and Light (OPALCO)[3]	Orcas	12.47	16/40
	Shaw	12.47	16/40
	Lopez	12.47	16/40
	Friday Harbor	12.47	16/40
Puget Sound Energy (PSE)	Anacortes	12.47	3-15[4]
	Coupeville	12.47	3-10[5]
	Clinton	12.47	3-10[5]
	Kingston	12.47	3-10[5]
	Bainbridge Island	12.47	3-10[5]
	Bremerton	12.47	3-10[5]
	Southworth	12.47	3-10[5]
	Vashon Island	12.47	3-10[5]
	Tahlequah	12.47	3-10[5]

[3] With improvements, a 16 MW demand can be met at a single terminal or a combined 40 MW demand multiple terminals on the San Juan Island grid managed by OPALCO.
[4] Power limits not provided by the local utility as of April 7, 2020; estimated value based on prior projects
[5] PSE has stated that they can provide 10 MW most of the year.

Utility	Terminal	Voltage (kV)	Power (MW)
Jefferson County PUD	Port Townsend	12.47	3-10[5]
Snohomish PUD	Mukilteo	12.47	13[6]
	Edmonds	12.47	13[6]
Seattle City Light (SCL)	Colman Dock	26.00	11[7]
	Fauntleroy	26.00	10[5]
Tacoma Power	Point Defiance	12.47	10[5]

Per discussion with OPALCO, the limit when one of the two BPA submarine cables is out of service is 100MW, of which 60MW is used for the current peak demand loads, leaving 40 MW to charge ferry batteries at the four San Juan Islands terminals: Friday Harbor, Orcas, Lopez, and Shaw.

SCL has signed an agreement with WSF to provide an 11MW feeder to Colman Dock using a new ductbank to be installed in early 2021. The capacity of this line was based on previous estimates of the power required to service the Seattle to Bainbridge Island route. Additional power would be required to support charging of the vessels planned for the Seattle to Bremerton route under the current operating schedule, which would require simultaneous charging several times per day. If the schedule can be changed to eliminate this requirement, the power required can be significantly reduced.

Engineering Service Agreements are needed with the various utilities for them to conduct the analyses necessary to determine amount of power available to each terminal as well as the cost to provide some or all of the additional power to each terminal. These costs will then need to be compared to the cost of installing an appropriately sized energy storage system (ESS). Section 8 includes a range of costs for both utility connections and ESS.

2.3 Power Management and Shoreside Battery Banks

Where the existing grid capacity is greater than the peak charge rate, ferry batteries can be charged directly from the grid. To mitigate the impact of this much power coming out of the grid, a ramp up and ramp down profile for the charging system will have to be developed in collaboration with each local utility.

Where the grid capacity cannot meet the charging demand directly, or if a suitable ramp-up/ramp-down profile cannot be developed, a shoreside Energy Storage System (ESS) will be required. An ESS consists of a battery or battery bank and the power conversion and management equipment necessary to convert current between AC and DC as well as step up and down the voltage to suit the other elements of the vessel charging system. Battery banks can be charged at a power level below the maximum available and the stored power can be added to the available grid power to charge the ferry batteries at the peak charge rate required to maintain schedule. In addition to

[6] Not planned for electrification.

[7] Per agreement between WSDOT and SCL for initial electrification of the Bainbridge Island route.

allowing charging where there is not enough grid capacity, shoreside batteries can reduce or eliminate the demand peaks that drive rates and the electrical system upstream of the ferry terminal. While the use of shoreside batteries would reduce the cost of power from the local utility, it would also require significantly higher capital costs for both additional batteries and power conversion and control equipment, as well as periodic battery replacement costs. Finally, the use of shoreside batteries may be required for WSF to meet the ultimate goal of reducing emissions by 76% by 2040 where available utility power is insufficient.

Shoreside batteries will require replacement every 5-15 years, depending on the type of battery used, the number of annual charge/discharge cycles, and the depth of discharge on each cycle. To reduce the battery acquisition costs, it may be possible to re-use vessel batteries that no longer have sufficient capacity for onboard service, thereby extending their useful life and reducing the periodic replacement cost. As not all marine batteries would be suitable for re-use, close coordination between the vessel design and terminal design efforts will be necessary to reduce the overall preservation costs of the system.

Although Colman Dock is adjacent to Seattle's downtown core which has very large power demands on every block, the grid is close to capacity and there is currently insufficient power on the waterfront to serve either of the routes operating from there. To meet the demands for the Bainbridge Island route, SCL has an agreed to provide an 11 MW feeder to Colman Dock and will install a new duct bank to support the future conductors. However, additional power will be needed for the Bremerton route, especially if the schedule requires two vessels to be charged simultaneously several times a day. Although this additional power could be provided by a second feeder, SCL has stated that this solution is not viable given the capacity of the existing substation and planned construction activities in the Alaskan Way right of way. Since a second feeder is not viable, a shoreside battery bank, charged by the planned 11 MW feeder, will be required to meet the additional demand. Preliminary calculations indicate a capacity of approximately 5.5 MWh would be required. Current containerized Energy Storage Systems provide approximately 1.2 MHw in a 20' ISO standard container[8]. For planning purposes, five 20' containerized battery units are assumed plus an additional 20' container for inverters and other necessary additional equipment, for a total of six 20' shipping containers or similar accommodations.

At Bainbridge Island however, it should be noted that PSE has roughly 10MW available most of the time but the power available may be interrupted during periods of high demand elsewhere on the island. With an estimated peak demand of 9.1 MW, the existing grid should be able to support charging at the Bainbridge Island terminal but if the peak charge rate increases, or other demands on the grid increase, shoreside batteries may be required to meet reliability and emission reduction goals.

All terminals to be electrified will require additional analysis in collaboration with the local utility will be required to determine amount of power available from the grid and acceptable ramp-up/ramp-down characteristics to determine the need for shoreside batteries. Because the costs of both batteries and utility improvements are high, additional trade-off studies will be needed for each terminal to find the most cost-effective combination, factoring in both capital and operating costs.

[8] https://www.saftbatteries.com/products-solutions/products/intensium%C2%AE-max-megawatt-energy-storage-system

Section 3

Grid Connections and Distribution Lines

Whether a terminal provides direct charging of vessel batteries during regularly schedule dwell times or a shoreside battery bank is used, improvements to the local electrical grid will be necessary. These improvements will be installed by the utility, with the cost paid by either WSDOT or the utility as specified in the service agreement for each terminal.

3.1 Grid Connections

Connections to the existing grid will be made at the nearest substation upland from the terminal. For the initial cost estimates, the nearest substation for each terminal was determined using Department of Homeland Security Homeland Infrastructure Foundation-Level Data online mapping tool[9]. Initial costs estimates assume each terminal will require a new transformer and associated switchgear at each substation. All of the new equipment would be acquired and installed by the local utility, with the cost paid by WSDOT as noted above.

3.2 Distribution Lines

New distribution lines will be needed to get power from the nearest substation to the terminal. In most rural areas, power will be delivered to the terminal using overhead lines. In urban areas or other areas where overhead lines are not allowed, underground duct banks will be required at substantially higher costs. Currently, installation of new overhead lines costs roughly $1.01 million per mile, while underground duct banks cost $3.60 million per mile. On Seattle's Central Waterfront, power to Colman Dock may be possible using submarine cables. At this point, there is not enough information available to estimate the cost of submarine cables. These new distribution lines will be installed by the utility, with the cost paid as specified in the service agreement for each terminal.

In Mukilteo, Edmonds, and Bremerton, the downtown area around the terminal is served by underground power lines so new underground duct banks will likely be required. Due to the excavation and traffic disruptions associated with installing new underground duct banks, getting power to these downtown terminals is considerably more expensive than providing charging power to other terminals.

In downtown Seattle, a new duct bank will be provided to serve Colman Dock. Although this duct bank is currently planned to terminate with conduits stubbed through the seawall at the foot of Yesler Way, discussions are underway regarding the possibility of having it terminate at Pier 48 instead.

[9] https://hifld-geoplatform.opendata.arcgis.com/datasets/electric-substations

All terminal distribution lines from the power grid will end at the meter provided by the utility. WSF will be responsible for providing and installing all equipment and conductors from the meter to the RCS.

Section 4

Terminal Transformers, Switchgear, and Batteries

At each terminal, the distribution lines from the meter will feed an isolation transformer that will power all of the terminal equipment. The transformer will feed a set of switchgear that will supply the appropriate power to the RCS at each electrified slip. At terminals like Kingston and Clinton, where two ferries are moored overnight, only the operating slip would have an RCS installed. The voltage used for power distribution within each terminal allows the transformers, switchgear, and batteries necessary to be located throughout the terminal if necessary but for inspection and maintenance purposes, keeping them adjacent or at least close to each other is preferred.

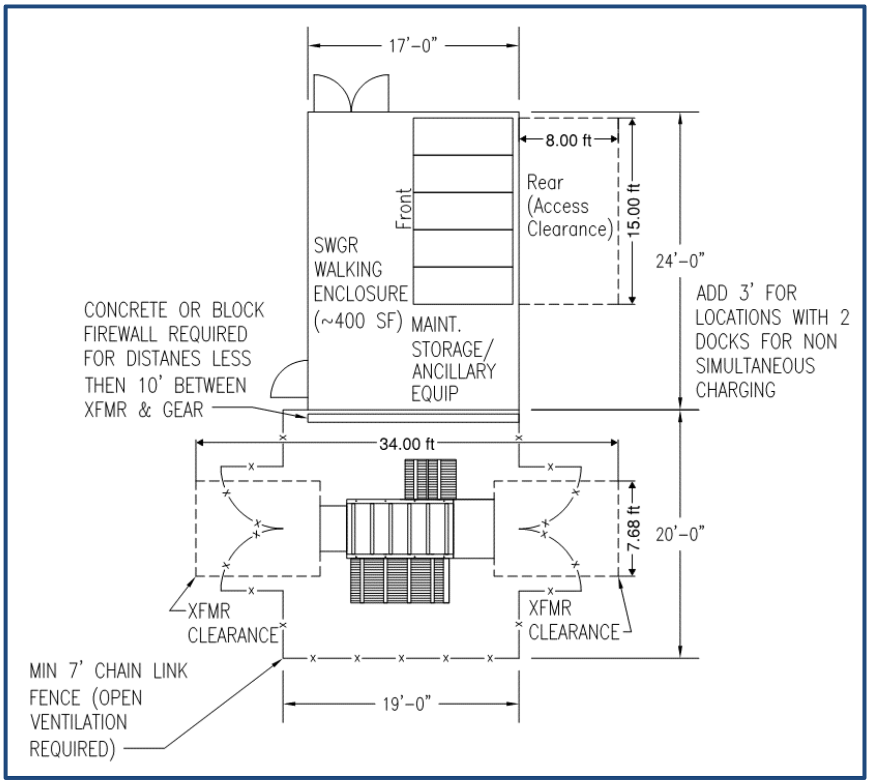


Figure 2: Typical Switchgear Building (top) and Isolation Transformer Yard (bottom) Layout

The above configuration includes a concrete or CMU firewall between the transformer and the switchgear, which is required if the transformer is less than 10' from the switchgear or another transformer.

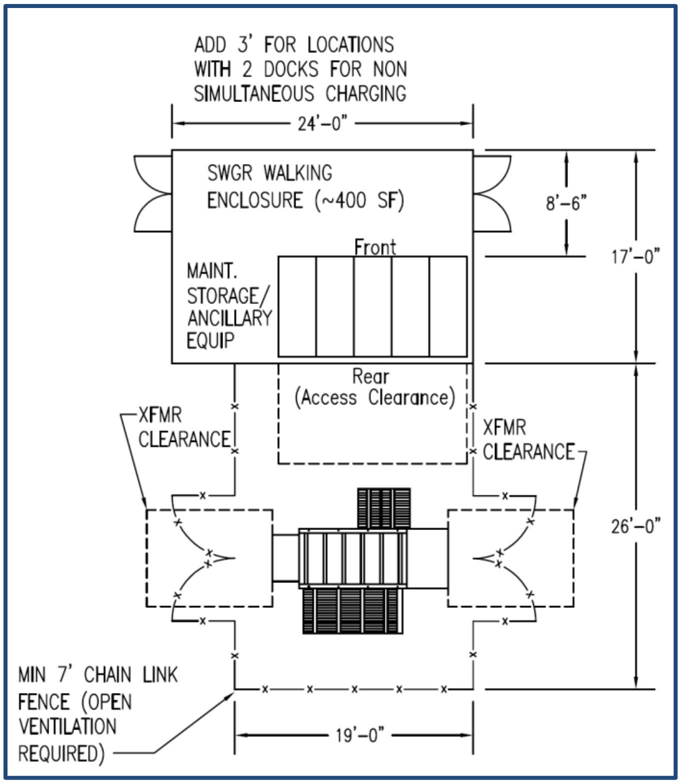


Figure 3: Alternate Equipment Layout (switchgear top, transformer bottom)

At Colman Dock, it will likely to be necessary to have the capability to charge ferries serving both the Bremerton and Bainbridge Island routes at the same time. A local transformer for each vessel is recommended to provide an isolated ungrounded electrical system. It may also be possible to serve two slips simultaneously with a single transformer, but this may affect reliability by eliminating redundant components. The shoreside system should be designed to separate the vessel ground system and the shore-based ground system to prevent galvanic corrosion and stray current. The approach also allows operation even if a fault is detected between a phase and ground as well as providing redundancy and limiting the impact of ay maintenance or repairs to a single slip. Duplicate systems that use the same design and components as the rest of the system will also simplify training and logistics. In this location, a slightly smaller footprint may be possible by combining the switchgear buildings and putting both transformers into a single enclosure. If the spaces are combined, the layout will still need to provide for the minimum access clearances required by the applicable codes.

4.1 Transformers

Each transformer will be approximately 12 feet by 14 feet and will require a 10-foot access clearance on each end. Transformers are typically enclosed by fencing for both security, fire safety, and maintenance. Transformers of this size have an expected service life of 20 to 30 years so their location will need to accommodate the heavy equipment necessary to replace them. Replacement of any new transformers would occur outside the planning window for this study and are not included in the financial analysis.

The fire risk presented by large transformers is generally mitigated by installing a concrete wall between the transformer and the associated switchgear or between adjacent transformers, if they are less than ten feet apart. The transformer area shown in the Appendix A site plans includes the clear areas required for maintenance access.

4.2 Switchgear

To minimize the footprint required at each terminal, a switchgear building is recommended rather than a fenced enclosure, as the clearance requirements are much larger for an open enclosure. In addition to the electrical equipment, the building should include limited space for maintenance and cleaning supplies. Maintenance access to the switchgear will be required from both inside and outside the enclosure or building. The exterior maintenance area can be a parking space or contain easily moved equipment if necessary.

4.3 Shoreside Battery Banks

Where a shoreside battery bank is required, it would ideally be located close to the main transformer and switchgear but if space constraints preclude putting all of the equipment in close proximity, the voltage used will allow for significant separation with negligible transmission losses. Currently, a self-contained commercial 1.2MWh / 3.0MW battery bank is available as a 20-foot ISO standard container[10]. These containers typically include fire protection and power management equipment. Depending on the battery capacity required, multiple containerized energy storage systems may be required. Where multiple battery units are required, separate power conversion and management equipment will likely be needed. The battery containers can be stacked and where they are, maintenance access via stairs or ladders will be required. In addition to the footprint of the container, an allowance will be needed for installation, maintenance, and personnel access.

Section 5

Terminal Power Distribution

5.1 Intra-Terminal Distribution Lines and Infrastructure

Because the RCS will be using medium voltage, transmission losses between the switchgear and the slip will be negligible, as long as the distance is less than a mile or so. Running the power from the charging system switchgear to the wingwall mounted RCS will entail a combination of underground ductbanks, conduit, and cable trays that will vary between terminals. At some terminals, it may be feasible to use submarine cables for distribution from shore to the RCS, but this is not standard WSF practice and sufficient information to develop cost estimates is not available. The power distribution system will also include the manholes, pull boxes, and other components as required by code and constructability guidelines.

The conduit preferred by WSF Terminal Engineering for running cables beneath the trestles is PVC coated Rigid Galvanized Steel (RGS) conduit, which costs roughly $90 per foot for five-inch

[10] Saft, https://www.saftbatteries.com/products-solutions/products/intensium%C2%AE-max-megawatt-energy-storage-system

conduit. Installing this conduit requires multiple people for each ten-foot section as well as work barges and heavy lifting equipment. Given the likely amount of conduit necessary throughout the system, consideration should be given to extra-heavy-duty fiberglass conduit, similar to that used by the US Navy for secure power and communications lines in high-risk areas, including overwater facilities.

5.2 Distribution Lines to Wingwall-Mounted RCS

Overhead, submarine, and cable tray supported lines were considered to make the connection between the trestle and wingwall at each slip. While overhead lines may be the least expensive to install, they present a greater risk of failure in ice storms and high wind events. Submarine lines are likely the most expensive and hardest to maintain. Using cable trays provides the lowest risk and easiest maintenance means of getting power to the wingwalls. If a catwalk is necessary for inspection, maintenance, and repair of the RCS, the cable tray could be incorporated into the catwalk design.

If a catwalk is not necessary for personnel access and the existing wingwall ladders are adequate, routing the power and control cables in a series of cable trays on the VTS, VTS lifting mechanism fixed structure, and wingwall would be viable. This concept is shown in Figure 4. In this concept, the elevation of the cable trays would need to be high enough that the loops remain clear of the water. Saddles and other details would also have to be developed to properly protect and support the cables. A mining grade cable will likely be necessary to achieve a reasonable service life. By connecting to the fixed VTS support structure on the landward side, the vertical range accommodated by the loop can be significantly less than the maximum range at the end of the VTS. For these loops, fabricating spare sections of cable and connections that can be stored at Eagle Harbor would be recommended. The loop between the VTS support structure and the wingwall only has to accommodate the movement of the wingwall so it should not need to be replaced as frequently. The main advantage of this approach is the elimination of new overwater structures.

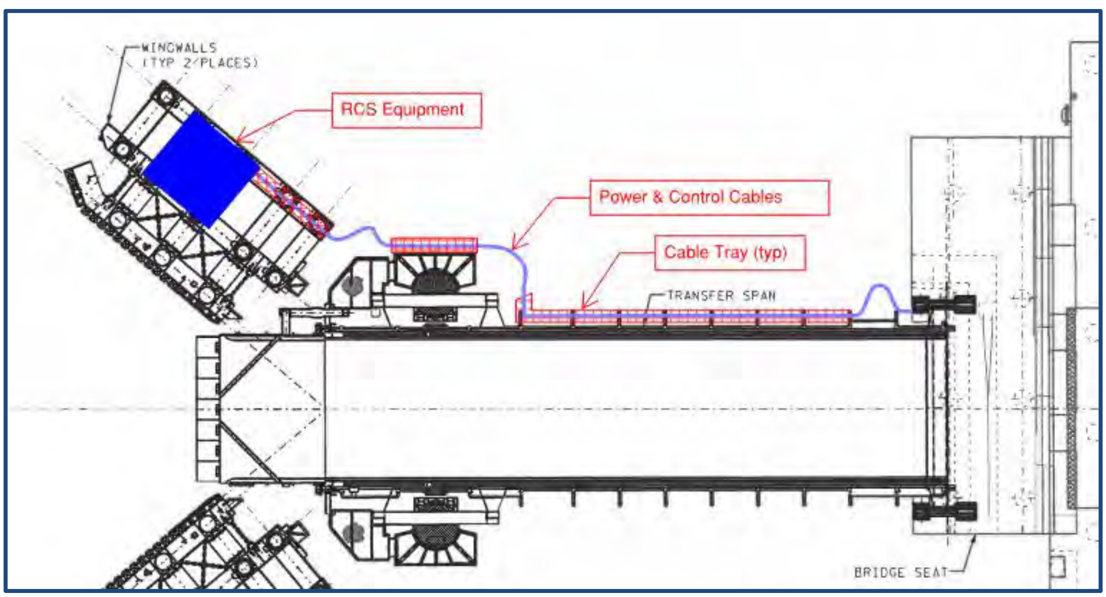


Figure 4: VTS mounted RCS cable routing

The figure above is based on the VTS and wingwall designs at the Mukilteo Terminal. The VTS support and wingwall designs vary from terminal to terminal so the concept will need to be adapted to accommodate each specific slip where it is used.

The existing ladders were designed primarily for self-rescue and safety but are used periodically by maintenance and contractor staff during inspections and repairs. Ladder safety standards should be reviewed to verify the design meets the requirements for more frequent use[11].

For system-wide consistency, the RCS equipment will be mounted on the port wingwall (from the perspective of the arriving ferry) at each electrified slip.

Section 6

Electrical Equipment Inspection, Maintenance and Repair

6.1 Terminal Transformers and Switchgear

The new transformers and switchgear should be relatively low maintenance items, but they will need periodic monitoring and inspection. Spare main breakers are recommended to minimize downtime in case of a breaker failure. Spare breakers and other special parts and tools should be stored in accordance with the Eagle Harbor best management practices.

6.2 Rapid Charging System

Access to the wingwall-mounted elements of the RCS will be required for regular inspection, maintenance, and repair. The inspection, maintenance, and repair requirements for the RCS are being developed by others. A more detailed description of the infrastructure required to support this work will be developed as additional information becomes available, including recommendations for spares and specialized tools.

If daily visual inspection of the RCS from the vessel is adequate and maintenance can be done without the use of heavy tools or parts, access via the existing wingwall ladder may be adequate. If a more detailed or hands-on inspection is required, or if the necessary tools and parts cannot be easily carried by hand, a catwalk from the trestle or VTS lifting mechanism fixed structure may be necessary. If a catwalk is necessary, it could incorporate a cable tray to support the power and control cables for the RCS.

---

[11] See · WAC 296-876, Safety Standards for Ladders, Portable and Fixed, and ANSI-ASC A14.3-2018, American National Standard for Ladders – Fixed – Safety Requirements

Section 7

Terminal Impacts

7.1 Operating Impacts

The primary impacts to terminal operations will be the relocation of other utilities, buildings, or functions to accommodate the required transformers, switchgear, and associated infrastructure. Relocations will include other electrical equipment, other utilities, storage buildings or areas, and staff parking. Where relocation of existing equipment or functions is not feasible, the new electrical equipment would displace a portion of the vehicle holding capacity at each terminal, which can impede efficient loading of ferries, hinder on-time performance, reduce the efficiency of terminal operations, and cause local traffic issues which are a concern to the local community.

Proposed locations for the new equipment and distribution infrastructure for the primary central Puget Sound terminals are shown in Appendix A. Equipment layout efforts were focused on these terminals as they serve the first routes currently planned for electrification. These layouts are based on available aerial imagery and discussions with WSF staff and represent the types of impacts that can be expected at other terminals. Additional size and location analyses will be required for each terminal to determine the final location and provide a more accurate estimate of the probable construction cost. The specific impacts on terminals not included in Appendix A will need to be assessed in conjunction with terminal-specific site planning studies that can build on lessons learned from the initial terminal electrification projects.

When determining the final location for all electrification equipment, consideration should be given to sea level rise projections and future flood hazard elevations to ensure the equipment is sufficiently protected from flooding. All equipment should also be delivered with coating and cathodic protection systems suitable for the harsh marine environment experienced at all WSF terminals.

7.1.1 Clinton

The new electrical equipment at Clinton would include a new fenced transformer enclosure, battery containers, and a small switchgear building. To accommodate the new overhead passenger loading infrastructure and planned second operating slip, the new equipment could be located just east of the current operating slip. The new overhead loading span will be elevated to pass over the current drive lanes and the new equipment would be under the elevated passenger walkway.

If the transformer is located under the passenger loading structure, additional fire protection may be necessary to mitigate the risk of fire associated with large transformers.

The proposed location currently serves a bicycle shelter and a small portable storage building, both of which would need to be relocated if the terminal were to be electrified before the overhead loading is constructed.

7.1.2 Kingston

Kingston would require the same electrical equipment as Clinton but there appear to be two options for locating the equipment. One option would be along the northwest edge of the terminal site, which is currently used for staff parking, and the other is on the existing trestle where it would displace some staff parking and modular buildings. For either location, the displaced staff parking could be relocated to an existing upland staff parking lot.

7.1.3 Bainbridge Island

The Bainbridge Island terminal does not have space for a new transformer and switchgear within the current operating footprint so it would be easier to accommodate the equipment within the nearby Eagle Harbor Maintenance Facility. The equipment would displace some of the material currently stored in the yard, but any displaced material can be accommodated elsewhere through a combination of more efficient storage, improved housekeeping, and disposal of unnecessary materials and equipment. The equipment could be installed on slab foundations requiring minimal ground disturbance of potentially contaminated soils.

Although overhead lines are viable for distribution lines from the Eagle Harbor facility to the terminal, underground ductbanks will likely be required. Within the terminal, a combination of underground duct banks and RGS conduit beneath the trestle will be needed.

If the equipment is not located at Eagle Harbor, or if the cost of an underground duct bank is prohibitive, there should be sufficient room within WSDOT property to the southwest of Holding Lane 15 and the bicycle lane, outside the existing guardrail. This location is considered a steep slope so any required grading or foundation design may have additional permit requirements. From this location, the distribution lines would likely be run in underground duct banks and RGS conduit to the operating slips.

7.1.4 Colman Dock

Colman Dock is currently being rebuilt and when completed, will face similar space constraints as other terminals. Because the sailing schedules for the two routes serving Colman Dock overlap several times a day, more electrical equipment will be required to electrify two slips. To improve service reliability, duplicate charging systems are recommended so that if one component fails, it will still be possible to charge a ferry at the other slip. If the sailing schedule can be modified so that only one ferry requires charging at any given time, the amount of power and equipment could be reduced.

In reviewing options for locating the necessary equipment at Colman Dock, the use of the WSDOT-owned upland area of Pier 48 was determined to be the preferred location. The distribution cables from Pier 48 to Colman Dock could either run in a duct bank in the Alaskan Way right of way or via submarine cables.

7.1.5 Bremerton

The Bremerton terminal is located on a constrained, urban site and provides a wide range of transportation services. As a result, there is very limited space for new electrical equipment and providing additional power will likely require additional duct banks be installed through the downtown area. The one portion of the terminal where the equipment could be accommodated is underneath the inbound bus ramp on the west side of the terminal. This area is currently used for WSF staff parking and access to the Puget Sound Navy Museum’s emergency generator. To accommodate the necessary equipment and batteries, additional parking would need to be found elsewhere in the neighborhood and the equipment would have to be arranged to allow the necessary access to the generator building.

7.1.6 Triangle Route Terminals (Fauntleroy, Vashon Island, and Southworth)

The terminal power requirements listed in Table 1 show that the greatest demands on the Triangle Route occur at Fauntleroy and Southworth, both of which are scheduled for major preservation projects within the same time frame that electrification will occur. To avoid duplication of effort and rework, site planning for the electrification of these terminals should be integrated with that of the terminal preservation work. Given that the terminal preservation planning has just started for these terminals, it is premature to develop preliminary site plans and site-specific construction cost estimates at this time. Seattle City Light (Fauntleroy) and Puget Sound Energy (Southworth) can both provide adequate power to these terminals.

At Vashon Island, additional analysis is recommended to determine if electrification is necessary or if sufficient power can be provided via the other two terminals to support fully electric service on the Triangle Route. If Vashon Island does need to be electrified, vessel operations could be optimized to reduce the power and electrical equipment required. There is sufficient power available on Vashon Island to support electrification and an initial review of the terminal and upland WSDOT property indicates there would be sufficient space for the necessary equipment.

7.2 Construction Impacts

The new electrical equipment and associated infrastructure must be designed to allow installation without requiring a shutdown of the terminal and sequencing of the work will be critical to minimizing disruptions to service. The initial layouts shown have been developed with this in mind, but additional studies will be necessary, and adjustments will likely be made to achieve these goals.

Section 8

Construction Cost Estimates

Capital costs include costs incurred by the local utility getting power to the terminal, electrical equipment at each terminal, electrical infrastructure improvements, and relocation of displaced equipment, buildings, or other terminal features necessary to accommodate the new electrical equipment. Given the preliminary nature of this report, all costs have been rounded up. It is important to note that these costs are intended to inform budget and programmatic planning efforts. As each route or terminal electrification effort moves forward, the construction cost estimates below can be expected to vary.

8.1 Utility Connections and Distribution Costs

Each utility will be responsible for improvements to the nearest substations and providing distribution lines to the terminal. For this initial analysis, we made the following assumptions:

- For utilities other than OPALCO, general costs for engineering, mobilization, management, and overhead would be approximately $200,000 per connection.
- A new transformer and other work at each substation would cost approximately $3.9 million.
- 12.47 kV overhead distribution lines would cost $1.01 million per mile.
- 12.47 kV underground distribution lines would cost $3.60 million per mile.

- Seattle City Light 26 kV underground lines would cost $2.4 million per mile, assuming the duct banks have already been installed.

The current distribution system to the San Juan Islands managed by OPALCO would need significant improvements to provide reliable power to all of the terminals it services. These costs could include new submarine cables, new shoreside infrastructure, and/or a battery bank installed at Anacortes that could serve all of the San Juan Island terminals through an enhanced distribution system. This cost would benefit the entire OPALCO system and are not included in the estimates below.

Based on these assumptions, the cost to the utility to provide 10 MW of power to each terminal in summarized in Table 3 below. These costs are very preliminary in nature as they reflect only conceptual level designs and historic unit costs. The actual costs at the time of construction are likely to vary as additional details are developed.

Table 3: Terminal Electrification Utility Costs (millions)

Utility	Terminal	Utility XFMR & General Cost	Utility Distribution	Total Utility Cost
Orcas Power and Light (OPALCO)	Orcas	$5.90	$1.5 – 2.0	$5.9
	Shaw	$6.10	$2.2 – 3.5	$6.1
	Lopez	$6.90	$1.8 – 3.0	$6.9
	Friday Harbor	$6.10	$1.6 – 2.2	$6.1
Puget Sound Energy (PSE)	Anacortes	$5.20	$1.9	$7.1
	Coupeville	$4.10	$3.1	$7.2
	Clinton	$4.10	$2.9	$7.0
	Kingston	$4.10	$4.3	$8.4
	Bainbridge Island	$4.10	$2.8	$6.9
	Bremerton	$4.10	$3.2	$7.3
	Southworth	$4.10	$4.7	$8.8
	Vashon Island	$4.10	$9.2	$13.3
	Tahlequah	$4.10	$6.6	$10.7
Jefferson PUD	Port Townsend	$4.10	$1.8	$5.9
Snohomish PUD	Mukilteo	$4.10	$4.3	$8.4
	Edmonds	$4.10	$3.3	$7.4
Seattle City Light (SCL)	Colman Dock	$0.20	$2.4	$2.6
	Fauntleroy	$4.10	$3.2	$7.3
Tacoma Power	Point Defiance	$4.10	$1.8	$5.9

8.2 Electrical Equipment

The equipment needed at each terminal to manage the charging power includes a transformer and switchgear, and in some locations an energy storage system or battery, as described in Section 4. The transformer and switchgear costs will be roughly the same for every terminal where charging will only occur at one slip at a time. At Anacortes and Colman Dock, where there will be the need to charge two vessels simultaneously, these costs will be considerably higher, but some economies of scale should be achievable, so they are not doubled. The assumed equipment costs are as follows:

- Isolation transformer: $430,000 ($850,000 at Anacortes and Colman Dock)
- Switchgear: $1.4 million ($2.8 million at Colman Dock to accommodate charging two vessels at the same time)
- Battery Bank: $800 per kWh

In addition to the electrical equipment, fencing, a foundation, and other site improvements will be required for the transformer and a small building will be required to house the switchgear. The site improvements for the transformers are assumed to cost $25,000 and the building, with furnishings, is assumed to cost $50 per square foot or $20,000. With other site improvements, an estimated cost of $100,000 per transform and switchgear pair will be included.

If the local utility cannot readily provide 10 kW of power, local batteries will be needed. The cost of the batteries and their footprint will vary with the amount of storage required. An initial estimate of the cost and size of batteries at each of the Central Sound terminals in shown the table below. Additional analysis and coordination with the local utility at each terminal will be required to determine the most cost-effective combination of additional grid power and battery power.

Table 4: Available Grid Power and Battery Cost

Terminal	RCS Charge Rate (kW)	Available Grid Power (kW)	Required Battery Power (kW)	Recommended Battery Capacity (kWh)	Estimated Battery Cost	Total Energy Storage System Cost	Number of 20-foot Units
Clinton	10,400	5,000	5,400	1,400	$1,120,000	$ 1,400,000	3
		7,500	2,900	800	$ 640,000	$ 800,000	2
(assumed utility power available)		10,000	400	100	$ 80,000	$ 00,000	2
		11,000	-	-	$ -	$ -	-
Kingston	11,000	,000	6,000	2,300	$1,840,000	$ 2,300,000	3
		7,500	3,500	1,400	$1,120,000	$ 1,400,000	3
(assumed utility power available)		10,000	1,000	400	$ 320,000	$ 400,000	2
		11,000	-	-	$ -	$ -	-

Terminal	RCS Charge Rate (kW)	Available Grid Power (kW)	Required Battery Power (kW)	Recommended Battery Capacity (kWh)	Estimated Battery Cost	Total Energy Storage System Cost	Number of 20-foot Units
Bainbridge Island	9,100	5,000	4,100	1,600	$1,280,000	$ 1,600,000	3
		7,500	1,600	600	$ 480,000	$ 600,000	2
(assumed utility power available)		10,000	-	-	$ -	$ -	-
Bremerton	15,200	5,000	10,200	3,900	$3,120,000	$ 3,900,000	5
(and Anacortes)		7,500	7,700	2,900	$2,320,000	$ 2,900,000	4
(assumed utility power available)		10,000	5,200	2,000	$1,600,000	$ 2,000,000	3
		12,500	2,700	1,100	$ 880,000	$ 1,100,000	2
		15,000	200	100	$ 80,000	$ 100,000	2
		16,000	-	-	-	-	-
Colman Dock	24,300	5,000	19,300	7,300	$5,840,000	$ 7,300,000	8
		7,500	16,800	6,300	$5,040,000	$ 6,300,000	7
SCL power per agreement w/WSF		11,000	13,300	5,000	$4,000,000	$ 5,000,000	6
		12,500	11,800	4,500	$3,600,000	$ 4,500,000	5
		15,000	9,300	3,500	$2,800,000	$ 3,500,000	4
		20,000	4,300	1,700	$1,360,000	$ 1,700,000	3
		25,000	-	-	$ -	$ -	-

The recommended battery capacity is 125% of the minimum battery capacity to avoid fully discharging the batteries during each charging cycle. The total ESS cost includes an additional 25% for power conversion and management equipment. The number of battery & ESS containers is based on the Intensium Max containerized battery system.

8.3 Terminal Power Distribution and Infrastructure

Within the terminal, the cost of underground duct banks will be roughly the same as those installed by the utilities to get power to the terminals, approximately $700 per foot. Where conduit runs under or alongside a trestle, the cost per linear foot is will be higher due to the high material cost for the PVC Rigid Coated Steel conduit and the challenges associated with installing it. To develop the initial terminal capital cost estimate, the distribution is assumed to required two x 5-

inch conduits for power and two x 2-inch conduits for monitoring and control. The direct material cost will be about $250 per foot and the installation cost is estimated to be three times the material cost, for a total of $1,000 per foot.

Conceptual locations for the new equipment and distribution were developed for the central Puget Sound terminals that have been the focus of attention for previous studies. For the other terminals, a budget allowance of $350,000 has been provided for power distribution within the terminal.

8.4 Power and Personnel Access to the RCS

Because the inspection, maintenance, and repair requirements for the RCS have not yet been finalized, the cost estimate assumes a catwalk will be provided at each electrified slip for personnel and power access. The construction cost will be significantly less if the final RCS access requirements can be satisfied by the existing wingwall ladders.

The assumed catwalk/cable tray will typically consist of two sections of aluminum catwalk and a single cantilever pile support at the middle of the total span. For estimating purposes, a 36" diameter pile was assumed. The catwalks were assumed to be a standard design, based on the 80-foot aluminum gangways in service at many marinas around Puget Sound.

The RCS receptacle maintenance platform is assumed to be a fiberglass grated platform with a galvanized and coated HSS steel frame, attached to the reaction pile frames at the starboard wingwalls. Similar structures are used on commercial floats and typically cost between $100 and $150 per square foot. To account for the added structure needed to attach the platform to the wingwalls, the unit price was assumed to be $300 per square foot.

Based on existing RCS in operation, the weight of the receptacle is estimated to be 500 pounds and the housing for it is assumed to be 1.5 times heavier. The housing will be made of steel, at a unit cost of $7.00 per pound, based on recent discussions with fabricators and bid tabs.

- Catwalk (2 x 80' sections) $140,000
- 36" Monopile..$30,000
- RCS Access Platform...........................$30,000
- RCS Enclosure......................................$6,000

Power and personnel access were assumed to be provided to each slip that would be electrified at each terminal. Most of the personnel access cost can be eliminated if the existing wingwall ladder is found to provide adequate access to the RCS. The cost of providing cable trays and the associated hardware will be much less than the cost of catwalks and will also eliminate the need to install any piling.

8.5 Relocation of Existing Equipment or Buildings

Preliminary locations for the new electrical equipment were chosen with the intent to minimize the need to relocate equipment or buildings. This could include the cost of moving temporary buildings or shelters, relocating electrical panels or utility connections, and/or restriping of pavement for relocated staff parking or conversion of holding lanes to staff parking. Because the building, equipment, utility, and parking relocations will vary between terminals, a $250,000 allowance has been provided for each terminal.

8.6 Mitigation and Settlement Costs

Mitigation costs are difficult to determine until an initial project scope that includes environmental impacts can be developed. At this point, the in-water impacts would be limited to the installation of a pile-supported catwalk to service the RCS. This will have both construction and habitat impacts from the installation of a support pile and the creation of additional overwater coverage. The mitigation costs are estimated at $130 per square foot at the Central Sound terminals for which a conceptual site plan has been developed. For the other terminals, mitigation costs are included in the overall “soft costs” allowance.

New catwalks will also impact tribal access to “usual and accustomed” fishing grounds, which will likely result in a need for tribal settlement payments. Because settlements for these impacts can affect more than one tribe at each terminal and the amount of the settlement is negotiated on a case-by-case basis, these costs are not included in the cost estimates below but is should be noted that these costs could equal or exceed the construction cost for relatively small projects like the new catwalks.

8.7 Cost Summary

8.7.1 Central Puget Sound Terminals

The estimated utility and base construction costs for the Central Sound terminals are summarized in Table 5 based on the conceptual layouts in Appendix A. These concepts suggest all of the displaced functions can be relocated. An allowance for the cost of these relocations is included in the construction costs. These costs assume 10 MW of grid power is provided to each terminal and is supplemented with batteries to meet the full power demand for charging the ferries. The number of 20’ battery containers assumed is as shown in Table 4.

Preliminary layouts and cost estimates were not developed for Mukilteo or Edmonds as round-trip charging for those routes will be provided at the Clinton and Kingston terminals, respectively.

Table 5: Base Construction Cost Summary

TE Cost Item #	Cost Item Description	Colman Dock	Bremerton	Bainbridge Island	Kingston	Clinton
(5)	Construction Contract	$ 3,720,000	$ 1,770,000	$ 1,530,000	$ 2,060,000	$ 1,320,000
(6)	Construction Engineering	$ 560,000	$ 260,000	$ 230,000	$ 310,000	$ 200,000
(7)	Contingency	$ 150,000	$ 70,000	$ 60,000	$ 80,000	$ 50,000
(8)	Below-the-Line Items	$ 6,610,000	$ 8,010,000	$ 7,910,000	$ 8,160,000	$ 7,670,000
(9.1)	Third Party Agreements	$ 790,000	$ 200,000	$ 200,000	$ 200,000	$ 200,000
(9.2)	Prior Contracts	$ 8,720,000	$ 1,830,000	$ 3,830,000	$ 2,230,000	$ 1,930,000
(9A)	**CN Phase Total**	**$ 20,550,000**	**$ 12,140,000**	**$ 13,760,000**	**$13,040,000**	**$11,370,000**
(12)	PE Phase Total	$ 3,730,000	$ 1,080,000	$ 1,610,000	$ 1,290,000	$ 980,000
(15)	**Total Project Cost**	**$ 24,280,000**	**$ 13,220,000**	**$ 15,370,000**	**$14,330,000**	**$12,350,000**

Cost estimate notes:

1. Below-the-Line Items includes utility agreements, city permits, procurement, and EOR consultant services. At Colman Dock, this includes the $2.75M duct bank previously installed by SDOT per agreement with WSDOT.
2. Third Party Agreements costs include tribal mitigation payments
3. Prior Contracts includes the purchase of long lead electrical equipment (transformers, switchgear, and batteries)
4. PE Phase costs are estimated as 30% of estimated Construction Contract (line 5) plus the cost of long-lead equipment.

At Colman Dock, WSF is in discussions with SCL, SDOT, Office of the Waterfront, and the Port of Seattle to install the transformers, main switchgear, and batteries on the upland portion of Pier 48, immediately to the south. This location would eliminate the need to build new structures, modify holding and exit circulation, or eliminate parking at Colman Dock. New conduit or submarine cables would be provided to connect the Pier 48 uplands with Colman Dock, in addition to the duct bank previously agreed to with SDOT and SCL. There will be a need for a smaller distribution switchgear on Colman Dock where the feed from Pier 48 will be split to serve Slips 1 and 3 separately. The footprint of the additional distribution switchgear should be determined early in the implementation phase, but it is expected to be small enough to have minimal impacts on operations.

The estimated cost of the Construction Contract for Colman Dock is notably higher than the other terminals due to need to charge two vessels simultaneously, the additional conduit or submarine cable from Pier 48, and more PVC RGS conduit than the other terminals. The Prior Contracts cost at Colman Dock is higher due to the need for secondary switchgear and the additional equipment and batteries necessary to charge two vessels simultaneously.

8.7.2 Other Terminals

Preliminary cost estimates for the other terminals in the system are provided in Table 6. These costs were extrapolated from the concept design costs for the Central Sound terminals. These costs should be updated as the electrification program moves forward, and additional conceptual layouts are developed.

Table 6: Other Terminal Construction Costs

Terminal	Total Base Cost	Program Markup	Total Project Cost
Orcas	$ 8,650,000	$ 3,028,000	$ 11,678,000
Shaw	$ 8,850,000	$ 3,098,000	$ 11,948,000
Lopez	$ 9,650,000	$ 3,378,000	$ 13,028,000
Friday Harbor	$ 8,850,000	$ 3,098,000	$ 11,948,000
Anacortes	$ 13,490,000	$ 4,722,000	$ 18,212,000
Coupeville	$ 11,150,000	$ 3,903,000	$ 15,053,000
Southworth*	$ 11,550,000	$ 4,043,000	$ 15,593,000
Vashon Island	$ 13,450,000	$ 4,708,000	$ 18,158,000
Port Townsend	$ 8,650,000	$ 3,028,000	$ 11,678,000
Fauntleroy*	$ 10,050,000	$ 3,518,000	$ 13,568,000
Point Defiance	$ 8,650,000	$ 3,028,000	$ 11,678,000

For the other terminals, utility costs include new equipment, distribution lines, and general costs. Terminal equipment includes transformers, switchgear, and batteries, which could be purchased prior to award of the construction contract. Terminal construction includes site work, buildings, distribution, catwalks, and relocation of other terminal elements. Utility, equipment, and construction make up the base cost for each terminal and a 35% allowance is provided for other program costs such as mitigation, permits, procurement, Engineer Of Record (EOR) services during construction, and Preliminary Engineering (PE) phase costs. This allowance is based on the estimated additional program costs for the central Puget Sound terminals.

8.8 Cost Mitigation Opportunities

8.8.1 Use of Batteries

The use of batteries to provide some of the charging power required could reduce the utility costs at each terminal. Finding the most efficient combination of grid and battery power will require terminal-specific trade-off analyses conducted in collaboration with the local utilities. In parallel with the analysis needed to determine the recommended battery capacity for each terminal, a site analysis to determine the best location for the battery storage system will be required.

For some terminals, if the benefits of battery power extend to other utility clients, it may be possible to shift some or all of that cost to the utility. One example would be on Seattle's Central Waterfront, where multiple agencies, including the Port of Seattle and possibly the King County Water Taxi and Kitsap Transit, are considering electrification projects that would have high intermittent power demands and/or fast ramp-up periods that could be served by a single battery bank that is designed and managed to serve multiple users over the course of a day.

8.8.2 Coordination with other WSF Projects

The costs above are based the electrification work being managed as stand-alone projects, independent of other work previously planned at each terminal. If the electrification work can be coordinated with other planned projects, the total cost can be reduced by reducing the number of construction contracts needing to be managed, improving the efficiency of the work, and eliminating the need for rework. Current major projects where coordination with the electrification work could reduce total costs include:

- Trestle preservation/replacement at Fauntleroy
- Trestle preservation/replacement at Southworth
- New overhead loading at Clinton
- Toll booth relocation at Kingston.

Given the status of the current terminal preservation project at Colman Dock, adding electrification work to the current contract is not recommended.

8.8.3 Colman Dock

As the only terminal that is planned to serve two routes in the near term, Colman Dock requires significantly more work than the other Central Puget Sound terminals. While some economies of scale from providing power to two slips simultaneously are reflected in the preliminary cost estimate, further study and discussions with potential partners is required to determine the final design requirements, system configuration, and construction strategy. Although the electrification of the Bremerton route is not planned until several years after the Bainbridge Island route, the improvements necessary for Slip 1 should be undertaken at the same time as Slip 3 to save construction costs and minimize disruptions to operations. It may be possible to defer some of the equipment acquisition costs, such as transformers and batteries, until they're needed for the Bremerton route but all of the associated infrastructure, such as equipment pads, conduit, and equipment relocations, for both routes should be installed at the same time.

Section 9
Recommended Next Steps

9.1 Pre-Design Study

As the improvements at each terminal will have program cost greater than $5M, a Pre-Design Study will be required. This study should be used to address the following issues.

9.1.1 Power Demands

The power demands and operating schedule for each route to be electrified should be reviewed and refined to provide final design requirements for each terminal prior to the design of improvements and selection of electrical equipment.

9.1.2 Utility Coordination

An Engineering Service Agreement with the utility serving each terminal to be electrified will be needed to conduct additional trade-off studies to determine the optimum combination of grid improvements and batteries at each terminal, as well as to provide more accurate utility cost estimates.

9.1.3 Equipment Siting Studies

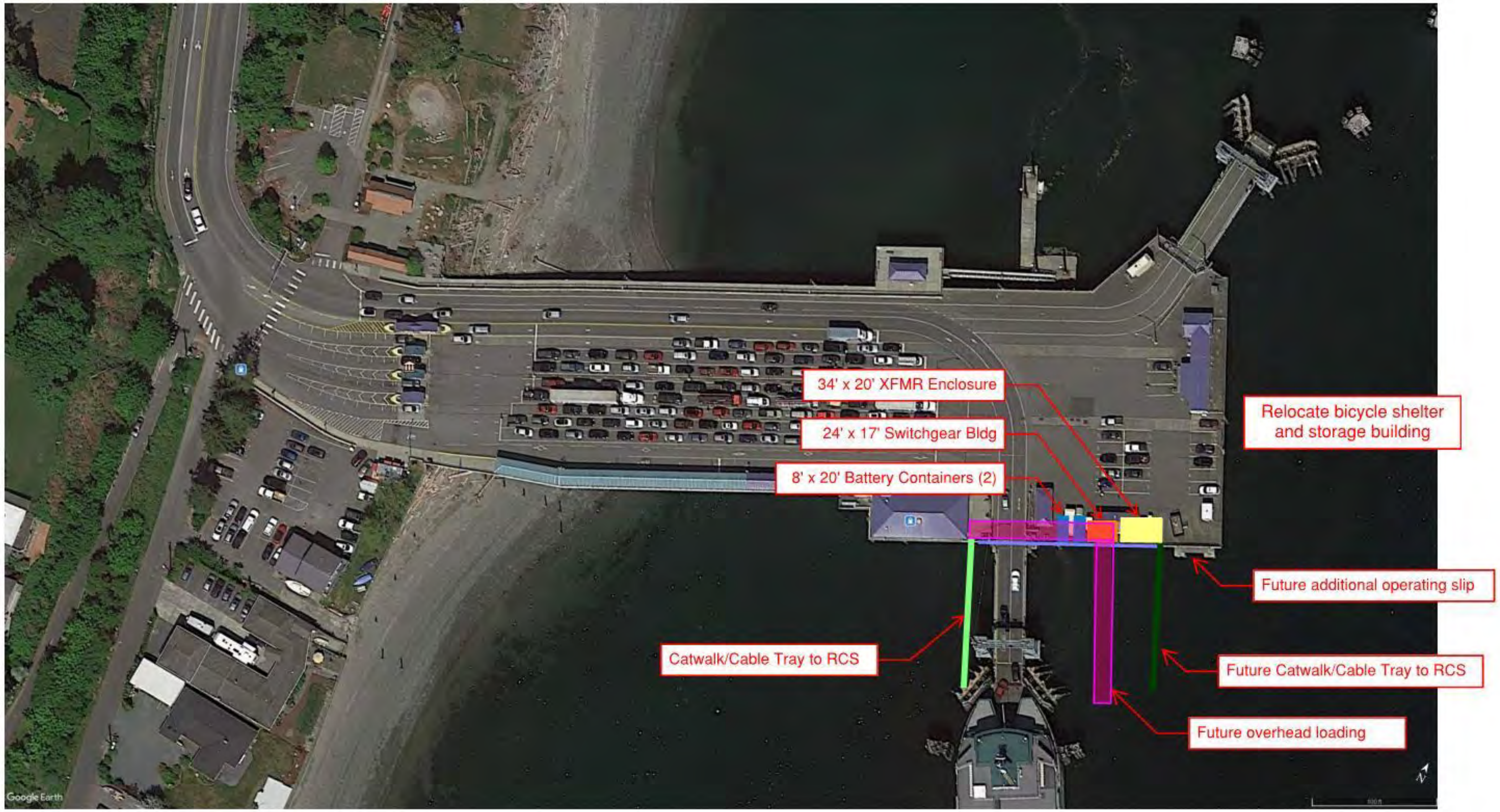
The terminal layouts included in this report were developed based on available aerial photographs and discussions with Terminal Engineering and Terminal Operations staff. Additional analysis of the existing terminal configurations and electrification equipment requirements is necessary to verify the viability of the locations identified and develop improved cost estimates for the terminal improvements.

9.2 Implementation Schedule

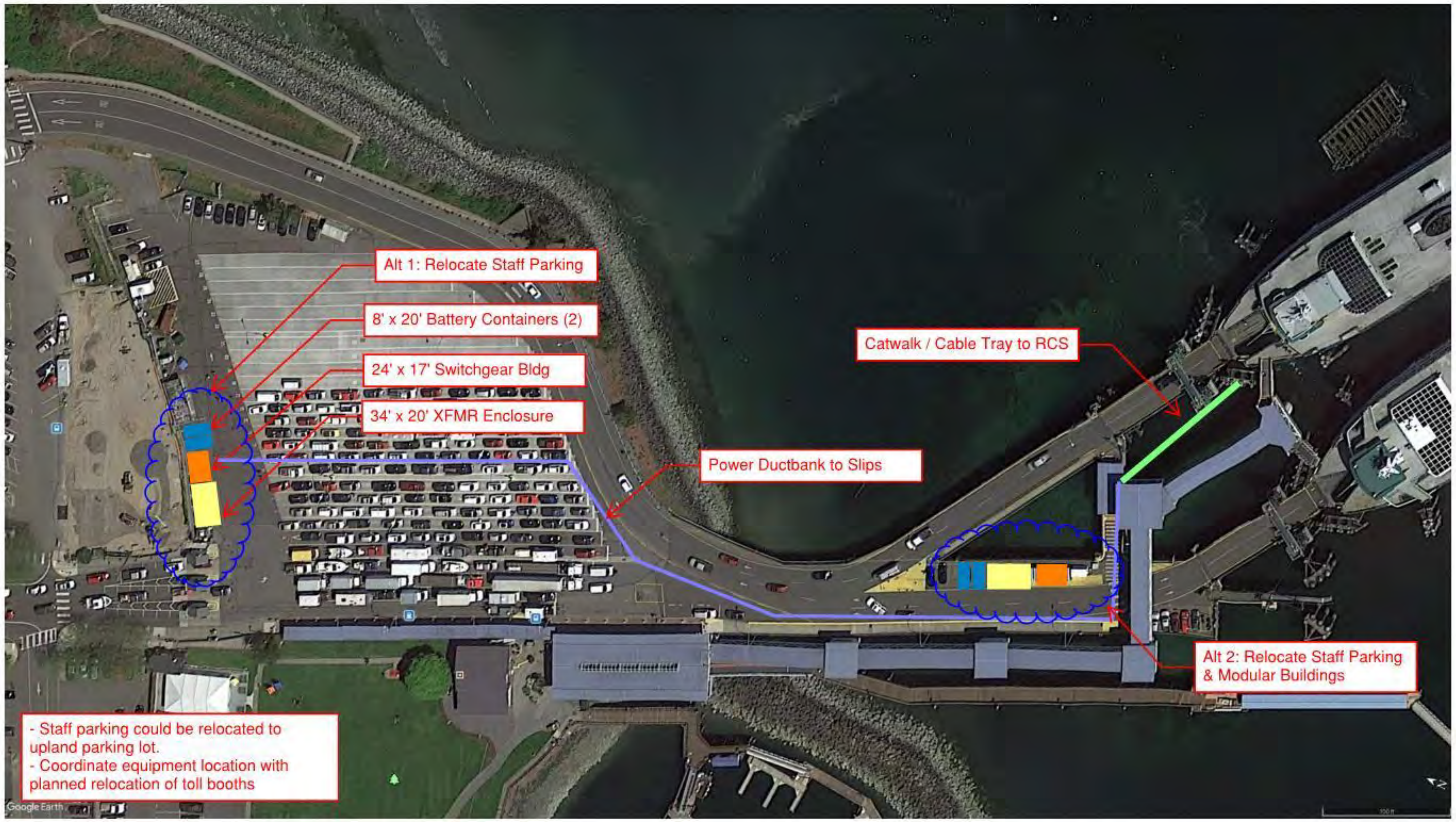
A preliminary implementation schedule has been developed as a separate task within the Systemwide Electrification Plan.

Appendix A
Terminal Layouts

Clinton

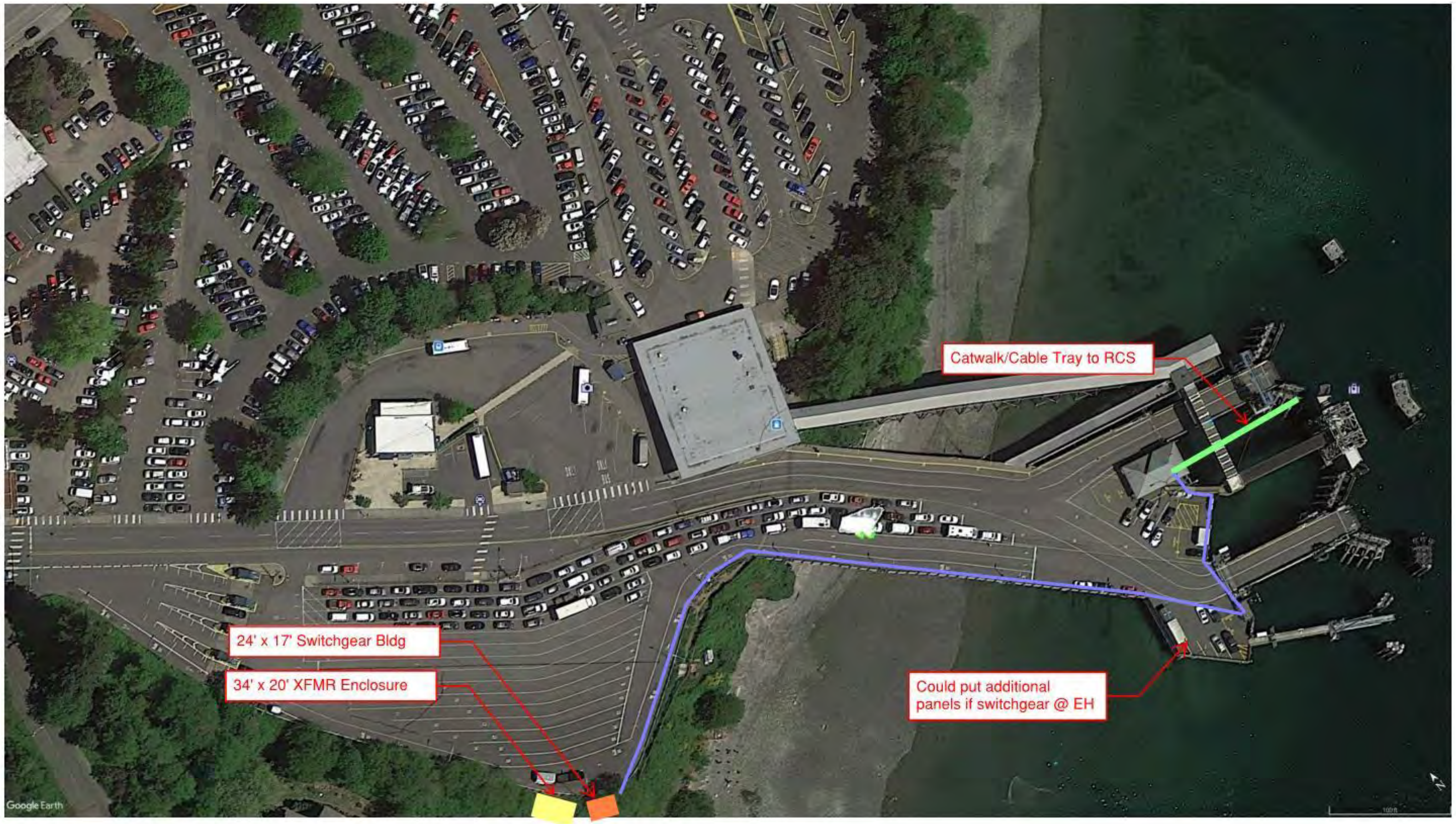

34' x 20' XFMR Enclosure
24' x 17' Switchgear Bldg
8' x 20' Battery Containers (2)
Relocate bicycle shelter and storage building
Future additional operating slip
Catwalk/Cable Tray to RCS
Future Catwalk/Cable Tray to RCS
Future overhead loading
Google Earth

Kingston

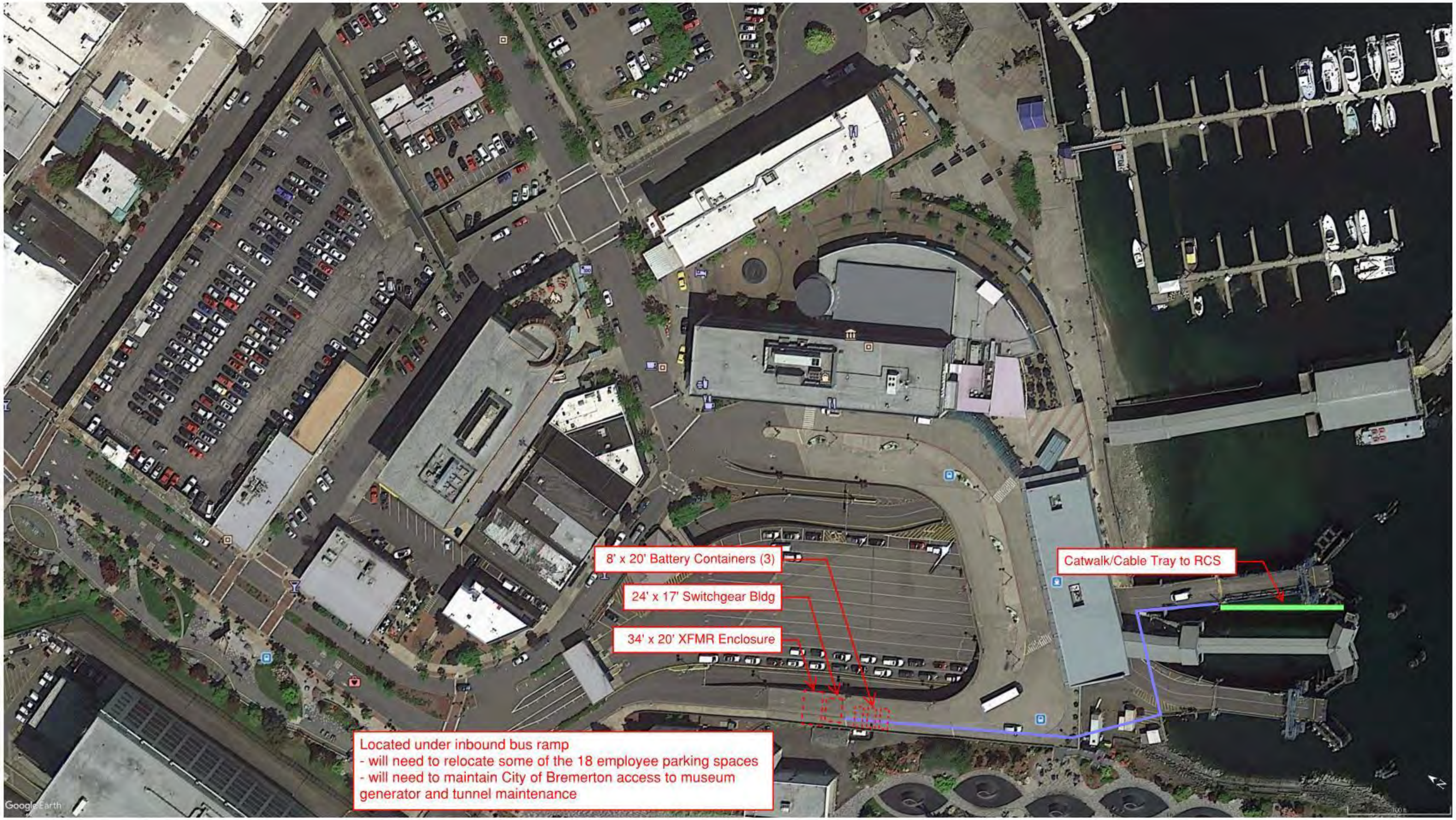

Alt 1: Relocate Staff Parking
8' x 20' Battery Containers (2)
24' x 17' Switchgear Bldg
34' x 20' XFMR Enclosure
Power Ductbank to Slips
Catwalk / Cable Tray to RCS
Alt 2: Relocate Staff Parking & Modular Buildings
- Staff parking could be relocated to upland parking lot.
- Coordinate equipment location with planned relocation of toll booths

Bainbridge Island and Eagle Harbor

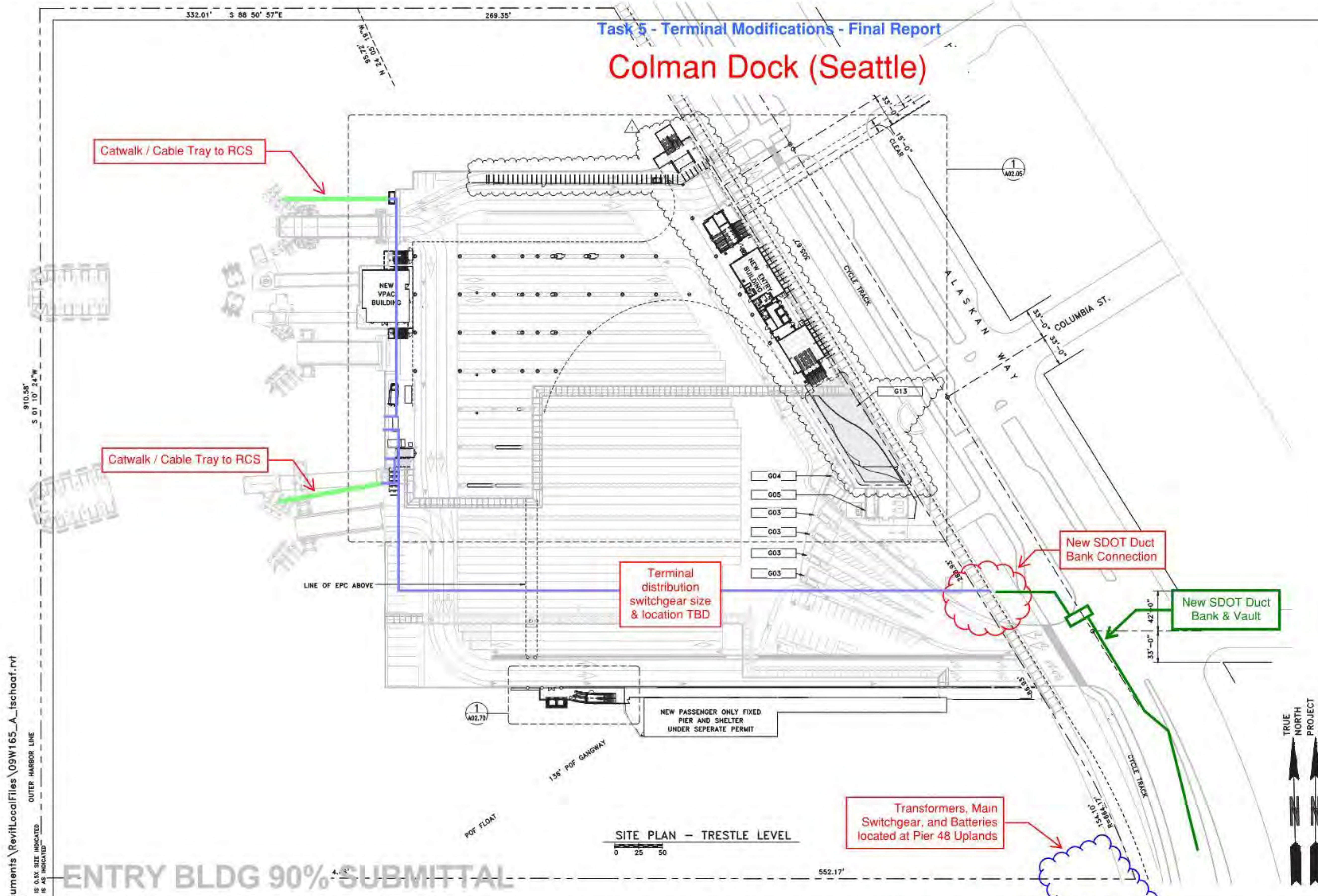
Bainbridge Island



Bremerton


8' x 20' Battery Containers (3)
24' x 17' Switchgear Bldg
34' x 20' XFMR Enclosure
Catwalk/Cable Tray to RCS
Located under inbound bus ramp
- will need to relocate some of the 18 employee parking spaces
- will need to maintain City of Bremerton access to museum generator and tunnel maintenance
Google Earth

Colman Dock (Seattle)



SITE PLAN NOTES:

1. GENERAL: WORK SHOWN BEYOND PROJECT LIMITS AND PROPERTY LINES IS FOR REFERENCE ONLY.

KEYNOTE LEGEND	
G03	EXISTING TOLL BOOTHS, N.I.C.
G04	EXISTING TOLL PLAZA AND TWO-STORY DOCK AGENT'S OFFICE BUILDING AND CANOPY (INCLUDES EXISTING SHOWER FACILITIES), N.I.C.
G05	EXISTING ELECTRICAL TRANSFORMER AND DISTRIBUTION BUILDING, N.I.C.
G13	COLUMBIA PLAZA SITE IMPROVEMENTS AND BIKE STORAGE FACILITIES ARE IN DESIGN. DO NOT INCLUDE IN THE 90% ENTRY BUILDING SUBMITTAL PRICING EXCERCISE.

AGENCY STAMP

nbbj

C:\Users\tschaaf\Documents\RevitLocalFiles\09W165_A_tschaaf.rvt
NBBJ JOB NUMBER: 101587.00
11"x17" SHEET SIZE: DRAWING SCALE IS 0.5X SIZE INDICATED
22"x34" SHEET SIZE: DRAWING SCALE IS AS INDICATED

FILE NAME: J:\SEA31\101587.00\08 3D MODELS\08.1 CENTRAL\09W165_A.RVT						
PRINTED: 6/14/2019 7:41:42 PM	LAST PRINTED BY:					FED. AID PROJ. NO.
SUBMITTAL DATE: 07/20/2017						
DESIGNED BY: N. MCDANIEL						WA-2017-024-00
ENTERED BY: N. MCDANIEL						REGION NO. 10 STATE WASH
CHECKED BY: D. YUAN						
MAR PROJ ENGR: VACANT						JOB NUMBER 09W165
DGN ENGR MNGR: G. RUCKI		1	ENTRY BLDG REDESIGN	06/17/2019		CONTRACT NO. 009074
ASST SECRETARY: A. SCARTON			REVISION	DATE	BY	

2020/09/03

DATE

DATE

Washington State Department of Transportation
WASHINGTON STATE FERRIES

SR519
SEATTLE FERRY TERMINAL
MULTIMODAL TERMINAL AT COLMAN DOCK
SITE PLAN – TRESTLE LEVEL

A02.01
SHEET
OF
SHEETS

APPENDIX D:
Task 6 – Vessel Delivery and Terminal Improvement Schedule

Washington State Ferries

System Electrification Plan

Table of Contents

Section 1: Introduction

This memo documents the vessel construction and terminal improvement schedules to align with the recommendations of Task 4, Vessel Functional Requirements, and Task 5, Terminal Functional Requirements.

The implementation schedule is divided into three categories:

- Near Term (0-5 years, 2020-2025)
- Medium Term (5-10 years, 2026-2030)
- Long Term (10-20 years, 2031-2040)

The System Electrification Plan (SEP) uses different schedule divisions than the Long Range Plan (LRP). Near term is redefined as efforts that are currently underway or expected to be underway in the next biennium. Medium term efforts are not yet underway but will require preliminary studies and planning within the near-term. Long term efforts are reflected in WSDOT plans but do not require near-term action.

While the goal of the implementation schedule is to align vessel delivery and completion of terminal electrification, the initial hybrid vessel designs are underway, and construction of the initial vessels has been funded. As a result, terminal electrification is expected to lag vessel delivery in the near term. The hybrid vessels will still be able to operate with the onboard generators until the necessary shore charging infrastructure is in place. However, the emissions reductions and lower energy costs associated with shore charging will not be seen until the terminal electrification is complete and shore charging is available on each route.

This schedule has been developed with the best information available during the SEP coordination, however there is a strong potential for continued delivery timeline adjustment especially in the near and medium terms.

Section 2: Vessel Construction Schedule

The vessel construction schedule from the LRP was updated to reflect the latest WSF direction with new vessel delivery dates in the near- and medium-term. Long term vessel delivery dates remain unchanged from the LRP.

Appendix A contains a summary schedule to document hybrid vessel conversion durations and newbuild delivery milestones, shown alongside durations of terminal improvements.

2.1 Near Term Vessel Construction

2.1.1 Jumbo Mark II Conversion

The retrofit schedule to hybridize the Jumbo Mark II Class was adjusted to align with the current contract as directed by WSF[1]. To minimize impacts to service, each vessel conversion is expected to occur during a five to six month shipyard period scheduled in winter. The JMII design, and Wenatchee conversion have been funded. The Tacoma conversion has been partially funded. the schedule, as provided by WSF, is shown in Table 1.

Table 1: Jumbo Mark II Conversion Schedule

Vessel	Conversion Period	Interim Route Assignment	2040 Route Assignment
WENATCHEE	October 2021 / March 2022	Seattle / Bainbridge	
TACOMA	October 2022 / March 2023	Seattle / Bainbridge	
PUYALLUP	October 2023 / March 2024	Edmonds / Kingston	Relief

2.1.2 Hybrid Electric Olympic Newbuild

Engineering for the Hybrid Electric Olympic (HEO) build program is currently underway. The Contractor estimates a 28-month construction period with 15 months between project starts. The HEOC design and first vessel construction has been funded. The delivery schedule as provided by WSF[2] is shown in Table 2.

The LRP had programmed HEO #3 to relief and HEO #5 to the international Sidney route. As discussed in Task 4, Vessel Functional Requirements, the Sidney route is not recommended for hybrid propulsion. The SEP instead recommends accelerating the assignment of vessels on the Seattle / Bremerton route with HEO #3 and #4 and assigning HEO #5 to relief[3].

---

[1] Original HEO delivery dates provided in the 11/20/19 Task 2 Prioritization Meeting were used to develop the financial model.

[2] Task 6 Input New Vessel Construction May 2020.xlsx, WSF, May 2020.

[3] The Joint Transportation Commission is investigating the feasibility of privatizing the international service that requires SOLAS-compliant vessel. If this service is ultimately privatized, there will not be a need for SOLAS vessels. Until that decision is finalized, the reassignment of HEO #5 leaves a hole in WSF international service. This study recommends further study to determine potential solutions and assumes a conversion of a diesel-mechanical Olympic Class vessel in the interim.

Table 2: Hybrid Electric Olympic Delivery Schedule

Vessel	Delivery	2040 Route Assignment
HEO #1	October 2023	Mukilteo / Clinton
HEO #2	April 2025	Mukilteo / Clinton
HEO #3	June 2026	Seattle / Bremerton
HEO #4	October 2027	Seattle / Bremerton
HEO #5	February 2029	Relief

2.2 Medium Term Vessel Construction

2.2.1 New 124-Car Class Newbuild

The LRP recommended an aggressive build program for the construction of the New 124-Car Class to replace the Issaquah Class, specifically on the Fauntleroy / Vashon / Southworth route. This Plan recommends no changes to the LRP delivery schedule as shown in Table 3.

Table 3: New 124-Car Class Delivery Schedule

Vessel	Delivery	2040 Route Assignment
New 124-Car #1	July 2027	Fauntleroy / Vashon / Southworth
New 124-Car #2	October 2028	Fauntleroy / Vashon / Southworth
New 124-Car #3	January 2030	Fauntleroy / Vashon / Southworth
New 124-Car #4	April 2031	Relief

2.3 Long Term Vessel Construction

2.3.1 Kwa-di Tabil Conversion

The KDTs are to be converted to hybrid propulsion with a potential propulsor conversion to an azimuth or cycloidal thruster. The LRP recommended this conversion to align with the projected engine overhaul period which already requires an extended shipyard period. The shipyard periods should occur in the winter season to the greatest extent possible to minimize any effects to service. The SEP recommends no changes to the LRP delivery schedule as shown in Table 4.

Table 4: KDT Conversion Schedule

Vessel	Conversion Period	Route Assignment
CHETZEMOKA	Winter 2030-2031	Point Defiance / Tahlequah
SALISH	Winter 2031-2032	Port Townsend / Coupeville
KENNEWICK	Winter 2032-2033	Port Townsend / Coupeville

2.3.2 New 144-Car Class Newbuild

The LRP recommended an aggressive build program for the construction of the New 144-Car Class as an effort to standardize the fleet. The SEP recommends no changes to the LRP delivery schedule as shown in Table 5.

Table 5: New 144-Car Class Delivery Schedule

Vessel	Delivery	Route Assignment
New 144-Car #1	2031	Edmonds / Kingston
New 144-Car #2	2032	Edmonds / Kingston
New 144-Car #3	2033	Edmonds / Kingston
New 144-Car #4	2034	San Juan Islands
New 144-Car #5	2035	San Juan Islands
New 144-Car #6	2036	San Juan Islands
New 144[4]-Car #7	2037	San Juan Islands / interisland

[4] The final New 144-Car vessel is to be constructed without the upper vehicle deck, resulting in a 114-Car vessel. This vessel is intended specifically for the interisland route to provide additional space on the car deck to accommodate the non-linear loading/unloading of vehicles.

Section 3:

Terminal Improvement Schedule

Figure 1 below and Appendix B contain a proposed schedule for the design, permitting, and construction for terminal electrification and utility upgrades. The overall timeline from design to completion of construction (less permitting) is estimated to require approximately two years for most terminals. Where possible, the terminal electrification work should be coordinated with other maintenance and preservation projects to minimize service disruptions and rework.

As the full project cost of terminal improvement effort will be more than $5M, a pre-design study will be required. During the pre-design study, the final vessel charging power requirements should be defined along with the amount of power to be provided by the utility. A trade-off analysis will be required between the peak grid power provided and battery storage capacity at each terminal. For this analysis, an Engineering Service Agreement will be required with the local utility at each terminal.

Designer selection was assumed to occur through an on-call agreement, hence the 8 week period. If it is not able to occur through an on-call agreement, the selection process could take 3 months.

The longest schedule element is environmental permitting, particularly if any of the improvements require in-water work. If in-water work is required, Endangered Species Act and Marine Mammal Protection Act consultation will be required, which can be quite lengthy. Even if in-water work is not necessary, Shoreline Substantial Development permits, which are valid for five years once approved[5], will be required. For all regulatory permits, the design needs to be approximately 30% complete to apply. At the start of the terminal electrification process, a permitting strategy should be developed for each terminal that integrates other planned projects at that terminal so that the permit applications can either be combined or at least address the projects' cumulative impacts.

Another long lead element is utility upgrade work. WSF will need to sign a service agreement for each terminal with the local electric utility to allow the utility to begin its internal design and construction effort. The service agreement will have to include both the peak demands and total usage to determine both the appropriate rate schedule and size the new equipment and distribution lines. This agreement should be in place at the start of the terminal improvements design to ensure the utility upgrades are not on the critical path for completing the terminal electrification.

The new transformers required at each electrified terminal can take six to nine months to fabricate and deliver so purchasing them in advance of the actual construction contract can save some time in the construction schedule. In addition, these items should be a standard design throughout the system, which WSF can ensure by controlling their acquisition.

[5] RCW 90.58.143 Time requirements – Substantial development permit, variances, conditional use permits

Terminal improvements should be constructed over the winter season whenever possible to minimize construction impacts during the summer peak travel season. In most areas, the in-water work window closes in February, so a spring delivery timeline would allow time to complete construction and commissioning.

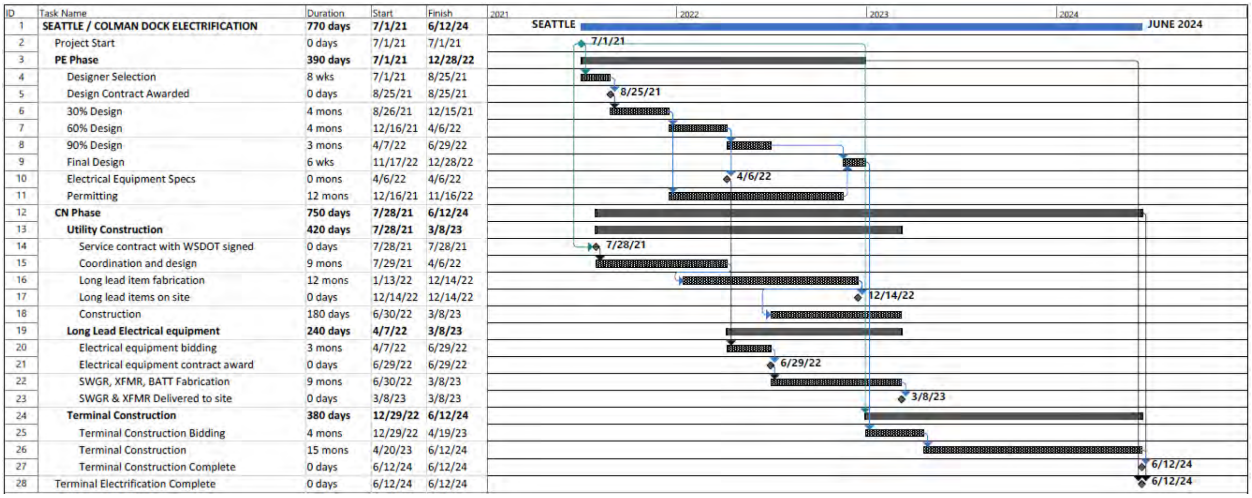


Figure 1: Concept Terminal Electrification Schedule; see Appendix B for a full scale version

Where terminal preservation and/or improvement projects are programmed to occur before terminal electrification, it is recommended to include electrification features (i.e. conduit, adequate space, structural improvements, etc.) as part of the design requirements to simplify the future terminal modification.

Appendix A contains a summary schedule to document the duration of terminal improvements, shown alongside vessel conversion durations and newbuild delivery milestones. Pre-design work is assumed to occur prior to the start dates shown in Appendix A.

3.1 Near Term Terminal Electrification

Terminals recommended for electrification in the near term are identified in this section. Electrification years from the LRP were revisited to align with the updated vessel construction schedule, other terminal construction projects, and the recommendation to perform the bulk of the construction in the winter. Table 6 shows the terminal electrification dates from the LRP and the updated dates in this Plan.

Table 6: Short Term Terminal Electrification

Terminal	LRP	SEP	Funding
Clinton	2023	November 2023	2021 Biennium
Seattle	2021/2027	June 2024	2021 Biennium
Bainbridge	2021	June 2024	2021 Biennium

3.1.1 Clinton

The Mukilteo / Clinton route has been identified as an ideal route for one-sided charging. As discussed in Tasks 4 and 5, the Clinton terminal is recommended for electrification. Construction of overhead passenger loading is anticipated in the 2025-2027 biennium. However, with the vessel delivery scheduled for October 2023 and April 2025, it is not recommended to postpone terminal electrification to align with the future improvement projects. The SEP recommends accelerating the electrification of the Clinton terminal with a completion date of November 2023, which requires funding for design and construction to be approved for the 2021 biennium.

3.1.2 Seattle / Colman Dock

The LRP had identified terminal electrification to occur in two phases; the first in 2021 for Seattle / Bainbridge and the second in 2027 for Seattle / Bremerton. The recommendation of this Plan is to perform all necessary infrastructure upgrades, with the possible exception of installing batteries, at Colman Dock in one construction period to minimize permitting and contracting efforts as well as service disruptions. With a two year design and construction period, a 2021 completion date is no longer possible as funding was not approved for the 2019 biennium.

A major preservation effort is currently underway at Colman Dock and is not scheduled to end until 2023. As the first hybridized vessel is scheduled to begin service on the Seattle / Bainbridge route in March of 2022, the terminal should be electrified as soon as possible. The SEP assumes that electrification of Colman Dock is completed in June 2024, which requires funding for design and construction to be approved for the 2021 biennium. Batteries will only be necessary once the Bremerton route is electrified, allowing them to be purchased and installed at a later date to better align the terminal costs with the start date for the new hybrid vessels on the Bremerton route.

3.1.3 Bainbridge Island

Electrification of the Bainbridge Island terminal was scheduled to align with vessel delivery in the LRP. With a two year design and construction period, a 2021 completion date is no longer viable as funding was not approved for the 2019 biennium. The SEP recommends alignment of the Bainbridge Island upgrades with the Colman Dock improvements for a completion date of June 2024, which also requires funding to be approved for the 2021 biennium.

3.2 Medium Term Terminal Electrification

Medium term terminal electrification efforts are programmed to begin in the next 5-10 years of the planning horizon. Table 7 shows the terminal electrification dates from the LRP and the updated dates in this Plan.

Table 7: Medium Term Terminal Electrification

Terminal	LRP	SEP	Funding
Edmonds	2023	n/a	
Kingston	2023	February 2026	2023 Biennium
Bremerton	2027	April 2026	2023 Biennium
Southworth	2027	October 2026	2023 Biennium
Fauntleroy	2027	March 2028	2025 Biennium
Vashon	2027	February 2027	2025 Biennium

3.2.1 Kingston

The LRP recommended electrification of the Edmonds and Kingston terminals in 2023 to align with the vessel delivery schedule. As discussed in Task 4, Vessel Functional Requirements, the Edmonds-Kingston route is recommended for one-sided charging at Kingston in the SEP. While the PUYALLUP is scheduled for delivery in March 2024, the SEP recommends electrification of the Kingston terminal with a completion date of February 2026, which requires funding for design and construction to be approved for the 2023 biennium. The delay between vessel delivery and terminal completion is intended to reduce the initial workload on Terminal Engineering by spreading out the terminal electrification projects.

3.2.2 Bremerton

The LRP recommended electrification of the Bremerton terminal in 2027 to align with anticipated vessel delivery. The SEP recommends starting the electrification process after the completion of the Seattle and Bainbridge terminals, for a recommended completion date of April 2026.

3.2.3 Fauntleroy / Vashon / Southworth

The LRP recommended electrification of the Fauntleroy, Vashon, and Southworth terminals in 2027 to align with both vessel delivery and scheduled terminal preservation projects in the 2025-2027 biennium. The SEP recommends staggering the design and construction periods of each terminal while still aligning the Fauntleroy and Southworth electrification with the scheduled trestle replacement projects. With the current anticipated dates of the preservation projects, the terminal electrification dates are as follows:

- Southworth – October 2026
    - Trestle Replacement – January 2023-October 2026
- Fauntleroy – March 2028
    - Trestle Replacement – January 2026-March 2028

VASHON CONSTRUCTION SCHEDULE:

The Vashon terminal electrification is not bundled with other terminal improvement or preservation projects. If the timelines for the Southworth and Fauntleroy trestle replacement projects are adjusted, the Vashon terminal electrification can be accelerated.

- Vashon – February 2029

3.3 Long Term Terminal Electrification

Long term terminal electrification efforts are programmed to begin in the next 10-20 years of the planning horizon. Table 8 shows the terminal electrification dates from the LRP and the updated dates in this Plan.

Table 8: Long Term Terminal Electrification

Terminal	LRP	SEP	Funding
Point Defiance	2031	February 2031	2027 Biennium
Tahlequah	2031	n/a	n/a
Coupeville	2032	August 2031	2027 Biennium
Port Townsend	2032	April 2032	2029 Biennium
Anacortes	2027	February 2034	2031 Biennium
Orcas	2034	October 2034	2031 Biennium
Friday Harbor	2034	July 2035	2031 Biennium
Shaw	2034	March 2036	2033 Biennium
Lopez	2034	November 2036	2033 Biennium

3.3.1 Point Defiance

The Point Defiance / Tahlequah route has been identified as an ideal route for one-sided charging. As discussed in Tasks 4 and 5, the Point Defiance terminal is recommended for electrification. To align with the delivery of the first KDT conversion, the SEP maintains the LRP recommendation for a terminal electrification completion of February 2031.

With the first KDT scheduled for delivery in March 2031, the vessel should be able to operate with shore charging almost immediately.

3.3.2 Port Townsend / Coupeville

The LRP recommended electrification of the Port Townsend and Coupeville terminals in 2032 to align with the delivery vessel of the second KDT conversion. The SEP recommends staggering the design and construction of the two terminals resulting in terminal electrification completion of August 2031 for Coupeville and April 2032 for Port Townsend. Each With the first KDT scheduled for delivery in March 2032, the vessels should be able to operate with shore charging almost immediately.

The Coupeville design phase is scheduled to begin when the Point Defiance 60% design has been completed, introducing a buffer between the two projects. Acknowledging the possibility that the Port Townsend and Coupeville terminal projects will be awarded to a single contractor, the construction of the Port Townsend terminal is not scheduled to begin until the Coupeville terminal has completed. The wingwalls at Port Townsend and Coupeville use a more flexible reaction frame design so additional effort may be required to provide adequate support to the RCS at these terminals.

3.3.3 Anacortes

The LRP recommended electrification of the Anacortes terminal in 2027 to align with the delivery of the fifth Hybrid Electric Olympic (HEO #5). As previously discussed in Section 2.1.2, this Plan no longer recommends assignment of HEO #5 to the international Sidney route. The first hybrid vessel is not programmed for assignment in the San Juan Islands until 2034. To align with vessel delivery, the SEP recommends electrification of the Anacortes terminal with a completion date of February 2034.

3.3.4 San Juan Islands

The LRP recommended electrification of the Orcas and Friday Harbor terminals in 2034. The SEP assumes electrification of the Orcas, Friday Harbor, Shaw, and Lopez terminals. Newbuild plug-in hybrid vessels are programmed for delivery in the San Juan Islands between 2034-2037. Staggering the electrification efforts for the Anacortes and San Juan Island terminals could potentially reduce the overall demand on WSF terminal engineering and contracting efforts. The SEP recommends electrification of the Orcas terminal in October 2034, Friday Harbor terminal in July 2035, Shaw terminal in March 2036, and Lopez terminal in November 2036.

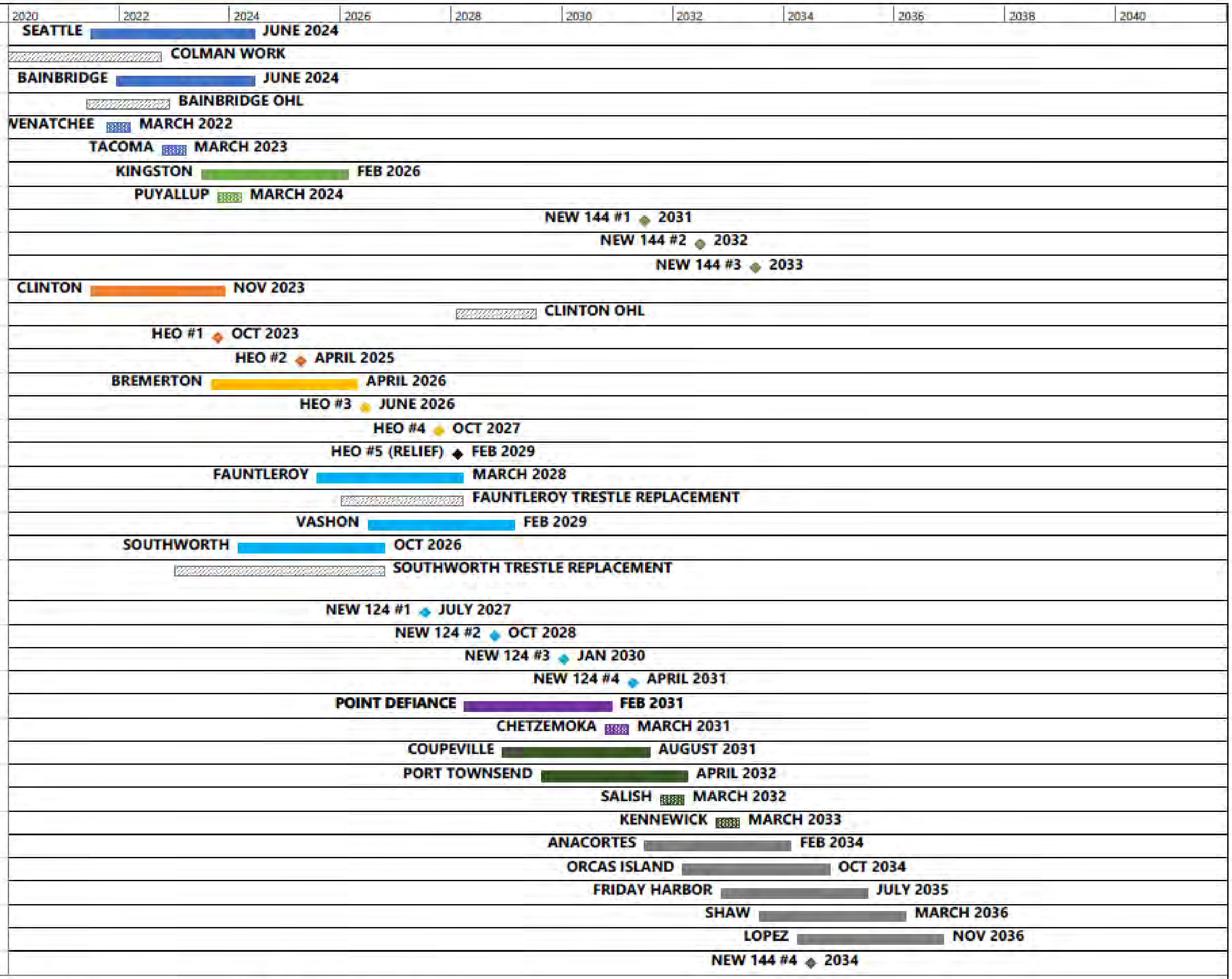
SAN JUAN ISLANDS CONSTRUCTION SCHEDULE:

If the terminal electrification work does not require pile driving, there may be some savings and efficiency to not stagger the work and have a single contractor move sequentially through the terminals on an expedited schedule.

All San Juan Island terminal electrification projects are linked to the completion of the 60% design effort of the prior terminal.

Appendix A
Implementation Schedule

ID	Task Name	Duration	Start	Finish
1	SEATTLE	770 days	7/1/21	6/12/24
29	COLMAN TERMINAL	1429 days	4/20/17	10/11/22
31	BAINBRIDGE	650 days	12/15/21	6/12/24
59	BAINBRIDGE OHL	393 days	6/1/21	12/1/22
60	WENATCHEE CONVERSION	108 days	10/15/21	3/15/22
61	TACOMA CONVERSION	108 days	10/15/22	3/14/23
62	KINGSTON	690 days	7/1/23	2/20/26
90	PUYALLUP CONVERSION	111 days	10/15/23	3/15/24
91	NEW 144 #1	0 days	7/1/31	7/1/31
92	NEW 144 #2	0 days	7/1/32	7/1/32
93	NEW 144 #3	0 days	7/1/33	7/1/33
94	CLINTON	630 days	7/1/21	11/29/23
122	CLINTON OHL	375 days	2/7/28	7/13/29
124	HEO #1 DELIVERY	0 days	10/15/23	10/15/23
125	HEO #2 DELIVERY	0 days	4/15/25	4/15/25
126	BREMERTON	690 days	9/1/23	4/23/26
154	HEO #3 DELIVERY	0 days	6/15/26	6/15/26
155	HEO #4 DELIVERY	0 days	10/15/27	10/15/27
156	HEO #5 DELIVERY	0 days	2/15/28	2/15/28
157	FAUNTLEROY	690 days	8/1/25	3/23/28
185	FAUNTLEROY TRESTLE REPL.	576 days	1/7/26	3/22/28
187	VASHON	690 days	7/3/26	2/22/29
215	SOUTHWORTH	690 days	3/1/24	10/22/26
243	SOUTHWORTH TRESTLE REPL.	988 days	1/3/23	10/15/26
245	New 124 #1	0 days	7/15/27	7/15/27
246	New 124 #2	0 days	10/15/28	10/15/28
247	New 124 #3	0 days	1/15/30	1/15/30
248	New 124 #4	0 days	4/15/31	4/15/31
249	POINT DEFIANCE	690 days	4/1/28	11/22/30
277	CHETZEMOKA CONVERSION	110 days	10/15/30	3/15/31
278	COUPEVILLE	690 days	12/8/28	8/1/31
306	PORT TOWNSEND	690 days	8/17/29	4/9/32
334	SALISH CONVERSION	109 days	10/15/31	3/15/32
335	KENNEWICK CONVERSION	108 days	10/15/32	3/15/33
336	ANACORTES	690 days	7/1/31	2/20/34
364	ORCAS	690 days	3/8/32	10/30/34
392	FRIDAY HARBOR	690 days	11/15/32	7/9/35
420	SHAW	690 days	7/25/33	3/17/36
448	LOPEZ	690 days	4/3/34	11/24/36
476	NEW 144 #4	0 days	7/1/34	7/1/34



Project: SEP Implementation Schedule
Date: 12/10/20

New Vessel Delivery ◆ Vessel Conversion Terminal Electrification

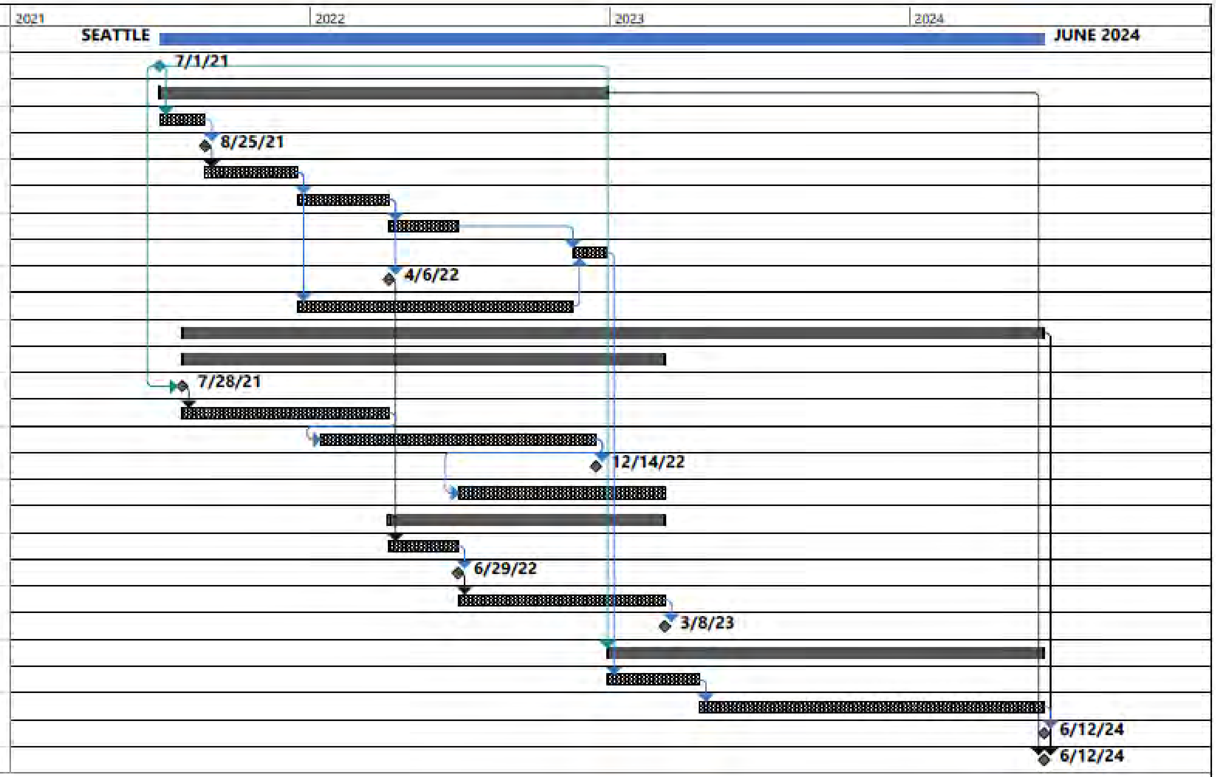
ID	Task Name	Duration	Start	Finish	2020 – 2040
477	NEW 144 #5	0 days	7/1/35	7/1/35	NEW 144 #5 ◆ 2035
478	NEW 144 #6	0 days	7/1/36	7/1/36	NEW 144 #6 ◆ 2036
479	NEW 144 #7	0 days	7/1/37	7/1/37	NEW 144 #7 ◆ 2037

Project: SEP Implementation Schedule
Date: 12/10/20

New Vessel Delivery ◆ Vessel Conversion Terminal Electrification

Appendix B
Concept Terminal Electrification Schedule

ID	Task Name	Duration	Start	Finish
1	**SEATTLE / COLMAN DOCK ELECTRIFICATION**	**770 days**	**7/1/21**	**6/12/24**
2	Project Start	0 days	7/1/21	7/1/21
3	**PE Phase**	**390 days**	**7/1/21**	**12/28/22**
4	Designer Selection	8 wks	7/1/21	8/25/21
5	Design Contract Awarded	0 days	8/25/21	8/25/21
6	30% Design	4 mons	8/26/21	12/15/21
7	60% Design	4 mons	12/16/21	4/6/22
8	90% Design	3 mons	4/7/22	6/29/22
9	Final Design	6 wks	11/17/22	12/28/22
10	Electrical Equipment Specs	0 mons	4/6/22	4/6/22
11	Permitting	12 mons	12/16/21	11/16/22
12	**CN Phase**	**750 days**	**7/28/21**	**6/12/24**
13	**Utility Construction**	**420 days**	**7/28/21**	**3/8/23**
14	Service contract with WSDOT signed	0 days	7/28/21	7/28/21
15	Coordination and design	9 mons	7/29/21	4/6/22
16	Long lead item fabrication	12 mons	1/13/22	12/14/22
17	Long lead items on site	0 days	12/14/22	12/14/22
18	Construction	180 days	6/30/22	3/8/23
19	**Long Lead Electrical equipment**	**240 days**	**4/7/22**	**3/8/23**
20	Electrical equipment bidding	3 mons	4/7/22	6/29/22
21	Electrical equipment contract award	0 days	6/29/22	6/29/22
22	SWGR, XFMR, BATT Fabrication	9 mons	6/30/22	3/8/23
23	SWGR & XFMR Delivered to site	0 days	3/8/23	3/8/23
24	**Terminal Construction**	**380 days**	**12/29/22**	**6/12/24**
25	Terminal Construction Bidding	4 mons	12/29/22	4/19/23
26	Terminal Construction	15 mons	4/20/23	6/12/24
27	Terminal Construction Complete	0 days	6/12/24	6/12/24
28	Terminal Electrification Complete	0 days	6/12/24	6/12/24



Project: SEP Implementation Schedule
Date: 11/17/20

New Vessel Delivery | Vessel Conversion | Terminal Electrification

APPENDIX E:
Task 7 – WSF Workforce Assessment

Washington State Ferries

System Electrification Plan

WSDOT

Washington State Ferries

Table of Contents

Section 1:

Introduction and Background

The Washington State Ferry (WSF) system functions because of talented individuals that operate, maintain, plan, and manage all the aspects of the system's many moving parts. This workforce is strengthened by the tools it uses by way of vessels, terminals, equipment, software, and training. As WSF works toward electrification of the fleet, the workforce that supports it will be central to its success. Technology will help with automation and reporting and will also require a different set of skills to operate and maintain. This memo is focused on workforce and the foreseen changes in workforce needs to deliver and sustain a hybrid-electric fleet. This memo draws upon information from other technical work, such as the vessel functional requirements memo and terminal improvements, and also feeds into the assumptions cost model. This assessment is the first step in mapping out the potential changes for the fleet. Additional coordination and collaboration once vessel and terminal designs are more solidified will be needed both internally to WSF and externally to WSF labor, regulatory and vendor partners.

1.1 WSF Workforce Background and Trends

In order to operate 10 routes between 20 terminals, WSF employs a large and complex workforce of over 1,900 employees throughout the Puget Sound region on vessels, in terminals, at the Eagle Harbor maintenance facility, and at its headquarters. To more fully understand WSF workforce needs, a baseline understanding of the current conditions and trends is needed. The following sections provide an overview of WSF operations and existing challenges to inform discussion of how the workforce will be affected by the electrification of the fleet.

1.1.1 WSF Operations

WSF's workforce is shaped by the inherent complexities of the system's operating environment, with considerations including:

- Geography: WSF terminals are located over a large area, on both sides of Puget Sound. Employees live in various locations, posing potential for varying commute times and complicating on-call and relief dispatch. Additionally, the distance between terminals is also a factor in planning for terminal inspections and maintenance.
- Seasonality: The system's workforce needs fluctuate between the winter and summer seasons. Summer service schedule increases lead to a 22% bump in scheduled labor hours from winter to summer—which is also a time that is popular for employee vacation time. This will pose a challenge as it relates to electrification of the fleet and specialized knowledge of vessel classes with different systems needed for Masters and Deck Crew. The 2040 Long Range Plan (LRP) has identified a need to increase the hiring and training of additional employees to reduce reliance on the on-call and relief pools. This is still true and also needs to be re-examined as it relates to what training employees receive or whether all employees

receive training for all systems/vessel types. Engine crew staff is not as impacted by seasonality as vessels maintain 24-hour crews on-board, regardless of season.

- Safety regulations: WSF operates in a highly regulated environment, working closely with the U.S. Coast Guard to follow safety and crewing requirements. Fleet-wide electrification is new to the United States. Close coordination with regulatory bodies to identify staffing and training needs for an electrified fleet will be paramount.
- Fleet mix and route characteristics: The 10 WSF routes each have unique ridership characteristics, operating profiles, navigation requirements, and terminal characteristics. Additionally, the current WSF fleet is made up of 21 vessels and seven different vessel classes—by 2040 the fleet is planned to grow to 26 vessels and 6 classes. Because of the differences between routes and vessels, many positions require route- or vessel-specific training. This route- and vessel-specific training may intensify with the introduction of new vessel systems. The alternative of wider training will be needed as the fleet mix becomes mostly electrified. Decisions will have to be made to balance the dispatching benefits of wide, across the board training versus the cost savings of more specified deployment and training which would hinder dispatch.

Electrification of the fleet has varying impacts to each of these categories, with many having an impact on the skills, training, recruitment, and dispatch of the WSF workforce.

1.1.2 Existing Workforce Trends and Challenges

Planning for the anticipated workforce impacts of vessel electrification must take into account the challenges that WSF is already facing, such as:

- Recruitment and hiring:
  - As a state agency, WSF is unable to offer market competitive wages for some higher-skilled positions.
  - Need to adapt workplace to values and expectations of younger workforce, such as work/life balance, flexible work arrangements, and professional development training programs.
  - Entry-level positions often have undesirable shifts and little control over work schedule.
  - Vessel and terminal workers have a long path to full-time positions.
- Accelerated retirement of the workforce: The national trend of the baby boomer generation reaching retirement began in 2011 and is expected to continue through 2030. Across the entire employment base, 9% of WSF employees are eligible to retire (65 years of age) in 2020 and 30% in the next five years. Retirements increase needs for recruitment, hiring, training, and supervision. Dispatch and scheduling will be impacted and may result in existing full-time employees needing to work overtime to overcome experience and labor pool gaps.
- Ridership: Staffing levels will likely need to be increased to serve forecast ridership, which is expected to grow more than 30% by 2040, per the LRP.
- Maintenance demands: Increased maintenance demands of aging vessels and terminal infrastructure is a challenge for WSF. Vessel retirements reduce the time spare vessels are available to allow for scheduled maintenance to meet scheduled level of service.

The 2040 LRP identified the need for a Workforce Development Plan to address the challenges above and ensure an adequate workforce to continue to provide safe and reliable service.

1.2 Electrification Workforce Assessment Approach

This assessment is informed by internal WSF stakeholders' representative of their specific disciplines. The consultant team held workshops with various WSF departments, covering the major working groups of Capital Improvements (vessels and terminals), Operations (from IT to crew), Maintenance and Safety and Risk Management. These workshop discussions focused on anticipated effects of fleet electrification on the workforce—both to deliver and sustain a hybrid-electric fleet. The goal of the workshops was to identify what changes will be needed onboard vessels, at terminals, at Eagle Harbor, at headquarters, and within management. The workshops aimed to answer the following questions:

- Which workforce functions and duties will be added, deleted, or modified because of the electrification process, and what knowledge and skills will be needed to perform them?
- What credentialing, licensing, and training will be necessary?
- Where should knowledge and skills most appropriately reside to support safe and reliable operations, and how can WSF ensure that the skills are consistently maintained into the future?
- What staffing levels will be required, including crewing levels/mixes onboard the vessels, maintenance staff, and engineering support staff?

It became clear through these discussions that workforce needs will change, with more support needed during the development and implementation of the System Electrification Plan. With vessel construction spanning a long timeframe, workforce needs internally will ebb and flow, with more nearer-term staffing needs to develop and implement the capital programs, training and public information effort and less additional duties and positions as all new vessels are in operation.

Section 2:
New Technology and the Fleet

First, an appreciation of this endeavor. While the technology is proven, there is no case study in the world that aligns with an electrification of a fleet with the diversity of routes within WSF, nor with the diversity and complexity of the WSF labor force.

2.1 High-level Understanding of New Technology

WSF already has skilled professions, so what is different about these systems? Electric-hybrid vessels will host a variety of new technology that the operators, maintenance, and management professionals are not currently experienced with. More detailed, technical analysis and explanation of this new technology can be found in supporting memos. This memo is focused on a high-level outline of the change or addition of duties as they relate to the electrification of the fleet, and therefore attempts to simplify the discussion.

The following list are high level identifications of new systems required for electric-hybrid vessels and its terminal interface.

On the vessel:

- Lithium ion batteries, converters, and inverters— Battery racks (consisting of approximately 10 modules per rack and 28 lithium ion cells) will be located in battery rooms. Batteries will be equipped with a battery management system that monitors temperature and other system alerts. Battery management system alarms will require intervention and monitoring by crew.
- Rapid changing system—robotic arm located on both ends of the vessel

At the terminal, either on the wing wall or transmission lines on terminal property:

- Rapid charging system receptacle located on the wing wall
- Medium voltage equipment located on the terminal property

The vessel and terminal electrical systems will need to be supported by vessel engineering crew, vessel engineering department, and the terminal engineering department. To support the vessels and terminals, the Eagle Harbor Maintenance Facility will also need to have the infrastructure and personnel to inspect and maintain pertinent equipment. Additionally, supporting all functions is the multitude of departments at WSF headquarters such as finance, human resources, security and training, operations dispatch, capital program management, planning and scheduling, customer service, information technology and others.

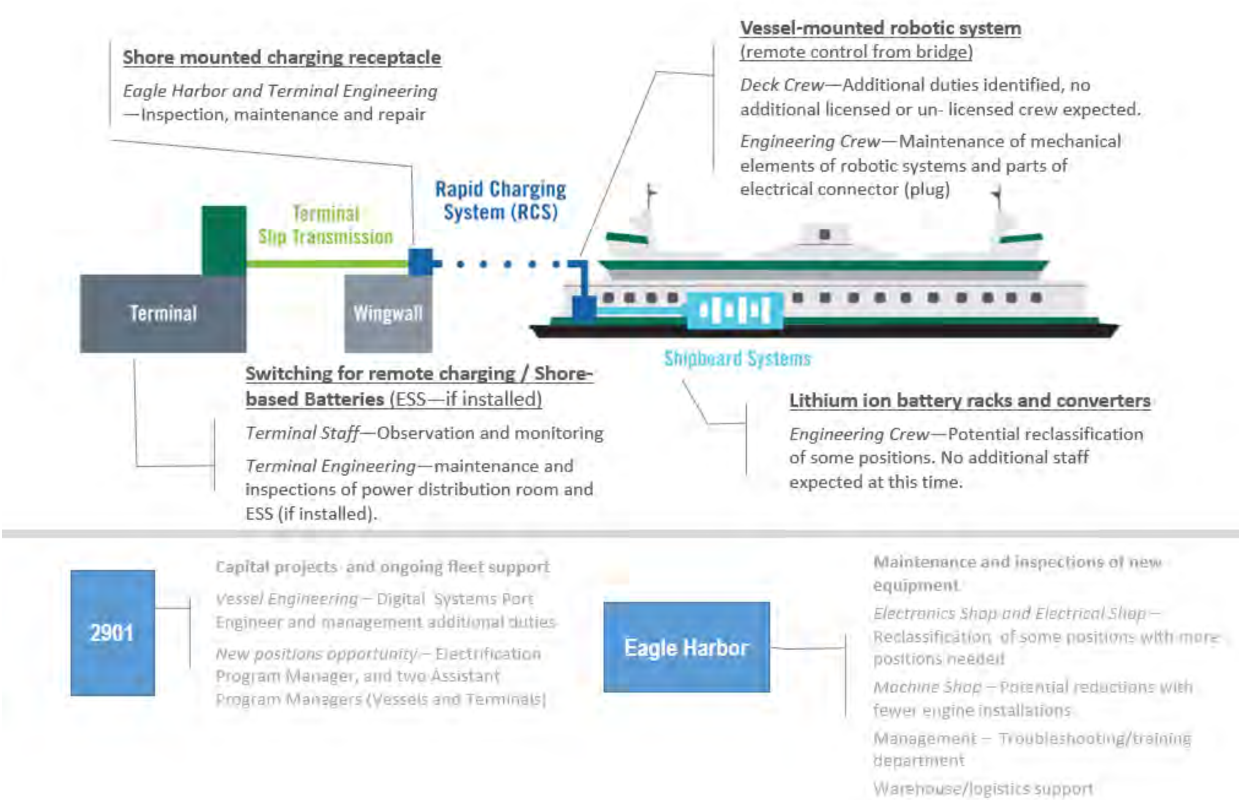


Figure 1: Overview of potential changes to workforce with electrification of the fleet and terminals.

2.2 Fleet Configuration

The electrification of the fleet is planned to occur over a period of approximately 20 years. Both vessels and terminal improvements require careful planning and time for design, engineering, and construction. The vessel and terminal construction schedules for the near, medium, and long terms are detailed in the Task 6 – Vessel Delivery and Terminal Improvement Schedule memo.

The length of the implementation phase results in a mixed fleet configuration for a period of time and the need to maintain the expertise for traditional diesel vessels, as well as the addition of new knowledge to build, operate and maintain the electric-hybrid vessels. Therefore, new functions and training will be required of the workforce without any initial reduction.

Section 3:

Managing Development and Implementation of New Technology

Planning, designing, building, and implementing hybrid vessels across the WSF system is a major undertaking spanning many years and multiple disciplines and organizational units. To achieve the maximum benefits as quickly and cost effectively as possible WSF should fully integrate vessel construction and deployment, shoreside electrification, workforce preparation, and system operation. Such integration will require a comprehensive implementation plan and a strong project management approach that will unite the various departments responsible for delivering the components of the electrified system, monitoring progress and making timely adjustments to ensure on time-delivery of multiple initiatives across time. A project of this complexity requires a centralized project management strategy best accomplished with a designated overall program manager accountable to executive management and supported by assistant program managers for vessel and terminal engineering. The three program management positions would work closely with key department directors and designated staff.

Section 4:

Building the Infrastructure

The 2040 LRP called for an extensive vessel build program to stabilize the fleet through the replacement of aging vessels and fleet expansion to support an adequate maintenance tempo. To support the fleet transition and the additional terminal capital improvements for charging infrastructure, capital program management will be needed to support both vessels and terminal working groups.

4.1 New and Changed Workforce Functions

4.1.1 Electrification Program Management

As described in Section 3, a program of this magnitude would benefit from a program manager that can be attentive to cross-discipline coordination, reporting and contract management. This position would be a new position for WSF and accountable to executive management. Two positions would support this overall program manager, that would include an individual with a vessel-specific focus and a terminal-specific program manager with coordination needed among the two.

4.1.2 Vessel Construction

Planned near-term vessel capital projects include the conversion of the Jumbo Mark II class and construction of five new hybrid-electric Olympic class vessels. Projects will require significant coordination with the vendor and project oversight, along with design/engineering review, for each vessel. The vessel new construction staff includes, a Project Engineer, inspectors, and the Construction Staff Chief Engineer. The Engine Crew reports prior to delivery of the vessel to assist with commissioning. This crew is required to remain with the vessel (or a similar vessel in the class) for a period of two years after delivery, in accordance with the Collective Bargaining Agreement.

4.1.3 Terminal Projects

Fleet electrification requires infrastructure improvements at nearly every WSF served terminal. The improvements vary in scope at each location, but will likely involve design, permitting, and construction for terminal electrification and utility upgrades, estimated to be a two-year process or longer for each. Any construction projects will require support for permitting and approval process. Terminal improvement projects require oversight and management whether contracted or completed in-house. These duties are envisioned to be managed by the Electrification terminal-focused program manager, with support from the terminal engineering team.

Section 5:

Operating the System

The workforce must be prepared to operate vessels and terminals with new and added systems while maintaining service, safety, and reliability. The systems will require the workforce to have new knowledge and skills, as well as some specific training and credentials.

5.1 U.S. Coast Guard Requirements

The U.S. Coast Guard (USCG) Officer in Charge, Marine Inspection (OCMI) issues a Certificate of Inspection (COI), which serves (among other things) as the safe manning document, stipulating how many crewmembers carrying what types of credentials are required. The issuance of credentialing and associated training and skills is managed within the National Maritime Center; however, the OCMI stipulates the combination of credentials, endorsements and training that are required for the crew on a particular vessel.

Hybrid-electric technology is relatively new to ferries, and the USCG does not currently have unique crewing or credential requirements for hybrid-electric vessels. It is anticipated that WSF will work closely with the local OCMI to establish requirements, potentially in advance of the issuance of USCG minimum standards. If the minimum crewing levels outlined on the COI are different than what is currently used, WSF will have to adjust their workforce accordingly.

5.2 New and Changed Workforce Functions

Electrification of the system will change the duties of various and day-to-day functions of many WSF departments. Because much of the technology and electrical systems are new and unique to WSF, it is anticipated that there will be a learning curve in their use. For a period of time, the workforce will need to be trained in the new systems while also retaining the skillset and training to operate the existing mechanical systems.

5.2.1 Deck Crew

The deck crew's primary role will be to ensure the safety of passengers in the vicinity of the equipment and some visual monitoring during normal operations. Although it is not expected that a larger deck crew will be required, crew will need more training.

Much of the new training will focus on the safe operation of the robotic charging arm. In addition to knowledge of how the electric system and robotic arm operate, the deck crew will need new safety hazards and high voltage training to help keep customers safe. The new systems will also require training in new and unique safe emergency response protocols. During landings, the Chief Mate will be required in the pilot house to assist the captain in monitoring the alignment of the robotic arm.

5.2.2 Engine Room

It is anticipated that there will be a learning curve associated with troubleshooting, features, and challenges of new equipment. Eventually some mechanical functions will shift to electrical, but in the near- and medium-terms the workforce will need to be trained in both diesel and electrical systems. The new electrical systems will require training for troubleshooting and maintenance, and medium/high-voltage safety. Crew will also perform regular maintenance on the robotic charging arm. One proposed solution to address this increase in workload is to reclassify one of the two oiler position to a licensed Junior Engineer/Electrician position to help engine crew and oversee robotic arm operations and maintenance. These additional duties are seen as added responsibility/reclassification of an existing position rather than a newly added position, and will be required as each new vessel comes online.

Engine room staffing may become more challenging as dispatch staff will have a more limited pool of trained personnel to serve as relief personnel. This is all dependent on what level of cross-training WSF undertakes. Qualified relief pool and potential challenges to dispatch should be considered, as discussed in the section below.

5.2.3 Electro-Technical Officer (ETO)

There is currently no regulation that requires an electro-technical officer (ETO), an engineering crew member dedicated to look after electronic equipment and systems, or electro-technical rating (ETR) on a domestic vessel[1]. However, the OCMI has the authority to require an ETO/ETR if it is warranted, as noted in the Marine Safety Manual, Volume 3 related to marine personnel.[2] ETOs or a non-certified equivalent could be added as new hires or potentially through a reclassification of the Oiler position, as referred to in the previous section.

5.2.4 Digital Systems Port Engineer

The new electrical systems will increase the use of automated systems onboard vessels and the required communication links between the ship and shore. This workload is the responsibility of the Digital Systems Port Engineer. Workload will grow to maintain security during the onboarding of vendors who typically have not had extensive access to WSF systems in the past, along with ongoing monitoring of their access to systems. The new systems will also offer new opportunities for real-time data reporting. These additional duties are seen as a newly added position within vessel engineering to support increased workload associated with program development, implementation phase and on-going vessel operation associated with of system electrification.

5.2.5 IT

It is understood that the majority of the IT needs to support the system will be managed by the Eagle Harbor and Vessel Engineering groups. Therefore, it is not anticipated that additional workforce will be required outside of coordination with the Digital Systems Port Engineer.

5.2.6 Dispatch and other management functions

The addition of new vessel technology will further complicate the tasks of recruiting, training, and scheduling the necessary workforce to provide service. Only deck and engine room crew with vessel-specific training, including on-call and relief employees, can be assigned to electrified vessels. This requirement will lead to workforce decisions regarding the balance between the flexibility afforded by training more workforce on the electrified vessels and routes, and the cost savings of having fewer trained crew available to schedule. The 2040 WSF LRP called for investment in recruiting, retaining, and developing a skilled workforce. This effort will require added support in administrative, HR, training, and management functions.

---

[1] https://www.dco.uscg.mil/Portals/9/DCO%20Documents/5p/MSIB/2017/006_17_5-12-2017.pdf

[2] https://media.defense.gov/2017/Mar/29/2001723818/-1/-1/0/THE%20MARINE%20SAFETY%20MANUAL,%20VOLUME%20III,%20MARINE%20INDUSTRY%20PERSONNEL,%20COMDTINST%20M16000.8B

Section 6:

Maintaining the fleet

6.1 Maintenance Program

WSF’s maintenance program is divided into three levels, based on the competencies, facilities and time required to complete tasks. The three levels are defined as follows:

- Organizational-Level (O-Level) Maintenance: Performed by the assigned vessel crew
- Intermediate Level (I-Level) Maintenance: Requires skills, equipment, material, or time beyond those available from the vessel’s normally assigned crew.
- Depot Level (D-Level) Maintenance: Requires the vessel to be at a commercial shipyard because the work is beyond the capabilities of the assigned crew or I-Level maintenance activity.

6.2 Maintenance Elements and Inspections

Maintenance assignments depend on the location of technology or infrastructure element and the frequency and scope of maintenance needed. While vessel system maintenance responsibilities are shared between the engine room crew and the Eagle Harbor Maintenance facility, so too are the terminal elements across the system. Terminal elements requiring maintenance are shared with the Terminal Engineering team, as well as Eagle Harbor staff. The Senior Port Engineer for Vessel Maintenance and the Terminal Engineering Maintenance Manger will review maintenance requirements and assign them to the appropriate internal or external resource (i.e., engine crew, Eagle Harbor, or contractor).These decisions will be documented in the Computerized Maintenance Management System. Some of the known maintenance conditions have been outlined in Figure 2 for illustrative and planning purposes.

In addition to these maintenance activities above, condition monitoring will also occur and are built into energy storage systems that monitor battery condition. This data will be uploaded to the equipment manufacturers, who will assess the condition and notify the vessel owner as required. This may require the development and management of support contracts. These contracts may also include some of the more technical maintenance requirements that are beyond the capability of the vessel crew or Eagle Harbor. Another support contract may be needed to support the rapid charging system.

Table 1: PRELIMINARY ONLY—Anticipated inspection elements, intervals and department leads.

Inspection	Anticipated Interval	Anticipated Department Lead	New or Existing Duty
Known Terminal Elements			
Plug system on Wingwall	TBD	Eagle Harbor	New
Electrical switching system	TBD	Eagle Harbor	New –add to semi/annual PM
Power distribution room (Utility)	TBD	Terminal Engineering and Eagle Harbor	New –add to semi/annual PM
Electrical semi-annual	year	Eagle Harbor	Existing
Electrical annual	year	Eagle Harbor	Existing
In-depth Electrical inspection	3 years	Terminal Engineering and Eagle Harbor	Existing
Known Vessel Elements			
Energy storage system condition monitoring	TBD	Eagle Harbor	TBD
Rapid charging system	TBD	Eagle Harbor	TBD
Additional maintenance procedures	TBD	Vessel Engineering/ Eagle Harbor	TBD

6.3 New/Changed Workforce Functions

New or changed workforce functions related to maintenance of the electric-hybrid fleet will fall under the purview of the professionals at the Eagle Harbor Maintenance Facility, the engine room crew on the vessels and terminal maintenance (for some terminal infrastructure related inspections).

6.3.1 On Vessels

In addition to changes to O-Level maintenance brought on by electrification discussed in the previous Engine Room section, I-Level maintenance will also see an increase in workload and required skills. Because of the high cost of vendor hours to perform troubleshooting and maintenance, it may be beneficial for WSF to develop in-house capabilities to perform some repairs on the new electrical systems. However, support may be needed by outside vendors prior to the internal knowledge, systems and training protocols are in place. Closer examination of the costs, risks, and benefits of internal vs. contract maintenance support may be needed to support decision making and investments moving forward.

6.3.2 Eagle Harbor

As the fleet size increases and new hybrid-electric vessels are delivered, the workload at Eagle Harbor and required skills will increase significantly. In order to support the new electrical systems, the Eagle Harbor workforce will need training in vessel systems and higher-level electrical capabilities, including some computer training for new systems. Eagle Harbor workers will require training to perform maintenance on the robotic charging arm. Along with new capabilities, the higher workload will require increased workforce over the project timeframe and would be quantitatively based on documented maintenance requirements.

The electronics shop was established in December 2019, and it is anticipated that the current staffing level will be at capacity with the existing workload. An expansion of this department, both in numbers and the time dedicated to electrical systems maintenance, would help reduce the reliance on vendors for troubleshooting and repairs. These additional duties are seen as a newly added position(s) during both the program development and implementation phase of the electrification work, as well as on-going during continued operation. Once the fleet has turned over to be majority one type of technology, some re-balancing of maintenance needs should be assessed. This effort did not include identifying exactly how many additional full-time employees would be needed to support maintenance of the fleet. This should be reviewed along with the level of maintenance contracting.

6.3.3 Terminal Engineering

As outlined in Table 1 Terminal Engineering maintenance staff will share in some of the inspection duties, which will be focused on land-side connections and infrastructure. Terminal Engineering maintenance already has protocols and schedules in place to make electrical inspections, however land-side power distribution equipment will be a new element at the terminals.

Section 7: Training the Workforce

Maintaining service reliability will depend upon a properly trained and skilled workforce. As the rollout of system electrification will be phased over approximately 20 years, in the short and medium terms the workforce will be required to have the knowledge and skillset to support both mechanical and the new electrical systems. WSF's training program will have to support an expanded and more highly-skilled workforce. Training needs will be vast at the development and initial implementation of this work and will shift over-time.

7.1 Training Program

Initially, training program development will be supported by vendors as the experts in the new technologies and systems, and included in the contracting requirements of underway vessel construction and conversion. As some of the technologies will be unique to WSF, training programs will be developed from scratch. Development and implementation of training programs will require increased personnel resources in administration, training staff, and managers, as well as training budget. WSF intends to prioritize high voltage electrical training for all crew assigned to the Jumbo Mark II vessels and those assigned to the Hybrid Electric Olympic Class, as those vessels will be delivered/converted at the earlier timeframe. Many already have this training, which will provide a vital foundation for the system-specific training that will follow.

In the past WSF has budgeted for eight weeks of labor for all deck and engine room personnel to cover the time from vessel acceptance until the vessel is placed in service. Sea trials, break-in and training occur during these eight weeks. It is possible that additional training time may be required for some vessel personnel to address new or different knowledge and responsibilities for hybrid propulsion. Once vessel design is sufficiently advanced to develop a training plan the adequacy of the eight-week labor budget can be confirmed.

In addition to hybrid training for personnel assigned to each new vessel it will be necessary to train designed relief personnel to key positions such as Chief and Assistant Engineer and Master and Mates. Additional labor costs for training relief personnel will be required.

Additional effort may be required within the training department, particularly at the time the first vessel in each class is delivered, to develop training plans and materials. These additional duties are seen as a newly added position during program development and implementation phase of the electrification work.

7.2 Workforce Development

The 2040 WSF LRP identified the need to grow the current workforce in order to maintain the reliability of service and prepare for upcoming retirements. On top of stepping up recruiting and hiring, reducing turnover levels will help grow a knowledgeable and skilled workforce and protect WSF's investment in training.

Some higher-skilled positions may not be able to be filled by training the current workforce meaning that, WSF will need to focus on recruiting and hiring. To attract the right people, compensation levels may be reviewed to compete with market rates. Recruiting programs can be developed in coordination with Marine Engineer's Beneficial Association (MEBA) schools and Seattle Maritime Academy.

Section 8: Communication of Changes

The electrification program should include clear and robust communication to staff, partner agencies and the public as an education campaign and also as part of risk management approach. This effort would be needed in the development and implementation phase as well as with every vessel delivery and terminal modification.

8.1 Safety Communications

On top of training the workforce in new systems, training and coordination will be performed with emergency responders, including USCG and fire departments near terminals. Some terminals do not have professional fire departments, therefore whatever the current protocol for engagement of first responders in or around the diverse geography of WSF terminals served should be engaged.

Training should include response to emergencies specifically involving batteries and high-voltage equipment. Once emergency response training and procedures have been developed, WSF's safety systems department will need to incorporate new procedures into the Safety Management System and security plans. These additional duties are seen as a newly added position during program development and implementation phase of the electrification work.

8.2 Public Outreach

As WSF implements new hybrid-electric systems on their ferries, the communications team will take on the effort of informing customers of the new systems and safety procedures. The program focus should be on educating the public regarding perceived risks of new technology, as well as real functions and benefits. An important aspect of public communication will be demonstrating that safety procedures are based on fact and science within evolving technologies. As always, safety is paramount for WSF. It is this culture and preparedness that will need to be clearly communicated so that customers with questions understand the systems in general terms—how they work and how the crew is prepared should emergency response be needed. These additional duties are seen as additional responsibility during program development and implementation phase of the electrification work. It is unclear if additional workforce would be needed to support this endeavor. Additionally, contracting resources may also be applied.

Section 9:

Final Summary and Next Steps for Implementation

Although much of the attention on WSF's system electrification plan focuses on the technology being deployed on vessels and at terminals, implementation depends entirely on the readiness of the workforce. Current unknowns such as inspection plans, USCG crewing requirements and in-house vs contracted labor will need to be determined before workforce levels can be planned in detail. It is clear however that there are two distinct timeframes associated with the expansion or contraction of WSF workforce as it relates to system electrification. These timeframes are early program development and implementation (or time of deployment of electric-hybrid vessels) and the on-going operation once vessels have been delivered.

A summary of new or changed duties and functions by department is included in Appendix A. This table identifies either anticipated "new/added responsibility" to an existing position or department as well as "new position: anticipated.

Appendix A: Summary of Workforce Findings

Department	Program Development and implementation*	On-going	Function
Electrification Program	●[3]		Electrification Program Manager, Electrification Assistant Program Manager (Terminals), Electrification Assistant Program Manager (Vessels).
Human Resources	○	◌	Recruiting and hiring highly skilled workforce.
Communications	○		Internal communication and public outreach regarding new technology and safety measures.
Operations			
Deck (licensed and unlicensed)	○[3]	○	Operating and observation of new systems. Time commitment for participation in design/construction of each new vessel class.
Terminal personnel	◌		Familiarization training required/work order call-in
Vessel Engineering/Maintenance			
Port Engineering	●	●	System controls vendor onboarding and security monitoring. Real-time data tracking and reporting.
Eagle Harbor	●	●	Increase mechanical and electrical workforce New dept. in charge of training and troubleshooting new systems. Inspecting and maintaining charging equipment on wingwalls. Power distribution room inspections shared with TE.
Fleet Maintenance (Engine Room)	○[3]	○	Reclassify (or upgrade) one of the existing Oiler positions to require a license as an electro-technical officer (ETO) or at least a QMED rating as an electrician
Capital Program (new build)	●		Vessel design/construction manager for each new class vessel.
Capital Program (preservation)	○	○	New equipment/systems for preservation management.
Terminal Engineering			
Maintenance Engineer	○		Shared with Eagle Harbor (distribution power room inspection-interval TBD and in-depth electrical inspection at terminals at an assumed 3-year interval)
Capital Program (new build)	○		Additional coordination related to electrification infrastructure projects.
Safety Systems	○	○	Incorporate new protocols into SMS and security plans
Training and Credentialing	●	○	Workforce training program development and implementation. Training for first responders
Finance and Administration	○		Contracting and budget management for construction projects.
Community Services and Planning	○		Schedule review and planning
Information Technology	◌		IT needs are currently assumed through VE. Some coordination will be needed with overall WSF IT.

Key:
○ New/added responsibility ● New position/department

---

[3] These elements are identified in the cost model as part of Task 8.

APPENDIX F:
Task 8 – Capital & Operating Financial Model

Washington State Ferries
System Electrification Plan

Washington State Ferries

Table of Contents

Section 1:

Introduction

The System Electrification Plan (SEP) is an addendum to the 2040 Long Range Plan(LRP). The SEP proposes a plan for implementation of hybrid electric vessels across the ferry system. As with the LRP, the SEP included a twenty-year financial outlook to allow decision makers to evaluate the financial implications of investment in system electrification. WSF revenue and expenditures are organized into two; Program W-Ferry Capital and Program X- Ferries Operations and Maintenance. This memo addresses each program separately. The SEP summary report provides a more wholistic view.

This financial outlook builds on the LRP and incorporates improved estimates and schedule for the required capital investment and a revised forecast for the resulting operating expenditures. Ongoing preservation and improvement needs are also included in the capital investment plan. The operating expenditure forecast carries forward recommendations from the LRP such as workforce development, expanded service levels, expansion of the size of the maintenance and reserve fleet, and refines projected energy cost reductions permitted through conversion to hybrid electric propulsion. While the financial outlook focuses on the financial implications an important benefit of system electrification is reduced carbon emissions. The carbon emission reductions calculated in Task 9 are included in this memorandum as a monetized value to represent the societal cost savings possible through the SEP.

Fare revenues and other funding sources have also been updated.

An alternative financial outlook has been prepared for a no shore charging scenario. This scenario assumes the same new vessel delivery and investment schedule. However, both terminal and vessel investments have been modified to exclude shore charging capability and projected energy expenditures have been adjusted accordingly.

Section 2:

Capital Investments

Electrification will be a multi-decade undertaking and will require internal coordination of WSF departments and external coordination with entities such as equipment vendors, regional and local energy utilities, and local fire and safety departments. Task 4 and Task 5 established the cost estimates for hybrid conversion, new hybrid vessel construction, and terminal electrification. Task 6 developed a vessel and terminal construction schedule to align vessel delivery by route with required terminal improvements. These cost estimates and schedules form the foundations of the Task 8 electrification capital investment plan.

2.1 Vessel Investments

Converting select existing vessel classes and building new hybrid vessels is anticipated to be more than a fifteen-year effort. The vessel delivery schedule is phased by:

- Near Term (0-5 years)
- Medium Term (5-10 years)
- Long Term (10-20 years)

2.1.1 Near Term

Electrification investments are planned for the following two vessel classes in the near term

- **Jumbo Mark II (JMII**) - Engineering work for conversion of three JMII vessels is underway with conversion planned for FY 21 through FY 24.
- **Hybrid Electric Olympic (HEO)** - Engineering work is underway now for construction of five new HEO vessels with construction planned for FY 22 through FY 29.

2.1.2 Medium Term

In the medium term, four new 124-car class vessels are planned to replace the Issaquah Class vessels on the Fauntleroy / Vashon / Southworth route. The first delivery is planned for FY 27 with the final vessel completed in FY 31.

2.1.3 Long Term

Longer term investments are planned for two following vessel classes.

- **Kwa-di Tabil (KDT)** - the three KDT vessels will be converted to hybrid electric conversion over the three consecutive winters of FY 31 through FY 33.
- **New 144-Car Class (New 144)** – Seven new 144-car class vessels will be built with the first vessel completed in FY 31 and the last vessel in FY 37.

2.1.4 Electrification Vessel investment Expenditures

Total investments for conversion and newly built hybrid electric vessels are expected to cost $3.6B dollars over the twenty-year planning period. Cost estimates developed during the SEP reflect WSF's most recent contract prices for the JMII class and the price of HEO class ferries are about $290M higher than estimated for the LRP. The new vessel construction programs are necessary to replace retiring vessels and ensure appropriate capacity. The marginal cost of building new hybrid electric vessels was estimated by WSF to be approximately $14M per vessel for the new HEO class vessels. Extrapolating from the estimated HEO electrification cost, the marginal cost for electrification investment for the converted vessels and replaced vessels would be in the range of $224M or about 6.5% of the cost of the vessel replacement program.

Table 1: Vessel Electrification Investments

	19-21	21-23	23-25	25 -27	27-29	29-31	31-33	33-35	35-37	37-39	Total
Hybrid Conversion											
JMII (3 vessels_)	8,197,760	71,231,000	36,636,000								116,064,760
KDT (3 vessels)						50,154,000	93,048,000				143,202,000
Total Conversion	**8,198,000**	**71,231,000**	**36,636,000**			**50,154,000**	**93,048,000**				**259,266,760**
New Hybrid											
HEO (5 vessels)	12,297,000	199,103,000	311,153,000	333,640,000	144,709,000						1,000,901,000
New 124 (4 vessels)			61,574,000	220,596,000	268,089,000	177,261,000					727,521,000
New 144 (7 vessels)					3,720,000	368,681,000	468,178,000	491,025,000	385,221,000		1,716,825,000
Total New Hybrid	**12,297,000**	**199,103,000**	**372,727,000**	**554,236,000**	**416,518,000**	**545,942,000**	**468,178,000**	**491,025,000**	**385,221,000**		**3,445,247,000**
Total Electrification	**20,495,000**	**270,334,000**	**409,363,000**	**554,236,000**	**416,518,000**	**596,096,000**	**561,226,000**	**491,025,000**	**385,221,000**		**3,704,514,000**

The investment costs displayed above have been adjusted for cost escalation to the year of investment. Baseline FY 20 level dollar estimates for vessel conversions and construction are identified below.

Table 2: Hybrid Conversion and Construction Cost Estimates

	Construction Cost [1] [2]	Number Vessels
Conversion		
JMII	33,100,000	3
KDT	33,000,000	3
New Hybrid		
HEO	173,000,000	5
New 124	141,800,000	4
New 144	173,000,000	7

[1] FY 20 level dollars

[2] Does not include design, procurement, and construction management

2.2 Terminal Investments

Seventeen of WSF's twenty terminals are designated for electrification. The total investment cost for the seventeen projects at sixteen terminals is projected to be $280M or $145M lower than estimated for the LRP as a result of cost estimate refinements and relocation of the rapid charging system from the terminals to the vessels.

Table 3: Terminal Electrification Investments

	19-21	21-23	23-25	25 -27	27-29	29-31	31-33	33-35	35-37	37-39	Total
Terminal Electrification		36,417,000	45,821,000	36,652,000	25,267,000	23,559,000	50,040,000	47,767,000	14,938,000		280,461,000

Planned completion dates and FY 20 level cost estimates for the sixteen terminals are listed below.

Table 4: Terminal Electrification Cost Estimates

Terminal	Date in Service	Estimated Cost [1]
	Near Term	
Clinton	November 2023	11,560,000
Colman	June 2024	24,680,000
Bainbridge	June 2024	13,880,000
	Medium Term	
Kingston	February 2026	13,390,000
Bremerton	April 2026	12,450,000
Southworth	October 2026	15,593,000
Fauntleroy	March 2028	13,568,000
Vashon	February 2029	18,158,000
	Long Term	
Pt Defiance	November 2030	11,678,000
Coupeville	August 2031	15,053,000
Port Townsend	April 2032	11,678,000
Anacortes	February 2034	18,590,000
Orcas	October 2034	11,678,000
Friday Harbor	July 2035	11,948,000
Shaw	March 2036	11,948,000
Lopez	November 2036	13,028,000
Total		228,880,000

[1] FY 20 level dollars

2.3 Battery Replacement

Useful battery life has been calculated for each vessel in Task 4. The replacement cycle calculations consider vessel class propulsion configuration and route operating characteristics such as crossing energy and cycle count. The resulting battery life expectancies are between 4 and 10 years. Battery replacement costs have been estimated using the expected useful life, the size of the battery bank to be replaced, and projected cost of lithium-ion batteries at the point in time the replacement is made. Overtime the price of lithium-ion batteries is expected to decrease reaching a stable price in FY 33. The table below displays the projected replacement costs only. The initial cost of batteries are not shown below but included in initial capital expenditures. Battery replacements costs have also been estimated for those terminals where batteries are installed. Battery replacement costs are classified as a capital preservation expenditure.

Table 5: Battery Replacement Expenditures

	25 -27	27-29	29-31	31-33	33-35	35-37	37-39	Total
Vessels	2,618,000	2,521,000	7,980,000	8,906,000	12,927,000	11,921,000	25,838,000	72,711,000
Terminals		95,000		5,388,000	2,098,000		5,890,000	13,471,000
Total	2,618,000	2,616,000	7,980,000	14,294,000	15,025,000	11,921,000	31,728,000	86,182,000
Price per KWh	$340	$302	$265	$227	$218	$218	$218	

[1] Price per KWh is $650 in 2020

2.4 Electrification Program Management

As discussed in the Task 7 memo planning, designing, building, and implementing system electrification is a major undertaking spanning many decades, multiple disciplines, and organizational units. Strong, centralized program management will be key to uniting the various departments responsible for delivering the components of the electrified system, monitoring progress, and making timely adjustments to ensure on time-delivery of multiple initiatives across time. The fully loaded cost for the three program management positions identified in Task 7 is estimated to be $605,000 in FY 20 level dollars.

2.5 Overall Electrification Capital Investments

Electrification of six existing vessels, sixteen new vessels, and seventeen terminal projects at sixteen terminals is projected to cost almost $4B dollars or about $145M(3.6%) more than estimated for the LRP. The lower estimated cost for terminal investments from the LRP is offset by higher vessel investments and inclusion of program management costs.

Table 6: System Electrification Plan Capital Investments

	19-21	21-23	23-25	25 -27	27-29	29-31	31-33	33-35	35-37	37-39	Total
Vessels	20,494,000	270,655,000	409,690,000	554,577,000	416,871,000	596,464,000	561,609,000	491,422,000	385,634,000		3,707,416,000
Terminals		36,738,000	46,148,000	36,992,000	25,621,000	23,927,000	50,422,000	48,164,000	15,351,000		283,363,000
Total	20,494,000	307,393,000	455,838,000	591,569,000	442,492,000	620,391,000	612,031,000	539,586,000	400,985,000		3,990,779,000

Table 7: System Electrification Plan Compared to Long Range Plan

	Long Range Plan [1]	System Electrification Plan
Vessels	3,414,346,000	3,707,416,000
Terminals	425,242,000	283,363,000
Total	3,839,588,000	3,990,779,000

[1] Cost escalation not adjusted

Section 3:

Operating Expenditures

The FY 20 budget forms the baseline for all projected future SEP operating expenditures in the same way it did in the LRP. [1] The FY 20 budget baseline is adjusted over time to incorporate the recommendations of the LRP and SEP such as workforce development, expanded service levels, fleet expansion, new vessel crew training, and energy cost reductions permitted through conversion to hybrid-electric propulsion. Some of the annual cost adjustments are cumulative such as service enhancements and some are onetime such as new vessel training. Each year's projected annual expenditures are inflated using standard cost escalation factors.

8 displays operating cost forecasts for the consolidated LRP and SEP by biennium.

Table 8: WSF Projected Operating Expenditures

	19-21	21-23	23-25	25 -27	27-29	29-31	31-33	33-35	35-37	37-39	Total
Labor	375,395,000	388,932,000	409,962,000	432,249,000	484,927,000	507,131,000	537,039,000	565,290,000	588,687,000	610,217,000	4,899,829,000
Energy/Fuel	79,120,000	84,636,000	83,031,000	80,491,000	81,818,000	82,364,000	86,000,000	83,871,000	86,636,000	89,810,000	837,777,000
Other	94,330,000	98,944,000	103,939,000	108,684,000	113,805,000	118,378,000	122,980,000	127,735,000	132,714,000	137,983,000	1,159,492,000
Total	548,845,000	572,512,000	596,932,000	621,424,000	680,550,000	707,873,000	746,019,000	776,896,000	808,037,000	838,010,000	6,897,098,000

[1] The impacts of service disruptions and reduced ridership resulting from the corona virus are not fully known and have not been considered.

Table 9: Operating Expenditures -SEP Compared to LRP

	Long Range Plan [1]	System Electrification Plan
Labor	4,743,756,000	4,899,829,000
Energy/Fuel	644,561,000	837,777,000
Other	1,273,168,000	1,159,492,000
Total	6,661,485,000	6,897,098,000

[1] Cost escalation not updated

[2] Labor expenditures over the 20-year period are approximately $123 M or 3% higher in the SEP due to a higher baseline labor budget in FY 20 compared to the FY 19 baseline used for the LRP.

The key changes to baseline operating expenditures are described below.

3.1 Labor

Three primary factors drove changes in labor expenditures for the LPR and are carried forward into the SEP financial plan: these factors are service enhancements, fleet size expansion, and additional training requirements for hybrid-electric propulsion. Labor expenditures estimates are higher in the SEP than in the LRP and reflect findings from Task 7. Furthermore, Task 7 explored potential workforce skill and staffing needs related to the SEP, further study and a more in-depth workforce assessment is required to identify specific staffing level or skill requirement changes, the costs for which were estimated for this financial plan. The labor expenditures for training are one-time expenses that occur each time a new vessel is delivered. Labor changes related to expansion of the fleet and service enhancements are phased and ongoing. All labor expenditures are assumed to grow at the rate of change expressed by the Implicit Price Deflator (IPD).

3.2 Energy Expenditures

3.2.1 Base Level Fuel Expenditures and Future Energy Prices

In this time of historically low fuel prices, establishing a base level of expenditure and forecasting future expenditure levels is particularly challenging. Between January 2020 and September 2020, the price per gallon WSF pays for diesel fuel varied from a high of $2.02 to a low of $.61 averaging about $1.34 over those nine months.

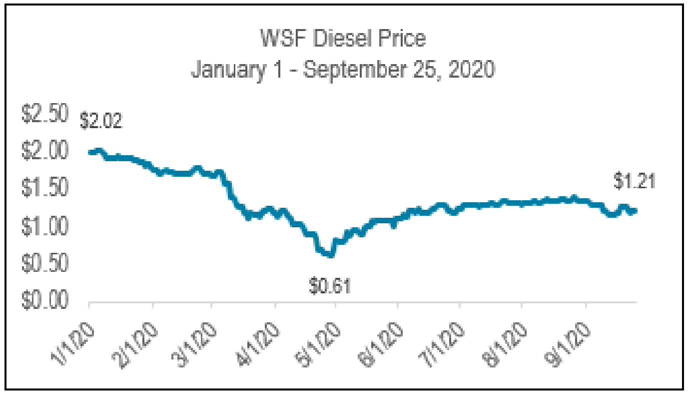


Figure 1: 2020 WSF Diesel Price

As noted above, FY 20 budgeted expenditures form the base year for forecasting operating expenditures. The FY 20 budgeted fuel price used to establish baseline diesel fuel expenditure for the SEP was $2.04. For every $0.10 change in fuel price WSF experiences an annual fuel expenditure difference of about $1.9M. If the FY21 budgeted fuel price of $1.78 were applied to FY 20 consumption, the base year fuel expenditure would be $33.7M rather than $38.5M; a difference of $4.8M or about 12%. Taking into consideration recent fuel prices the FY 20 fuel budget provides a conservative estimate of fuel expenditures over the next few years.

A key factor is projecting energy expenditures over a twenty-year period is forecasting the unit price of diesel fuel and electricity. As demonstrated in recent months, the price of diesel fuel is marked by fluctuations. However, over the last twenty-three years diesel prices have shown a steady increase. [2] Whereas, the price of electricity has been very stable, particularly in the Pacific Northwest. [2] It should be noted that the reliability of any future energy price projection may be low due to the global uncertaniity. For this project, the US Energy Information Administration's (EIA) unadjusted annual B5 price forecast was used to calculate diesel price adjustments over the planning period. [3] Base electricity rates were estimated from current cost schedules of local utilities and then adjusted overtime using annual price changes used in the EIA's electricity price forecast. [4]

3.2.2 Projected Energy Expenditures

---

[2] Source: Jumbo Mark II Class Hybrid System Integration Study Rev A, Prepared for Washington State Ferries, Elliot Bay Design Group, January 17,2020

[3] US EIA does not publish price forecasts for B10 diesel. The EIA B5 diesel price forecast was used to calculate annual price changes which were then applied to the baseline WSF B10 based fuel budget.

[4] The US EIA forecasts electricity end use prices for four customer classes; residential, transportation, commercial, industrial with residential being the highest and industrial the lowest. The all sector average was used to calculate price changes.

The most profound change to WSF operating expenditures occurs as reliance on diesel propulsion is replaced by hybrid electric propulsion. As shown in Figure 2, energy expenditures in FY 39, will be 30% lower than they would be without hybrid-electric propulsion.

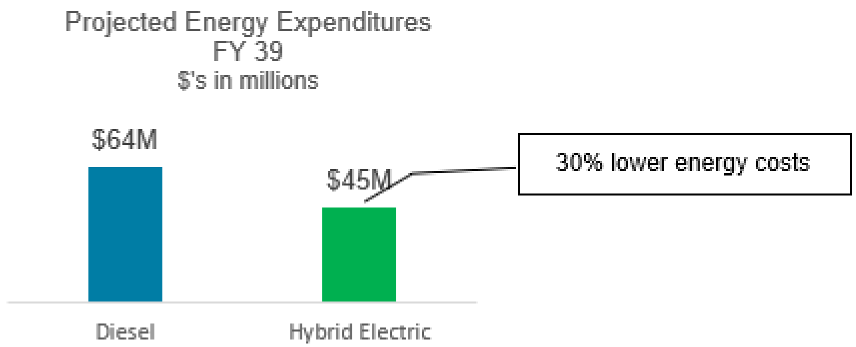


Figure 2: Projected Energy Expenditure Comparison

A hybrid-electric propulsion system relies on lithium-ion batteries to store electric energy that powers the vessel. These batteries must be continuously re-charged either through a shore-based plug in charging system or through the on-board diesel generators.

The SEP assumes shore charging at sixteen of WSF's twenty terminals. Analysis conducted in Task 4 determined electricity and diesel usage rates for each route and the monthly demand charge[5]at each of the sixteen terminals. Energy expenditure estimates were developed by applying these usage rates to current crossing costs and projecting to the year FY40 and then adding the demand charge for each route.

Hybrid energy costs were phased in by route in accordance with the delivery plan developed in Task 6. In some cases, hybrid vessels are deployed on a route before the terminals are electrified. In these cases, vessel energy costs are estimated based on the no shore charging fuel reductions estimated in Task 4 until shore side charging is available. The energy cost for no shore charging is higher than when shore charging is available, but less than non-hybridized vessels.

3.2.3 Carbon Emission Reductions

[5] The demand charge is the monthly cost billed by utilities to capture the maximum power consumption experienced that month.

Reductions in carbon emission are an important non-financial benefit of the SEP. While carbon emission reductions will not reduce annual WSF operating expenditures they are widely recognized as a way to reduce the overall social costs associated with environmental damages. Carbon emission reductions realized through the SEP afford WSF an opportunity to have a large-scale positive impact on both ferry riders and the non-ferry riding public. The table below displays the monetized value of WSF's carbon emission reductions through the timeline of the SEP. Carbon emission reductions are measured relative to 2005 level emissions to align with the directive of RCW 70A.45.050.

Table 10: *Monetized Carbon Emissions Reductions*[1]

	19-21	21-23	23-25	25 -27	27-29	29-31	31-33	33-35	35-37	37-39	Total
Carbon Emissions Reduction	714,649	1,465,380	10,197,927	14,693,594	19,450,419	21,686,499	26,753,914	32,306,273	37,050,000	40,107,672	204,426,329

[1] Monetized values are adjusted for inflation.

Section 4:

Revenue

The 2040 LRP projected revenues available to both build and maintain needed infrastructure and to sustain continued operations of the ferry system. Recent travel and economic changes triggered by the corona virus have altered the anticipated level and timing of some funds available to WSF. However, estimated total revenue available for the SEP is $143M more than two years ago when the LRP was prepared reflecting recent revenue appropriations to the capital program that are greater than anticipated at the time the LRP was prepared.

Historically, WSF has received funds through direct user sources in the form of fares and concessionaire income and from tax revenues including statutory distribution, transfers, statewide bonding programs, and Federal grants. Revenue sources were documented in the LRP relying on the Transportation Revenue Forecast Council (TRFC) and WSDOT financial plans prepared in conjunction with the 19-21 biennial budget request. These forecasts have been updated using the most recent TRFC and WSDOT projections, This revenue forecast includes competitive grants awarded through June 2020 and projects on ongoing formula grants based on amounts in the current business plans. Promoting significant reductions in diesel fuel consumption and lower CO2 emissions, WSF's electrification projects should compete well in national and regional discretionary funding programs. *Section 7: Implement and Invest- Funding Opportunities* in the SEP Report provides a fuller discussion of potential grant funding sources.

Overall operating program revenue is down from the LRP by about $316M or 5.1% with both fares and operating program tax revenues lower than previously expected. The June 2020 TRFC forecast was used to project fare revenue through FY29.[6] This fare revenue forecast predicts a reduction in fare revenue of about 22% for the 19-21 biennium from what was predicted in February. However, the June TRFC forecast predicts that fare revenue will rebound in 21-23 to about 6% below what the February TRFC forecast was for that biennium. Dedicated tax revenue distributions such as gas tax are down due to overall lower statewide gas tax revenue collections

Capital program revenues increased by about $458M due in part to a carry forward of unexpended revenue from the previous biennium and increased appropriations from other WSDOT tax revenues. While gas tax revenue distributions are lower due to overall lower statewide gas tax revenue collections, appropriations from the Capital Vessel Replacement Account, funded through a surcharge on fares, are greater than anticipated at the time of the LRP.

The Legislature makes revenue and expenditure appropriation decisions each biennium that balance the needs of all State funded transportation programs. The TRFC forecast and WSDOT's fund business plans are useful planning tools for both WSDOT/WSF and the legislature, but the level of revenue available to WSF may change every biennium. The revenue forecasts here, as with the LRP, reflected the best information available at a point in time.

Table 11: Funding Comparison

	Long Range Plan	System Electrification Plan	Change $'s	Change %
Operating Sources	**6,237,301,000**	**5,921,423,000**	-315,878,000	-5.1%
Fare and Misc	5,300,585,000	5,045,152,000	-255,433,000	-4.8%
Operating Tax Revenues	936,716,000	876,271,000	-60,445,000	-6.5%
Capital Sources	**1,480,928,000**	**1,939,329,000**	458,401,000	31.0%
Total Funding Available	**7,718,229,000**	**7,860,752,000**	142,523,000	1.8%

[6] The ongoing uncertainty surrounding the course of the corona virus, how the economy will reopen and rebound, and what the lasting impact remote work may have on future commuting behavior likely undermines the reliability of any current forecast.

Section 5:

Financial Outlook

The twenty-year LRP financial outlook has been updated to incorporate planned electrification investments and a revised forecast for operating expenditures. The capital investments include the cost to implement the SEP as well as preserve and improve WSF's existing capital assets. The SEP financial outlook also updates anticipated funding sources and predicted funding gaps over the twenty-year period.

Table 12. Washington State Ferries - SEP Financial Outlook (Dollars in Millions)

Operating Program	19-21	21-23	23-25	25-27	27-29	29-31	31-33	33-35	35-37	37-39	Twenty Year Total
Operating Revenue	324	419	446	469	492	519	547	577	609	643	5,045
Operating Revenue Percentage Change	-18.0%	29.2%	6.7%	5.0%	5.1%	5.4%	5.5%	5.5%	5.5%	5.5%	
Operating Expenditures	549	573	597	621	681	708	746	777	808	838	6,897
Operating Expenditure Percent Change	5.8%	4.3%	4.3%	4.1%	9.5%	4.0%	5.4%	4.1%	4.0%	3.7%	
Operating Revenue Recovery	59.0%	73.1%	74.8%	75.4%	72.3%	73.3%	73.4%	74.3%	75.4%	76.7%	73.1%
Subsidy Required	-225	-154	-150	-153	-188	-189	-199	-200	-199	-196	-1,852
Presumed Level of Subsidy Available	82	82	84	85	87	88	90	91	93	94	876
Additional Subsidy Required	-143	-72	-67	-67	-101	-101	-109	-108	-106	-101	
Cumulative Operating Funding Shortfall	**-143**	**-215**	**-281**	**-349**	**-450**	**-551**	**-660**	**-768**	**-874**	**-976**	**-976**
Capital Program											
Revenue (Presumed Level)	469	286	113	114	145	145	164	166	168	170	1,939
Capital Program Investment	420	612	819	1,015	883	1,138	1,204	1,014	825	516	8,447
Biennial Shortfall	**49**	**-326**	**-706**	**-901**	**-738**	**-993**	**-1,040**	**-848**	**-657**	**-346**	
Cumulative Capital Funding Shortfall	**49**	**-277**	**-983**	**-1,884**	**-2,622**	**-3,616**	**-4,656**	**-5,504**	**-6,161**	**-6,508**	**-6,508**
Total Plan Funding Needed	-93	-541	-987	-1,250	-1,188	-1,544	-1,700	-,1616	-1,532	-1,322	-7,483

Overall the SEP financial outlook predicts a $568M (8%) greater funding shortfall than the LRP. The primary drivers of the increased shortfall are lower operating program revenues that are unrelated to the SEP, higher electrification capital investment estimates, lower energy savings additional vessel training requirement for hybrid propulsion and actual changes in FY 20 baseline labor expenditures.

Table 13: Financial Outlook SEP Compared to LRP

	Long Range Plan [1]	System Electrification Plan	Change
Operating			
Revenue	6,237,300,810	5,921,423,000	-315,877,810
Expenditures	6,661,485,000	6,897,099,000	235,614,000
Funding Shortfall	-424,184,190	-975,676,000	-551,491,810
Capital			
Revenue	1,480,928,000	1,939,329,000	458,401,000
Investments	7,972,385,000	8,446,920,000	474,535,000
Funding Shortfall	-6,491,457,000	-6,507,591,000	-16,134,000
Combined Shortfall	-6,915,641,190	-7,483,267,000	-567,625,810

[1] Cost escalation not adjusted

SEP Electrification investments are approximately $145M higher than in the LRP with vessel investments up $290M while terminal investment estimates are down by $145M. As mentioned earlier in this memo, WSF estimates the marginal cost of electrification on a newly built vessel to be approximately $14M making the marginal cost of vessel electrification and conversion approximately $224M or 6.5% of the total capital program. Although terminal electrification projects are integrated to the extent possible with other planned terminal improvements and preservation, the terminal electrification costs estimate below are entirely for electrification.

Table 14: Electrification Investments SEP Compared to LRP

	Long Range Plan [1]	System Electrification Plan	Change
Vessel - Conversions and New Build	3,414,346,134	3,704,514,000	290,167,866

Terminal Electrification	425,241,554	280,461,000	-144,780,554
Total Electrification	3,839,587,688	3,984,975,000	145,387,312

Section 6:

No Shore Charging Scenario

The SEP recommends a shore-based charging system to achieve the greatest environmental benefits from electrification. To help evaluate opportunities for reducing capital investments, costs were estimated for a system that does not utilize shore-based charging systems. In the no shore charging scenario all of the electrification investment at the terminal would be avoided. For vessels, costs would be lower due to elimination of the Rapid Charging System and the potential for smaller sized, less costly battery banks achievable due to higher reliance on diesel propulsion. While the no shore charge scenario reduces capital investments by $526 M, annual energy costs are higher by nearly $13M (28%) in FY 39 relative to the recommendations of the SEP. This is because in this scenario battery charging relies upon on-board diesel generators instead of terminal based charging systems powered by local utilities. Further, as noted in Task 9 WSF would not meet emission reduction requirements of RCW 70A.45.050 in the no shore charging scenario.

Table 15: Capital Investments- Shore Charging Compared to No Shore Charging

	Shore Charging	No Shore Charging	Difference
Vessels	6,142,305,000	5,917,542,000	224,763,000
Terminals	2,109,401,000	1,808,432,000	300,969,000
Total	8,251,706,000	7,725,974,000	525,732,000

Table 16: Energy Cost Comparison

	Shore Charging	No Shore Charging
FY 39 Energy Expenditure	45,204,000	58,053,000

The financial outlook for the no shore charging scenario is shown below.

Table 17. Washington State Ferries No Shore Charging Scenario Financial Outlook

Operating Program	19-21	21-23	23-25	25-27	27-29	29-31	31-33	33-35	35-37	37-39	Twenty Year Total
Operating Revenue	324	419	446	469	492	519	547	577	609	643	5.045
Operating Revenue Percentage Change	-18.0%	29.2%	6.7%	5.0%	5.1%	5.4%	5.5%	5.5%	5.5%	5.5%	
Operating Expenditures	549	573	600	629	692	722	767	802	833	863	7,030
Operating Expenditure Percent Change	5.8%	4.3%	4.7%	5.0%	10.0%	4.3%	6.3%	4.6%	3.8%	3.7%	
Operating Revenue Recovery	59.0%	73.1%	74.5%	74.4%	71.1%	71.9%	71.3%	71.9%	73.1%	74.4%	71.8%
Subsidy Required	-225	-154	-153	-161	-200	-203	-220	-225	-224	-221	-1,985
Presumed Level of Subsidy Available	82	82	84	85	87	88	90	91	93	94	876
Additional Subsidy Required	-143	-72	-69	-75	-113	-115	-130	-134	-131	-126	
Cumulative Operating Funding Shortfall	**-143**	**-215**	**-284**	**-360**	**-473**	**-587**	**-717**	**-851**	**-983**	**-1,109**	**-1,109**
Capital Program											
Revenue (Presumed Level)	469	286	113	114	145	145	164	166	168	170	1,939
Capital Program Investment	420	558	752	952	838	1,082	1,106	933	784	496	7,921
Biennial Shortfall	**49**	**-272**	**-639**	**-837**	**-693**	**-937**	**-942**	**-768**	**-617**	**-327**	
Cumulative Capital Funding Shortfall	**49**	**-223**	**-862**	**-1,699**	**-2,392**	**-3,329**	**-4,271**	**-5,039**	**-5,655**	**-5,982**	**-5,982**
Total Plan Funding Needed	0	0	-1,000	-2,000	-3,000	-4,000	-5,000	-6,000	-7,000	-7,000	-7,000

Due to rounding, numbers presented in this overview may not add up precisely to the totals indicated

APPENDIX G:
Task 9 – Emissions Impact Estimate

Washington State Ferries
System Electrification Plan

Table of Contents

Section 1:

Introduction

The System Electrification Plan (SEP) includes an emissions reduction initiative driven by the Long Range Plan (LRP) and Executive Order 20-01. The Executive Order aims to reduce government spending on energy, decrease the release of harmful pollutants into the atmosphere, and support climate change initiatives by utilizing clean-energy vehicles in all aspects of State Government including the Washington State Ferry (WSF) fleet.

As the nation's largest ferry system, the WSF transition to an electrified fleet is an ambitious undertaking that will become a case study for future fleet electrifications. While the success of the plan can be measured in a multitude of ways, reductions in emissions will be a crucial metric that represents an opportunity for WSF to have a large-scale positive impact on the population, including non-ferry users. The capital investment required by the plan could ultimately improve WSF's environmental and financial sustainability, as illustrated in Figure 1.

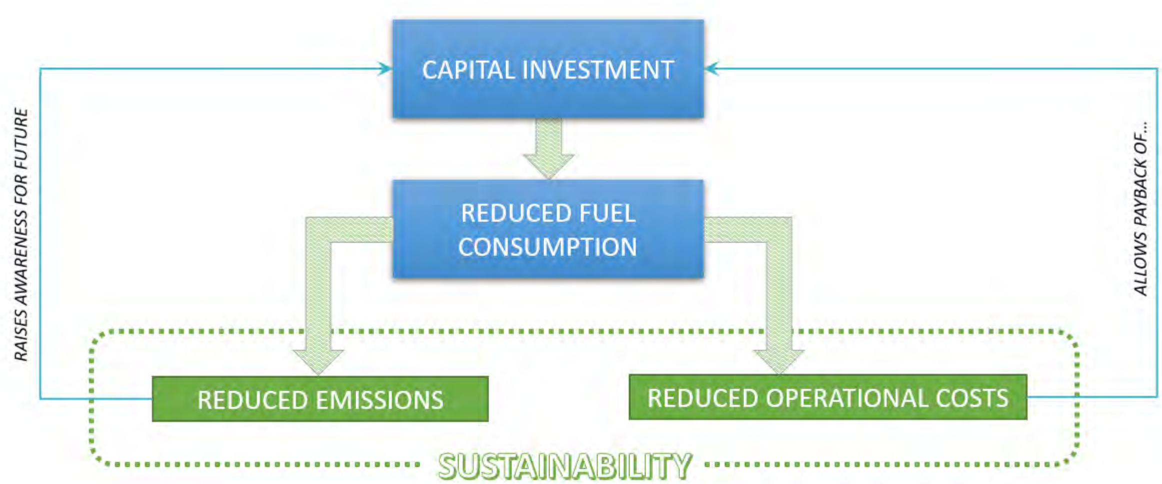


Figure 1: Environmental and Financial Sustainability

The System Electrification Plan Task 9 prescribed development of this Emissions Impact Estimate technical memorandum. The objective is to summarize the emissions reductions resulting from fleet electrification, both with and without the installation of shore charging, to include CO_2 equivalent, NO_x, and particulate matter. The quantitative results presented are dependent on the assumed electrification timeline, fleet composition, and vessel route assignments.

Section 2:

Procedure and Assumptions

The emissions impact estimate is based on two calculators provided by the Washington State Department of Transportation (WSDOT) to calculate greenhouse gas[1] and particulate matter emissions[2]. The results are compared against green house gas limits identified in RCW 70A.45.050 which require overall emission reductions to 45% below 2005 levels by 2030, and 70% by 2040.

The methodology prescribed by the calculators was combined with information and assumptions generated by the LRP and the SEP to capture fleetwide emissions for the varying fleet composition and vessel assignments expected through the 2040-time horizon. Several input variables and assumptions are discussed in further detail in the following sections.

This estimate captures emissions generated on the vessel by the engine/generator and upstream emissions produced by the power utilities. A 'cradle to grave' analysis, including the upstream and downstream emissions related to battery and other vessel system manufacturing and recycling are not included in these calculations.

At a high level, the following issues should be considered for marine batteries:

- There are environmental and humanitarian challenges related to extraction of cobalt and other minerals used in batteries. Mineral recovery rate through recycling and raw material pricing is dependent on unique supply and demand dynamics.
- Marine batteries have an advantage over vehicular batteries for being reused in a grid application and may be used in shore side applications.
- Reuse of marine batteries may require greater coordination upfront and service support at the back end by the original manufacturer.
- Marine batteries are not as cost effectively recycled as vehicular batteries due to the lack of standardization and limited volume of each battery type to be recycled. The cost effectiveness of recycling will evolve as vessel hybridization becomes more common place and the battery recycling industry matures.

[1] WSDOT GHG Summary 190912.xlsx

[2] Ferries Green Marine EI 2020.xlsx

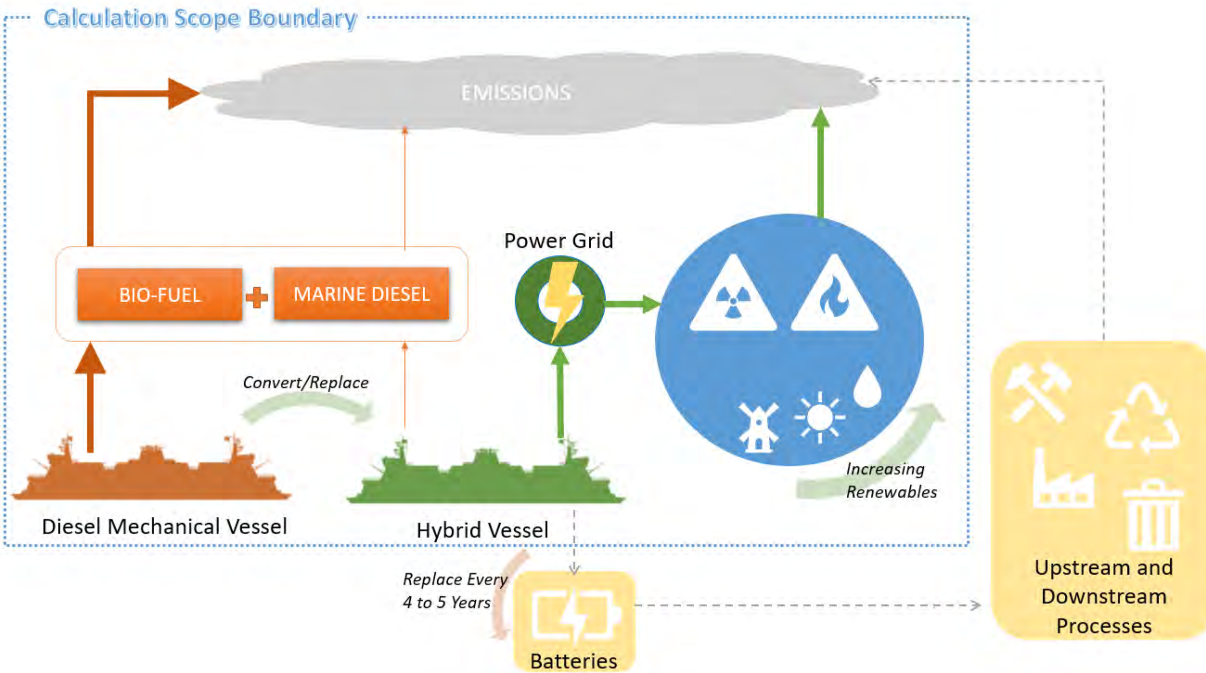


Figure 2: Emission Sources and Calculation Scope

The emissions impact estimate was performed for two scenarios: 1) with shore charging and 2) without shore charging. For both scenarios, emissions generated by the diesel power plant are calculated based on historical fuel consumption. Diesel mechanical vessels are assumed to consume their entire baseline fuel consumption, and hybridized vessels are assumed to consume a percentage of their baseline fuel consumption depending on the availability of shore charging and their route assignment. For the scenario with shore charging, upstream utility emissions are calculated based on estimated crossing energy, utility specific fuel blends, and associated emission factors.

The scenario without shore charging assumes all hybrid vessels operate using a load leveling mode where the generator is run at its most efficient point with onboard charging. This scenario is unable to take advantage of the cleaner power sources and economy of scale offered by power plants and will result in smaller emissions reductions.

The percentage of historical fuel consumption for both scenarios were calculated under Task 4 Vessel Functional Requirements and are discussed further in Section **Error! Reference source not found.**.

The emissions calculated herein are carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NO_x), and particulate matter (PM). Results for GHGs are presented as an overall carbon dioxide equivalent (CO_2e) to illustrate the combined global warming effect of carbon dioxide, methane, and nitrous oxide (N_2O). Note that N_2O is a unique compound that makes up only a very small fraction of the total NO_x emissions and is considered a GHG. The vast majority of NOx emissions are toxic pollutants that negatively impact human health but are not known to have a greenhouse effect. See Table 5 for detailed emission information.

2.1 Assumptions

The input variables and assumptions required for this analysis are described and information sources are identified below.

2.1.1 Fleet Composition and Vessel/Route Assignments

The overall fleet composition for the plan time horizon was informed by the LRP. Known necessary and assumed changes to the plan from Task 6, Vessel Delivery and Terminal Improvement Schedule incorporated in this draft are summarized below:

- The 3rd and 4th Hybrid Electric Olympic vessels to be assigned on the Seattle-Bremerton route
- The 5th Hybrid Electric Olympic vessel assigned as a relief vessel
- Hybrid PUYALLUP assigned as a relief vessel when the Edmonds-Kingston three vessel schedule begins
- Diesel mechanical Olympic Class vessels operating on the Sidney route

This emissions estimate was calculated on an annual basis based on the summer schedule and annual fuel consumption numbers. While the analysis does not explicitly look at the shoulder and winter seasons, these trends are captured by using an annual fuel consumption.

Emissions for each existing and planned vessel in the WSF fleet were calculated individually and the results were combined into a fleetwide analysis. It was necessary to first establish the fuel consumption (FC) of each vessel in the fleet.

- For existing vessels, the annual FC from available historical data[3] was used as the baseline.
- Baselines for new vessels were calculated using the average from vessels currently operating on the route, or as the average of all vessels of a similar class. In some instances, there was no historical FC data available from a similar class of vessel. In these instances, the average known FC was adjusted using the ratio of installed horsepower between the two classes. Depending on the scheduled assignment, the most salient method of determining baseline FC for a planned vessel was used.
- As vessels are converted to or built new as hybrid vessels, it was assumed that they would then consume a percentage of their baseline FC.
- Fuel consumption for vessels assigned as relief are not explicitly calculated. Instead, relief vessel fuel consumption is accounted for by a contingency margin that includes fuel budget for vessel moves, sea trials, and for relief vessels.

For the scenario without shore charging, the fuel consumption (and consequently emissions) reductions for each vessel class/route are shown in Table 1. The reductions were estimated by calculating differences in propulsion system efficiencies. Note that a significant contributor to these fuel reductions is a result of WSF intentions to adopt newer generators which have improved brake specific fuel consumptions (BSFC) compared to the historical vessels. In other words, these fuel and emissions reductions are a comparison of *older* diesel mechanical

[3] Fuel Usage thru 2018.xlsx

technology to *newer* diesel-electric hybrid technology and are not representative of the difference in fuel and emissions reductions between new diesel mechanical and new diesel electric hybrid vessels.

Table 1: No Shore Charging Fuel Reductions

Route or Vessel Position		Vessel Class	Estimated Fuel Reductions
Seattle	Bainbridge	JMII	13.5%
Mukilteo	Clinton	HEO	13.3%
Seattle	Bremerton	HEO	13.3%
Port Townsend	Coupeville	KDT	13.3%
Point Defiance	Tahlequah	KDT	13.3%
Edmonds	Kingston	JMII	13.5%
Edmonds	Kingston	144	13.3%
Fauntleroy/Vashon/Southworth		124	8.4%
San Juan Island Routes		144	13.3%

For the scenario with shore charging, it was necessary to account for instances of generator reliance.

Even when shore charging is available, all routes were still assumed to consume at least 4.3% of their baseline FC to account for instances of power disruptions (allowing for the interruptible utility rate schedules) and rapid charging system (RCS) connection reliability. The percentage of FC was increased for routes with perceived schedule risk (as identified in Task 4, Vessel Functional Requirements). The minimum incidental FC for each route (except those in the San Juan Islands) are summarized below in Table 2.

Table 2: Minimum Incidental FC by Route for Shore Charging Scenario

Route	Estimated Fuel Reductions
Seattle - Bainbridge	90.5%
Seattle - Bremerton	84.5%
Mukilteo - Clinton	95.7%
Edmonds – Kingston (JMII)	78.4%
Edmonds – Kingston (144)	95.7%
Point Defiance - Tahlequah	95.7%
Port Townsend - Coupeville	95.7%
Southworth - Fauntleroy	88.4%
Vashon - Fauntleroy	95.4%
Vashon - Southworth	92.0%

For the San Juan Island routes, the current recommendation is hybrid operation that takes advantage of but is not fully reliant on the power grid. A rough-order-of-magnitude FC percentage was assigned based on vessel position to align with the current recommendations of Task 4, Vessel Functional Requirements.

The vessel position-based percentage of baseline FC for the San Juan Island routes are summarized below in Table 3.

Table 3: Minimum Incidental FC by Vessel Position for Shore Charging Scenario

Route and Vessel Position	Estimated Fuel Reductions
SJI Position 1 (SOLAS)	0%
SJI Position 2	65.3%
SJI Position 3	65.3%
SJI Position 4 (Interisland)	48%

2.1.2 Energy Consumption

Energy consumption for each hybrid vessel (except those in the San Juan Islands) operating with shore charging was calculated by multiplying crossing energies estimated in Task 4, Vessel Functional Requirements with estimated annual crossing numbers for each route.

The hybrid vessels of the future WSF fleet, assigned operating routes, and governing utilities are summarized in Table 4 below. For routes recommended for single sided charging, an assumption was made to use the terminals powered by Puget Sound Energy. WSDOT has joined the Green Direct Program through PSE, further discussed in Section 2.1.3.2, allowing WSF to utilize electricity generated solely by wind and solar, zero-emission renewable sources.

Table 4: Hybrid Vessel and Route Assignment Summary

VESSEL	ROUTE (A/B)	UTILITY Terminal A	UTILITY Terminal B	Double/Single Sided Charging*
TACOMA	Seattle/Bainbridge	Seattle City Light	Puget Sound Energy	Double
WENATCHEE	Seattle/Bainbridge	Seattle City Light	Puget Sound Energy	Double
CHETZEMOKA	Point Defiance/ Tahlequah	Tacoma Power	Puget Sound Energy	Single (Tahlequah)
SALISH	Port Townsend/ Coupeville	Jefferson County PUD	Puget Sound Energy	Double
KENNEWICK	Port Townsend/ Coupeville	Jefferson County PUD	Puget Sound Energy	Double
OLY1	Mukilteo/Clinton	Snohomish PUD	Puget Sound Energy	Single (Clinton)
OLY2	Mukilteo/Clinton	Snohomish PUD	Puget Sound Energy	Single (Clinton)
OLY3	Seattle/Bremerton	Seattle City Light	Puget Sound Energy	Double
OLY4	Seattle/Bremerton	Seattle City Light	Puget Sound Energy	Double
OLY5	Relief	n/a	n/a	n/a
ISS1	FVS 1	Seattle City Light	Puget Sound Energy	Double
ISS2	FVS 2	Seattle City Light	Puget Sound Energy	Double
ISS3	FVS 3	Seattle City Light	Puget Sound Energy	Double
ISS4	Relief	n/a	n/a	n/a
NEW1	Edmonds/Kingston	Snohomish PUD	Puget Sound Energy	Single (Kingston)
NEW2	Edmonds/Kingston	Snohomish PUD	Puget Sound Energy	Single (Kingston)
NEW3	Edmonds/Kingston	Snohomish PUD	Puget Sound Energy	Single (Kingston)
NEW4	San Juan Islands 2	OPALCO	Puget Sound Energy	Double
NEW5	San Juan Islands 3	OPALCO	Puget Sound Energy	Double
NEW6	San Juan Islands 4	OPALCO	Puget Sound Energy	Double
NEW7	San Juan Islands 5 (Interisland)	OPALCO	OPALCO	Double

Energy consumption for the hybrid vessels assigned to the San Juan Islands was estimated based on historical fuel consumption. The historical fuel consumption, accounted for in Table 3, was multiplied by an assumed energy density for B-5 of 37.5 kWh/gal.

2.1.3 Emission Factors

The following emissions are estimated:

- CO_2 – Carbon Dioxide
- CH_4 – Methane

- N_2O – Nitrous Oxide (subset of total NOx emissions)
- NO_x – Nitrogen Oxides
- PM – Particulate Matter (with a diameter of 10 microns or less)

These emissions are categorized as a greenhouse gas (GHG), a toxic pollutant, or both.

Greenhouse gases contribute to global warming and have an associated global warming potential (GWP). CO_2 is assigned a GWP of one, and other greenhouse gases are assigned GWPs depending on the severity of global warming contribution relative to CO_2[4]. For example, one gram of methane with a GWP of 25 would have the same warming effect as 25 grams of CO_2.

Toxic pollutants do not necessarily contribute to global warming but do have a negative impact on human health and are reported in metric tons (MT). Table 5 summarizes the categories and GWPs for the emissions analyzed.

Table 5: Emissions Analyzed

Emission	Category	GWP
CO_2	GHG	1
CH_4	GHG	25
N_2O	GHG, subset of NO_x	298
NO_x	Toxic Pollutant	N/A
PM	Toxic Pollutant	N/A

2.1.3.1 *Emission Factors for Diesel Fuel*

The rate at which emissions are generated from fossil fuel combustion can vary widely depending on engine load and rpm, especially for NO_x and PM. This analysis uses high-level representative emission factors (EF) based on guidance from the EPA and WSDOT. EFs are summarized in Table 6.

[4] United States Environmental Protection Agency, 2018

Table 6: Emission Factors

Emission	Engine Rated Power	Engine Certification Year	Emission Factor	Data Source
CO_2	All	All	10.21 kg/gal	EPA
CH_4	All	All	0.06 g/gal	EPA
N_2O	All	All	0.45 g/gal	EPA
NO_x	1400-2000 kW	2010-2012	150.7 g/gal	WSDOT
		2014-2015	111.6 g/gal	
		2016+	23.5 g/gal	
	2000-3700 kW	2005-2013	150.7 g/gal	
		2014+	23.5 g/gal	
PM	1400-2000 kW	2005-2012	5.6 g/gal	
		2013-2015	2.89 g/gal	
		2016+	0.54 g/gal	
	2000-3700 kW	2005-2012	5.6 g/gal	
		2013-2015	NA	
		2016+	0.54 g/gal	

For CO_2, CH_4, and N_2O, the EPA has established emission factors that are identified directly in either grams or kilograms of emission produced per gallon of fuel burned[5]. WSF considers the CO_2 generated from biodiesel to be carbon neutral. For the purpose of this analysis, it is assumed that the WSF fleet is using a 5% biodiesel blend, and only 95% of total fuel consumption is contributing to CO_2 emissions. There is not a clear consensus among regulatory agencies regarding emission factors for CH_4 and N_2O from biodiesel. The use of biodiesel is therefore omitted for these emissions, and CH_4, and N_2O emissions are calculated assuming 100% regular marine diesel fuel. CO_2, CH_4, and N_2O emission factors are applied to the entire fleet and are not impacted by propulsion engine make, model, or certification year.

WSDOT, as part of the Green Marine effort, has established emission factors for NOx and PM specific to each individual main propulsion engine in the fleet[6]. These factors are represented in g/kWh and assume a fleet wide brake specific fuel consumption of 185 grams of fuel per kWh generated. For consistency, these factors were converted to g/gal and used to calculate emissions directly from estimated fuel consumption. Similar to CH_4 and N_2O, there is not a clear consensus on emission factors for NO_x and PM from biodiesel, thus these emissions are calculated assuming 100% regular marine diesel fuel.

[5] EPA Emission Factors for GHG Inventories, 2018

[6] *Ferries Green Marine EI 2020.xlsx*

2.1.3.2 *Emission Factors for Shoreside Electricity*

Emission factors for electricity obtained from the shoreside grid are dependent on the utility providing the power and the upstream power plants feeding the grid. While Puget Sound benefits from proximity to hydropower, the interconnectivity of the grid means that the power being drawn is from a blend of upstream sources, including non-renewable sources.

Note that upstream power sources are evolving, with more and more renewable power sources coming online. The passage of the Clean Energy Transformation Act (CETA) "commits Washington to an electricity supply free of greenhouse gas emissions by 2045".[7] While this estimate does not account for increasing sources of renewable power, it is very likely that emissions from upstream power sources will continue to decrease in the future as utilities work towards compliance with CETA. Note that some utilities provide the option to purchase zero-carbon footprint electricity at an additional cost in accordance with Washington State law.

The utility provider at each terminal is identified below in Figure 3 (with the exception of the Sidney, BC, terminal).

[7] Association of Washington Cities, "Clean Energy Transformation Act proposed rules", 11/15/2019

Figure 3: Utility Provider and Terminals

Each utility is required to disclose their fuel mix to the Washington State Department of Commerce and the results of this disclosure are published on an annual basis[8]. The 2018 fuel mix for the utilities relevant to this plan are summarized below in Table 7.

Table 7: 2018 Utility Specific Fuel Mix

SOURCE	OPALCO	Seattle City Light	Puget Sound Energy	Snohomish PUD	Jefferson County PUD	Tacoma Power
Hydro	85.69%	85.87%	22.29%	79.51%	86.47%	84.98%
Nuclear	10.66%	4.84%	0.36%	9.88%	10.75%	6.12%
Biogas		1.16%	0.14%	0.15%		
Wind		6.77%				5.64%
Unspecified	3.64%	1.36%	19.58%	2.55%	2.77%	1.58%
Biomass			0.05%	0.55%		1.67%
Coal			31.18%			
Geothermal			0.02%			
Natural Gas	0.01%		17.24%	0.01%	0.01%	
Petroleum			0.06%			
Solar			0.67%	0.23%		0.01%
Wind			8.41%	7.05%		
Other Biogenic				0.07%		
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Electricity sources that are non-zero emissions are highlighted in gray. Note that except for Puget Sound Energy (PSE), the electricity sources that are expected to incur emissions are minor and consist of less than 5% of the total for each utility.

For this analysis, it was assumed that PSE's source specific emissions factors can be applied to the non-zero emissions sources (noted as unspecified) of the other utilities because the percentage of electricity sources that are expected to incur emissions are negligible. In reality, emission factors for electricity sources are specific to each utility. PSE's emissions factors are shown below in Table 8.

[8] https://www.commerce.wa.gov/wp-content/uploads/2019/12/2018-Preliminary-Disclosure-Data-03122019.pdf

Table 8: Puget Sound Energy GHG Inventory 2018 Table A-3, Emission Factors for Purchased Electricity

Fuel Type	Heat Rate [8]	Emission Rate			Emission Rate (6)		
		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
	(Btu/kWh)	(lb/MMBtu)	(lb/MMBtu)	(lb/MMBtu)	(lb/kWh)	(lb/kWh)	(lb/kWh)
Coal (1)	**8,800**				**2.095** [5]	**1.241E-05** [7]	**2.869E-05** [7]
Natural Gas (2),(5)					**1.321** [5]	**3.626E-05** [7]	**1.325E-05** [7]
Hydro	**0**	**0**	**0**	**0**	**0** [7]	**0** [7]	**0** [7]
Wind	**0**	**0**	**0**	**0**	**0** [7]	**0** [7]	**0** [7]
Nuclear	**0**	**0**	**0**	**0**	**0** [7]	**0** [7]	**0** [7]
Biomass (3)	**13,500**	**195** [4]	**0.021** [4]	**0.013** [4]	**2.633** [7]	**2.835E-04** [7]	**1.755E-04** [7]
Petroleum (4)	**9,960**	**161.27** [1]	**0.00163** [2]	**0.0014** [2]	**1.969** [5]	**1.623E-05** [2]	**1.394E-05** [2]
Other					**0.976** [6]	**1.110E-05** [2]	**1.920E-05** [2]

Data Source:
[1] Voluntary Reporting of Greenhouse Gases Program – Fuel and Energy Source Codes and Emission Coefficients (DOE/EIA 2011).
[2] Updated State-level Greenhouse Gas Emission Coefficients for Electricity Generation 1998-2000, Table 1 & Table 3 (DOE/EIA, April 2002).
[3] AP-42 Ch 3, Table 3.1-2a (EPA April 2000).
[4] AP-42 Ch 1, Table 1.6-3 (EPA September 2003).
[5] Carbon Dioxide Emissions from the Generation of Electric Power in the United States, Table 4 (DOE/EPA July 2000).
[6] Provided by WUTC on 5.7.2019 (Andrew Rector, WUTC staff). Average of past 5 years of Northwest Power Pool Net System Mix Emissions Rates
[7] Calculated values.
[8] Assumptions to the Annual Energy Outlook 2017, Table 8.2 (DOE/EIA January 2018); https://www.eia.gov/outlooks/aeo/assumptions/pdf/0554(2017)

PSE will be the most significant utility provider to WSF and serves nine out of twenty terminals. PSE's normal fuel blend had significantly less hydroelectric power compared to the remaining utilities, and approximately a third of the power is from coal. However, WSDOT has signed an agreement to participate in PSE's Green Direct Program in 2018, which allows some of WSDOT's accounts to be carbon footprint free. It is our recommendation that WSF continue pursuing the Green Direct Program, especially at those terminals that will be charging hybrid ferries. This analysis assumes that PSE powered terminals that charge ferries will be a part of the Green Direct Program and are consequently emissions free. The additional fees associated with the Green Direct Program are incorporated into the financial model in Task 8, Capital and Operating Financial Model.

The assumed overall emission factors (EF) for each utility in terms of CO_2e and N_2O in kg/kWh are provided below. Note that using the same method as described above, N_2O is represented both as a standalone emission factor and as a portion of CO_2e.

Table 9: Overall Emission Factor for Each Utility

Emission Factor	OPALCO	Seattle City Light	Puget Sound Energy*	Snohomish PUD	Jefferson County PUD	Tacoma Power
CO_2e (kg/kWh)	0.01627368	0.01122476	0	0.01911531	0.01239847	0.02743254
N_2O (kg/kWh)	0.00000032	0.00000022	0	0.00000068	0.00000024	0.00000147

*Zero Emissions as result of Green Direct Program

2.2 Emissions Calculations

To determine the CO_2e emitted from burning diesel fuel, the weight in MT of each individual GHG was calculated by first multiplying fuel consumption by the corresponding emission factor and a unit conversion factor. See Equation 1.

Equation 1: $GHG\ (MT) = FC\ (gal) * EF\ \left(\frac{g}{gal}\right) * \frac{1}{1{,}000{,}000}\ \left(\frac{MT}{g}\right)$

The resulting weight in MT for each GHG was then multiplied by its corresponding global warming potential, see Equation 2. This yields the equivalent weight in MT of CO_2 that would yield the same warming effect. Summing the results of Equation 2 for all GHGs and the MT of CO_2 generated directly yields MT in CO_2e.

Equation 2: $CO_2e\ per\ GHG\ (MT) = GHG * GWP$

To determine NO_x and PM emitted from burning diesel fuel, the weight in MT of each toxic pollutant was calculated by multiplying fuel consumption by the corresponding emission factor.

To determine CO_2e and N_2O emitted from upstream utility power sources, the annual energy consumption of the vessel was multiplied by the average emission factor of the utilities specific to each route.

Section 3:

Results

The Green House Gas and Toxic Pollutant emissions for the scenarios with and without shore charging are presented below in Figure 4 and Figure 5. Results are presented as estimated future annual fleet emissions relative to 2005 annual fleet emissions. This means that the total, cumulative reduction in emissions from the fleet will continue to improve over time.

For the scenario with shore charging, this analysis found that greenhouse gas emissions (CO_2e) would decrease by 53% by 2030 and 76% by 2040. This meets and exceeds the requirements of RCW 70A.45.050 of 45% emissions reduction by 2030 and 70% by 2040. Toxic pollutant emissions will decrease by 59% by 2040 with shore charging. Note that emissions reductions of 70% may be attained as soon as 2035 in this plan.

The scenario without shore charging can provide modest greenhouse gas emissions (CO_2e) reduction of approximately 20% by 2040. This is not compliant with RCW 70A.45.050.

Note that RCW 70A.45.050 has emission reduction goals beyond the time horizon of this SEP of 95% by 2050. While these emission estimates show that the SEP is providing an appropriate foundation to meet these goals, WSF will need to continue to seek emission reduction opportunities to meet the ambition reduction goals of 2050. Electrification of the San Juan Islands will be necessary to meet this goal, the San Juan Islands dedicated study recommended by Task 4 should include feasibility of meeting this 95% emissions reduction goals. An additional consideration for meeting the 95% emissions reduction goal will be the potential electrification of the diesel-mechanical Olympic vessels that would occur beyond this SEP's planning horizon.

Detailed tabulations of the emissions are compiled in the appendices. For the scenario with shore charging, note that the contribution to the overall emissions from upstream utility sources are incredibly minor and account for only 1.2% of the overall emissions.

The societal benefits of emissions reductions are quantified to capture the social cost of carbon emissions that are avoided in Task 8.

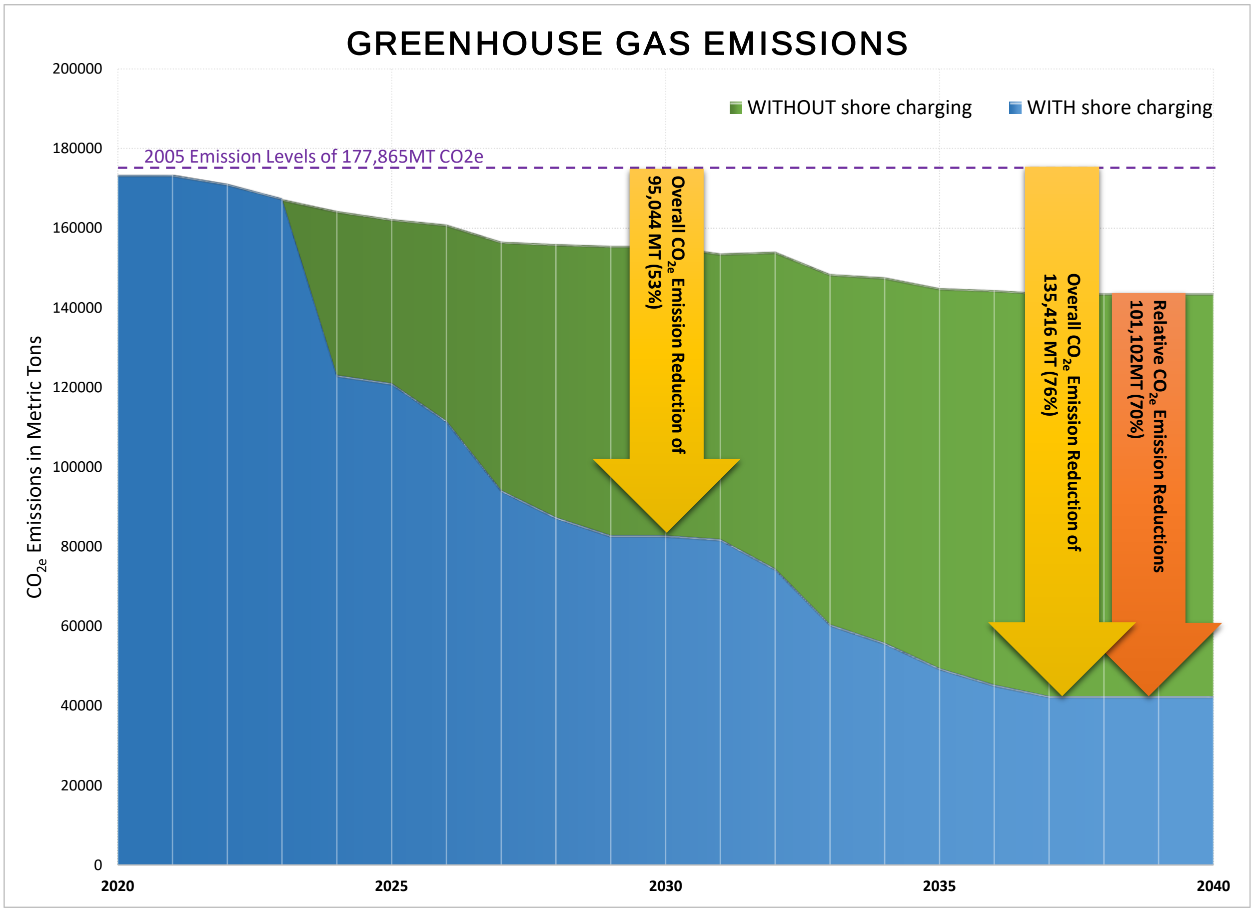


Figure 4: Green House Gas Emissions for Scenarios with and without Shore Charging

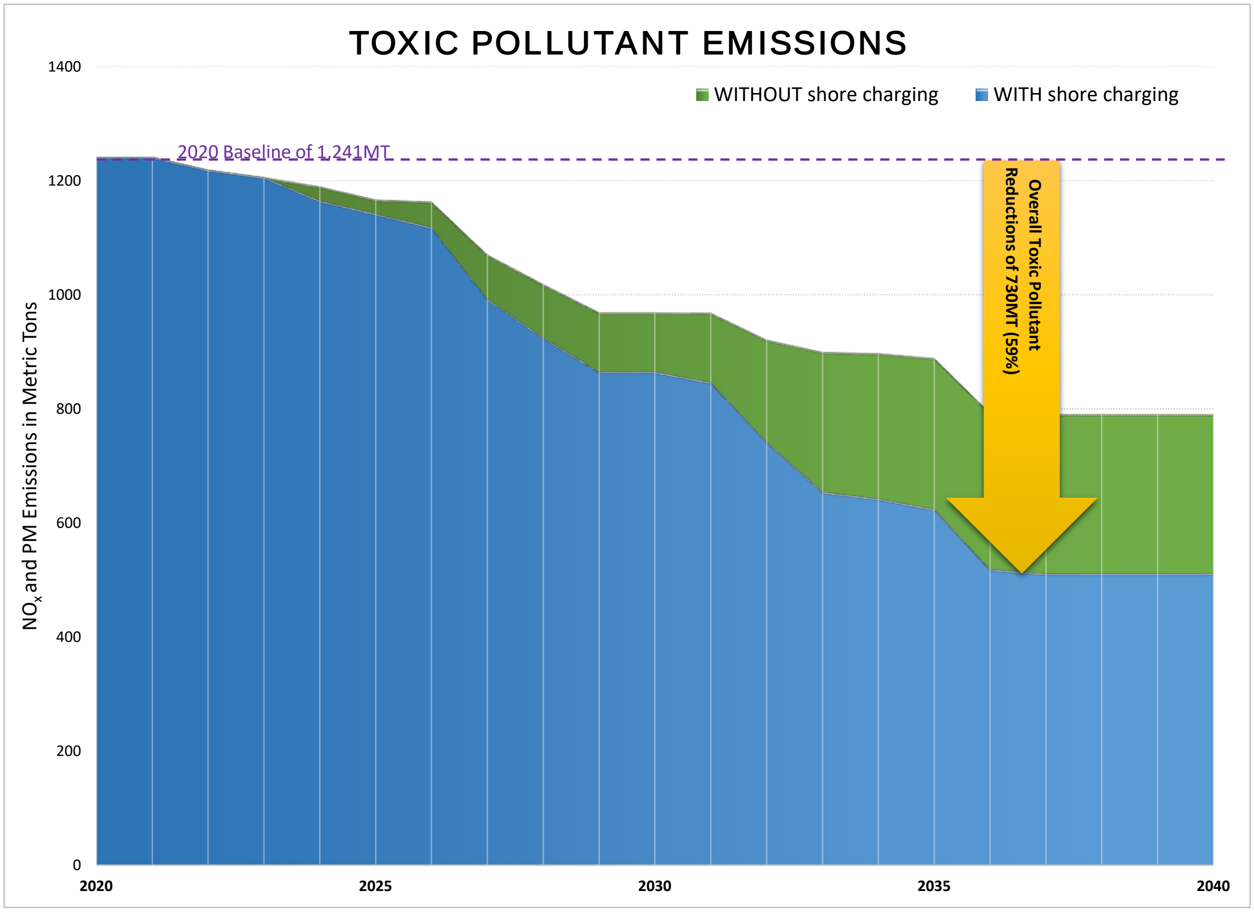


Figure 5: Toxic Pollutant Emissions for Scenarios with and without Shore Charging

Appendix A
Emissions Summary WITH Shore Charging

Fleet-wide CO2e Emissions WITH Shore Charging (MT)

VESSEL	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	TOTAL
Ferry-SPOKANE	10540	10540	10540	10540	10540	10540	10540	10540	10540	10540	10540	10540	10540	0	0	0	0	0	0	0	0	137014
Ferry-WALLA WALLA	11487	11487	11487	11487	11487	11487	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	68921
Ferry-TACOMA	15085	15085	15085	12941	1707	1707	1707	1707	1707	1707	1707	1707	1707	1707	1707	1707	1707	1707	1707	1707	1707	87219
Ferry-WENATCHEE	15880	15880	13617	13617	1791	1791	1791	1791	1791	1791	1791	1791	1791	1791	1791	1791	1791	1791	1791	1791	1791	89446
Ferry-PUYALLUP	14162	14162	14162	14162	3182	3182	3182	3182	3182	3182	3182	0	0	0	0	0	0	0	0	0	0	78925
Ferry-KALEETAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferry-YAKIMA	9333	9333	9333	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28000
Ferry-ELWHA	10914	10914	10914	10914	10914	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54572
Ferry-ISSAQUAH	6111	6111	6111	6111	6111	6111	6111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42775
Ferry-KITTITAS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferry-KITSAP	7519	7519	7519	7519	7519	7519	7519	7519	0	0	0	0	0	0	0	0	0	0	0	0	0	60151
Ferry-CATHLAMET	5276	5276	5276	5276	5276	5276	5276	5276	5276	0	0	4582	0	0	0	0	0	0	0	0	0	52068
Ferry-CHELAN	7047	7047	7047	7047	7047	7047	7047	7047	7047	7047	7047	7047	7047	7047	7047	7047	0	0	0	0	0	112746
Ferry-SEALTH	0	0	0	6334	6334	6334	6334	6334	6334	6334	6334	6334	6334	6334	6334	6334	6334	0	0	0	0	88674
Ferry-TILLIKUM	4761	4761	4761	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14284
Ferry-TOKITAE	6515	6515	6515	7473	7473	8911	8911	8911	8911	8911	8911	8911	8911	8911	8911	8911	8911	8911	8911	8911	8911	177061
Ferry-SAMISH	9260	9260	9260	9260	9260	9260	9260	9260	9260	9260	9260	9260	9260	9260	9260	0	0	0	0	0	0	138901
Ferry-CHIMACUM	13834	13834	13834	13834	13834	13834	13834	0	0	0	0	0	0	0	0	0	0	0	0	0	0	96837
Ferry-SUQUAMISH	5742	5742	5742	5742	0	7473	7473	7473	7473	7473	7473	7473	7473	7473	0	0	0	0	0	0	0	90227
Ferry-CHETZEMOKA	2850	2850	2850	2850	2850	2850	2850	2850	2850	2850	2850	160	160	160	160	160	160	160	160	160	160	32944
Ferry-SALISH	3398	3398	3398	3398	3398	3398	3398	3398	3398	3398	3398	3398	222	222	222	222	222	222	222	222	222	42780
Ferry-KENNEWICK	4079	4079	4079	4079	4079	4079	4079	4079	4079	4079	4079	4079	4079	261	261	261	261	261	261	261	261	55111
OLY1	0	0	0	5324	343	343	343	343	343	343	343	343	343	343	343	343	343	343	343	343	343	11164
OLY2	0	0	0	0	343	343	343	343	343	343	343	343	343	343	343	343	343	343	343	343	343	5839
OLY3	0	0	0	0	0	0	2064	2064	2064	2064	2064	2064	2064	2064	2064	2064	2064	2064	2064	2064	2064	30965
OLY4	0	0	0	0	0	0	0	2064	2064	2064	2064	2064	2064	2064	2064	2064	2064	2064	2064	2064	2064	28901
OLY5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ISS1	0	0	0	0	0	0	0	398	398	398	398	398	398	398	398	398	398	398	398	398	398	5568
ISS2	0	0	0	0	0	0	0	0	733	733	733	733	733	733	733	733	733	733	733	733	733	9529
ISS3	0	0	0	0	0	0	0	0	0	713	713	713	713	713	713	713	713	713	713	713	713	8553
ISS4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NEW1	0	0	0	0	0	0	0	0	0	0	0	352	352	352	352	352	352	352	352	352	352	3518
NEW2	0	0	0	0	0	0	0	0	0	0	0	0	352	352	352	352	352	352	352	352	352	3166
NEW3	0	0	0	0	0	0	0	0	0	0	0	0	0	352	352	352	352	352	352	352	352	2815
NEW4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2874	2874	2874	2874	2874	2874	2874	20115
NEW5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2874	2874	2874	2874	2874	2874	17242
NEW6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2874	2874	2874	2874	2874	14368
NEW7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3471	3471	3471	3471	13886
Contingency	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	201393

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
YEARLY TOTALS	173383	173383	171120	167498	123079	121076	111653	94171	87385	82821	82821	81883	74477	60470	55871	49484	45311	42449	42449	42449	42449
FUEL EMISSIONS	173383	173383	171002	167262	122844	120840	111284	93631	86808	82207	82207	81269	73831	59793	55017	48454	44105	41106	41106	41106	41106
UTILITY EMISSIONS	0	0	118	236	236	236	369	540	577	614	614	614	646	678	854	1030	1206	1343	1343	1343	1343

Color Key: Vessel Does Not Exist | Relief Vessel - Zero Emissions

FLEET-WIDE TOTAL CO2e	1925680

Fleet-wide NOX Emissions WITH Shore Charging (MT)

VESSEL	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	TOTAL
Ferry-SPOKANE	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	327.56
Ferry-WALLA WALLA	27.46	27.46	27.46	27.46	27.46	27.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	164.77
Ferry-TACOMA	133.57	133.57	133.57	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	2439.56
Ferry-WENATCHEE	140.62	140.62	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	2546.89
Ferry-PUYALLUP	79.63	79.63	79.63	79.63	64.90	64.90	64.90	64.90	64.90	64.90	64.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	772.79
Ferry-KALEETAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ferry-YAKIMA	22.31	22.31	22.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	66.94
Ferry-ELWHA	61.37	61.37	61.37	61.37	61.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	306.84
Ferry-ISSAQUAH	93.61	93.61	93.61	93.61	93.61	93.61	93.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	655.25
Ferry-KITTITAS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ferry-KITSAP	66.58	66.58	66.58	66.58	66.58	66.58	66.58	66.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	532.62
Ferry-CATHLAMET	59.87	59.87	59.87	59.87	59.87	59.87	59.87	59.87	59.87	0.00	0.00	51.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	590.79
Ferry-CHELAN	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	0.00	0.00	0.00	0.00	0.00	1727.12
Ferry-SEALTH	0.00	0.00	0.00	15.14	15.14	15.14	15.14	15.14	15.14	15.14	15.14	15.14	15.14	15.14	15.14	15.14	15.14	0.00	0.00	0.00	0.00	211.99
Ferry-TILLIKUM	11.38	11.38	11.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	34.15
Ferry-TOKITAE	99.80	99.80	99.80	114.48	114.48	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	2712.34
Ferry-SAMISH	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	0.00	0.00	0.00	0.00	0.00	0.00	332.07
Ferry-CHIMACUM	33.07	33.07	33.07	33.07	33.07	33.07	33.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	231.51
Ferry-SUQUAMISH	13.73	13.73	13.73	13.73	0.00	17.87	17.87	17.87	17.87	17.87	17.87	17.87	17.87	17.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	215.70
Ferry-CHETZEMOKA	6.81	6.81	6.81	6.81	6.81	6.81	6.81	6.81	6.81	6.81	6.81	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	77.87
Ferry-SALISH	52.06	52.06	52.06	52.06	52.06	52.06	52.06	52.06	52.06	52.06	52.06	52.06	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	644.82
Ferry-KENNEWICK	62.48	62.48	62.48	62.48	62.48	62.48	62.48	62.48	62.48	62.48	62.48	62.48	62.48	2.69	2.69	2.69	2.69	2.69	2.69	2.69	2.69	833.79
OLY1	0.00	0.00	0.00	12.70	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	23.41
OLY2	0.00	0.00	0.00	0.00	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	10.71
OLY3	0.00	0.00	0.00	0.00	0.00	0.00	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	64.49
OLY4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	60.19
OLY5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ISS1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	9.42
ISS2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	18.70
ISS3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	17.57
ISS4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NEW1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	6.45
NEW2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	5.81
NEW3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	5.16
NEW4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.29	6.29	6.29	6.29	6.29	6.29	6.29	44.04
NEW5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.29	6.29	6.29	6.29	6.29	6.29	37.75
NEW6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.29	6.29	6.29	6.29	6.29	31.45
NEW7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.88	7.88	7.88	7.88	31.51
Contingency	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	1583.03

YEARLY TOTALS	1195	1195	1174	1162	1122	1101	1078	956	891	832	832	814	712	628	616	601	499	492	492	492	492
FUEL EMISSIONS	1195	1195	1174	1162	1122	1101	1078	956	891	832	832	814	712	628	616	601	499	492	492	492	492
UTILITY EMISSIONS	0.000	0.000	0.002	0.005	0.005	0.005	0.007	0.011	0.011	0.012	0.012	0.012	0.013	0.013	0.017	0.020	0.024	0.026	0.026	0.026	0.026

Color Key: Vessel Does Not Exist | Relief Vessel - Zero Emissions

FLEET-WIDE TOTAL NOX 17375

Fleet-wide PM Emissions WITH Shore Charging (MT)

VESSEL	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	TOTAL
Ferry-SPOKANE	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.75
Ferry-WALLA WALLA	0.63	0.63	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.80
Ferry-TACOMA	6.52	6.52	6.52	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	119.06
Ferry-WENATCHEE	6.86	6.86	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	124.30
Ferry-PUYALLUP	1.63	1.63	1.63	1.63	1.33	1.33	1.33	1.33	1.33	1.33	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.80
Ferry-KALEETAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ferry-YAKIMA	1.63	1.63	1.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.89
Ferry-ELWHA	2.56	2.56	2.56	2.56	2.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.80
Ferry-ISSAQUAH	3.48	3.48	3.48	3.48	3.48	3.48	3.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.39
Ferry-KITTITAS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ferry-KITSAP	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.80
Ferry-CATHLAMET	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	0.00	0.00	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.32
Ferry-CHELAN	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	0.00	0.00	0.00	0.00	0.00	64.27
Ferry-SEALTH	0.00	0.00	0.00	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.00	0.00	0.00	0.00	4.89
Ferry-TILLIKUM	0.26	0.26	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.79
Ferry-TOKITAE	2.82	2.82	2.82	3.23	3.23	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	76.52
Ferry-SAMISH	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	0.00	0.00	0.00	0.00	0.00	0.00	40.87
Ferry-CHIMACUM	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.34
Ferry-SUQUAMISH	0.32	0.32	0.32	0.32	0.00	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.98
Ferry-CHETZEMOKA	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	1.80
Ferry-SALISH	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	24.00
Ferry-KENNEWICK	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	31.03
OLY1	0.00	0.00	0.00	0.29	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.54
OLY2	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.25
OLY3	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.49
OLY4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	1.39
OLY5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ISS1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.22
ISS2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.43
ISS3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.41
ISS4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NEW1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.15
NEW2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.13
NEW3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.12
NEW4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.15	0.15	0.15	0.15	0.15	0.15	1.02
NEW5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.15	0.15	0.15	0.15	0.15	0.87
NEW6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.15	0.15	0.15	0.15	0.73
NEW7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.18	0.18	0.18	0.73
Contingency	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	56.66

YEARLY TOTALS	46.45	46.45	45.41	43.58	42.70	41.17	40.64	36.50	34.19	32.67	32.67	32.55	29.37	25.95	25.68	23.10	19.23	19.06	19.06	19.06	19.06
FUEL EMISSIONS	46.45	46.45	45.41	43.58	42.70	41.17	40.64	36.50	34.19	32.67	32.67	32.55	29.37	25.95	25.68	23.10	19.23	19.06	19.06	19.06	19.06
UTILITY EMISSIONS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Color Key: Vessel Does Not Exist | Relief Vessel - Zero Emissions

FLEET-WIDE TOTAL PM	675

Appendix B
Emissions Summary WITHOUT Shore Charging

Fleet-wide CO2e Emissions WITHOUT Shore Charging (MT)

VESSEL	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	TOTAL
Ferry-SPOKANE	10540	10540	10540	10540	10540	10540	10540	10540	10540	10540	10540	10540	10540	0	0	0	0	0	0	0	0	137014
Ferry-WALLA WALLA	11487	11487	11487	11487	11487	11487	R	R	R	R	R	R	R	R	0	0	0	0	0	0	0	68921
Ferry-TACOMA	15085	15085	15085	12823	12823	12823	12823	12823	12823	12823	12823	12823	12823	12823	12823	12823	12823	12823	12823	12823	12823	276069
Ferry-WENATCHEE	15880	15880	13500	13500	13500	13500	13500	13500	13500	13500	13500	13500	13500	13500	13500	13500	13500	13500	13500	13500	13500	288253
Ferry-PUYALLUP	14162	14162	14162	14162	11578	11578	11578	11578	11578	11578	11578	R	R	R	R	R	R	R	R	R	R	137692
Ferry-KALEETAN	R	R	R	R	R	R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferry-YAKIMA	9333	9333	9333	R	R	R	R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28000
Ferry-ELWHA	10914	10914	10914	10914	10914	R	R	R	0	0	0	0	0	0	0	0	0	0	0	0	0	54572
Ferry-ISSAQUAH	6111	6111	6111	6111	6111	6111	6111	R	R	0	0	0	0	0	0	0	0	0	0	0	0	42775
Ferry-KITTITAS	R	R	R	R	R	R	R	R	R	R	R	R	0	0	0	0	0	0	0	0	0	0
Ferry-KITSAP	7519	7519	7519	7519	7519	7519	7519	7519	R	R	0	0	0	0	0	0	0	0	0	0	0	60151
Ferry-CATHLAMET	5276	5276	5276	5276	5276	5276	5276	5276	5276	R	R	4582	R	R	R	0	0	0	0	0	0	52068
Ferry-CHELAN	7047	7047	7047	7047	7047	7047	7047	7047	7047	7047	7047	7047	7047	7047	7047	7047	0	0	0	0	0	112746
Ferry-SEALTH	0	0	0	6334	6334	6334	6334	6334	6334	6334	6334	6334	6334	6334	6334	6334	6334	0	0	0	0	88674
Ferry-TILLIKUM	4761	4761	4761	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14284
Ferry-TOKITAE	6515	6515	6515	7473	7473	8911	8911	8911	8911	8911	8911	8911	8911	8911	8911	8911	8911	8911	8911	8911	8911	177061
Ferry-SAMISH	9260	9260	9260	9260	9260	9260	9260	9260	9260	9260	9260	9260	9260	9260	9260	R	R	R	R	R	R	138901
Ferry-CHIMACUM	13834	13834	13834	13834	13834	13834	13834	R	R	R	R	R	R	R	R	R	R	R	R	R	R	96837
Ferry-SUQUAMISH	5742	5742	5742	5742	R	7473	7473	7473	7473	7473	7473	7473	7473	7473	R	R	R	R	R	R	R	90227
Ferry-CHETZEMOKA	2850	2850	2850	2850	2850	2850	2850	2850	2850	2850	2850	2476	2476	2476	2476	2476	2476	2476	2476	2476	2476	56106
Ferry-SALISH	3398	3398	3398	3398	3398	3398	3398	3398	3398	3398	3398	3398	2952	2952	2952	2952	2952	2952	2952	2952	2952	67350
Ferry-KENNEWICK	4079	4079	4079	4079	4079	4079	4079	4079	4079	4079	4079	4079	4079	3544	3544	3544	3544	3544	3544	3544	3544	81377
OLY1	0	0	0	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	95840
OLY2	0	0	0	0	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	5324	90516
OLY3	0	0	0	0	0	0	10075	10075	10075	10075	10075	10075	10075	10075	10075	10075	10075	10075	10075	10075	10075	151118
OLY4	0	0	0	0	0	0	0	10075	10075	10075	10075	10075	10075	10075	10075	10075	10075	10075	10075	10075	10075	141043
OLY5	0	0	0	0	0	0	0	0	R	R	R	R	R	R	R	R	R	R	R	R	R	0
ISS1	0	0	0	0	0	0	0	5604	5604	5604	5604	5604	5604	5604	5604	5604	5604	5604	5604	5604	5604	78461
ISS2	0	0	0	0	0	0	0	0	6896	6896	6896	6896	6896	6896	6896	6896	6896	6896	6896	6896	6896	89647
ISS3	0	0	0	0	0	0	0	0	0	4839	4839	4839	4839	4839	4839	4839	4839	4839	4839	4839	4839	58069
ISS4	0	0	0	0	0	0	0	0	0	0	R	R	R	R	R	R	R	R	R	R	R	0
NEW1	0	0	0	0	0	0	0	0	0	0	0	5466	5466	5466	5466	5466	5454	5454	5454	5454	5454	54597
NEW2	0	0	0	0	0	0	0	0	0	0	0	0	5466	5466	5466	5466	5454	5454	5454	5454	5454	49131
NEW3	0	0	0	0	0	0	0	0	0	0	0	0	0	5466	5466	5466	5454	5454	5454	5454	5454	43665
NEW4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6600	6600	6585	6585	6585	6585	6585	46125
NEW5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6600	6585	6585	6585	6585	6585	39525
NEW6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6585	6585	6585	6585	6585	32925
NEW7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5503	5503	5503	5503	22012
Contingency	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	9590	201393
YEARLY TOTALS	173383	173383	171002	167262	164261	162257	160845	156579	155956	155519	155519	153616	154053	148444	147571	144911	144382	143551	143551	143551	143551	

Color Key: Vessel Does Not Exist | Relief Vessel - Zero Emissions

FLEET-WIDE TOTAL CO2e 3263148

Fleet-wide NOX Emissions WITHOUT Shore Charging (MT)

VESSEL	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	TOTAL
Ferry-SPOKANE	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	327.56
Ferry-WALLA WALLA	27.46	27.46	27.46	27.46	27.46	27.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	164.77
Ferry-TACOMA	133.57	133.57	133.57	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	113.27	2439.52
Ferry-WENATCHEE	140.62	140.62	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	119.24	2546.84
Ferry-PUYALLUP	79.63	79.63	79.63	79.63	64.90	64.90	64.90	64.90	64.90	64.90	64.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	772.79
Ferry-KALEETAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ferry-YAKIMA	22.31	22.31	22.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	66.94
Ferry-ELWHA	61.37	61.37	61.37	61.37	61.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	306.84
Ferry-ISSAQUAH	93.61	93.61	93.61	93.61	93.61	93.61	93.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	655.25
Ferry-KITTITAS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ferry-KITSAP	66.58	66.58	66.58	66.58	66.58	66.58	66.58	66.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	532.62
Ferry-CATHLAMET	59.87	59.87	59.87	59.87	59.87	59.87	59.87	59.87	59.87	0.00	0.00	51.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	590.79
Ferry-CHELAN	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	107.95	0.00	0.00	0.00	0.00	0.00	1727.12
Ferry-SEALTH	0.00	0.00	0.00	15.14	15.14	15.14	15.14	15.14	15.14	15.14	15.14	15.14	15.14	15.14	15.14	15.14	15.14	0.00	0.00	0.00	0.00	211.99
Ferry-TILLIKUM	11.38	11.38	11.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	34.15
Ferry-TOKITAE	99.80	99.80	99.80	114.48	114.48	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50	2712.34
Ferry-SAMISH	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	22.14	0.00	0.00	0.00	0.00	0.00	0.00	332.07
Ferry-CHIMACUM	33.07	33.07	33.07	33.07	33.07	33.07	33.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	231.51
Ferry-SUQUAMISH	13.73	13.73	13.73	13.73	0.00	17.87	17.87	17.87	17.87	17.87	17.87	17.87	17.87	17.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	215.70
Ferry-CHETZEMOKA	6.81	6.81	6.81	6.81	6.81	6.81	6.81	6.81	6.81	6.81	6.81	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	134.01
Ferry-SALISH	52.06	52.06	52.06	52.06	52.06	52.06	52.06	52.06	52.06	52.06	52.06	52.06	45.13	45.13	45.13	45.13	45.13	45.13	45.13	45.13	45.13	1030.87
Ferry-KENNEWICK	62.48	62.48	62.48	62.48	62.48	62.48	62.48	62.48	62.48	62.48	62.48	62.48	62.48	54.17	54.17	54.17	54.17	54.17	54.17	54.17	54.17	1245.68
OLY1	0.00	0.00	0.00	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	228.64
OLY2	0.00	0.00	0.00	0.00	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	215.94
OLY3	0.00	0.00	0.00	0.00	0.00	0.00	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	360.52
OLY4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	24.03	336.48
OLY5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ISS1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.38	13.38	13.38	13.38	13.38	13.38	13.38	13.38	13.38	13.38	13.38	13.38	13.38	13.38	187.34
ISS2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.47	16.47	16.47	16.47	16.47	16.47	16.47	16.47	16.47	16.47	16.47	16.47	16.47	214.05
ISS3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.55	11.55	11.55	11.55	11.55	11.55	11.55	11.55	11.55	11.55	11.55	11.55	138.65
ISS4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NEW1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.04	13.04	13.04	13.04	13.04	13.01	13.01	13.01	13.01	13.01	130.25
NEW2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.04	13.04	13.04	13.04	13.01	13.01	13.01	13.01	13.01	117.21
NEW3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.04	13.04	13.04	13.01	13.01	13.01	13.01	13.01	104.17
NEW4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.75	15.75	15.71	15.71	15.71	15.71	15.71	110.04
NEW5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.75	15.71	15.71	15.71	15.71	15.71	94.29
NEW6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.71	15.71	15.71	15.71	15.71	78.55
NEW7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.13	13.13	13.13	13.13	52.51
Contingency	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	75.38	1583.03
YEARLY TOTALS	1195	1195	1174	1162	1146	1125	1121	1032	982	934	934	933	887	867	865	858	766	764	764	764	764	

Color Key: Vessel Does Not Exist | Relief Vessel - Zero Emissions

FLEET-WIDE TOTAL NOX: 20231

Fleet-wide PM Emissions WITHOUT Shore Charging (MT)

VESSEL	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	TOTAL
Ferry-SPOKANE	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.75
Ferry-WALLA WALLA	0.63	0.63	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.80
Ferry-TACOMA	6.52	6.52	6.52	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53	119.06
Ferry-WENATCHEE	6.86	6.86	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	5.82	124.30
Ferry-PUYALLUP	1.63	1.63	1.63	1.63	1.33	1.33	1.33	1.33	1.33	1.33	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.80
Ferry-KALEETAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ferry-YAKIMA	1.63	1.63	1.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.89
Ferry-ELWHA	2.56	2.56	2.56	2.56	2.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.80
Ferry-ISSAQUAH	3.48	3.48	3.48	3.48	3.48	3.48	3.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.39
Ferry-KITTITAS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ferry-KITSAP	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.80
Ferry-CATHLAMET	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	0.00	0.00	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.32
Ferry-CHELAN	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	0.00	0.00	0.00	0.00	0.00	64.27
Ferry-SEALTH	0.00	0.00	0.00	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.00	0.00	0.00	0.00	4.89
Ferry-TILLIKUM	0.26	0.26	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.79
Ferry-TOKITAE	2.82	2.82	2.82	3.23	3.23	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	76.52
Ferry-SAMISH	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	0.00	0.00	0.00	0.00	0.00	0.00	40.87
Ferry-CHIMACUM	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.34
Ferry-SUQUAMISH	0.32	0.32	0.32	0.32	0.00	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.98
Ferry-CHETZEMOKA	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	3.09
Ferry-SALISH	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	38.36
Ferry-KENNEWICK	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	46.36
OLY1	0.00	0.00	0.00	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	5.28
OLY2	0.00	0.00	0.00	0.00	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	4.98
OLY3	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	8.32
OLY4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	7.76
OLY5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ISS1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	4.32
ISS2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	4.94
ISS3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	3.20
ISS4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NEW1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	3.01
NEW2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	2.70
NEW3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	2.40
NEW4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.36	0.36	0.36	0.36	0.36	0.36	2.54
NEW5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.36	0.36	0.36	0.36	0.36	2.18
NEW6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.36	0.36	0.36	0.36	1.81
NEW7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.30	1.21
Contingency	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	56.66
YEARLY TOTALS	46	46	45	44	43	42	42	38	36	35	35	35	34	33	33	30	27	27	27	27	27	

Color Key: Vessel Does Not Exist | Relief Vessel - Zero Emissions

FLEET-WIDE TOTAL PM	752