



Guemes Island Ferry Replacement Project

Agenda

- Background
- Terminology
- Assumptions
- Charging Technology
- Operational Performance
- Conclusion



Background

- SuperTruck 2
 - Mild-Hybrid Diesel Electric
 - \$40 million
- SuperTruck 3
 - Fleet Electrification
 - Fully Electric Fleet
 - Infrastructure Upgrades
 - \$68 million
- Hydrogen
 - Fuel Cell
 - Internal Combustion Engine



U.S. DEPARTMENT
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Terminology

- **Kilowatt (kW)**: a unit of power that measures the rate at which an electrical device uses or produces energy at any given moment.
- **Kilowatt Hours (kWh)**: a unit of measurement for energy that represents how much electricity is used over time.
- **Regeneration**: A system that converts the kinetic energy into electricity, feeding it back into the battery to extend range.
- **Combined Charging Standard (CCS)**: a global electric charging standard for transportation solutions. **Power up to 400 kW**
- **State of Charge (SOC)**: is a measure of how much energy is currently stored in a battery compared to its maximum usable capacity.

Assumptions

- Ferry Energy Requirements:

- Normal Operation (R/T): 140 kWh
- Bad Weather Operation(R/T): 190 kWh
- Battery Capacity: 1,000 kWh (1 MWh)
- Electric Operation: 75% Energy Contribution from Batteries

- Ferry Terminal Electrical Service:

- 480v
 - 400-amp
 - 3 – Phase
- } = 332.5 kW Capacity

- Charging/Dwell Times:

- Charging Assumptions:

- 360 kW charger
- Optimal Battery Performance Conditions (e.g. temperature, state of charge)
- Optimal Charger Performance (e.g. initialization)
- Subtracted 10% for buffer

Interval	Charge Time	Energy Added
30 minutes	10 minutes	54 kW
45 minutes	25 minutes	135 kW
60 minutes	40 minutes	216 kW
75 minutes (Dinner)	55 minutes	297 kW
105 minutes (Lunch)	85 minutes	459 kW

Charging Options

- 360 kW Max Rating
- Cost ~ \$100,000
- Flexible Site Setup

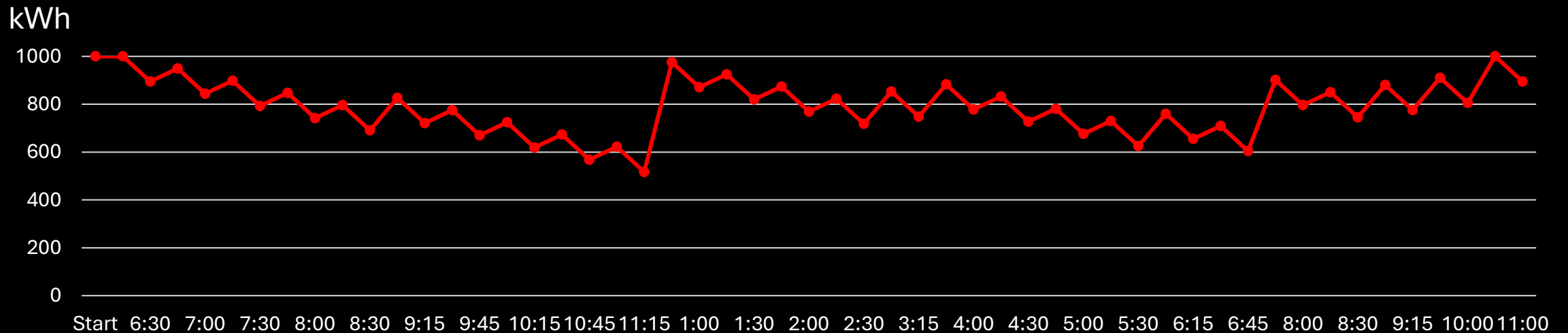
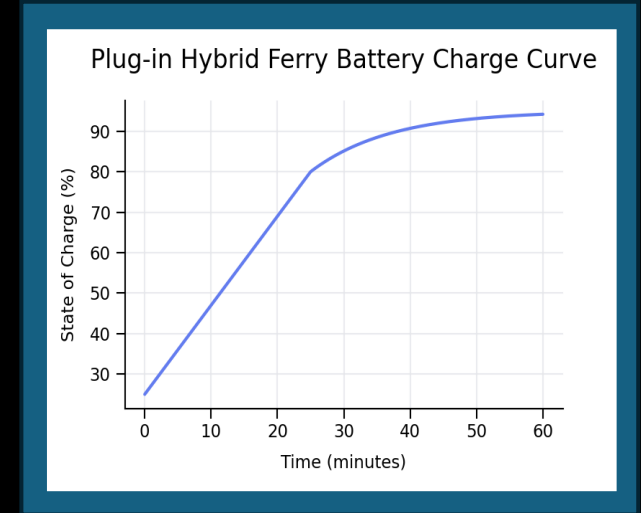


ABB HVC 360 + ChargeDock



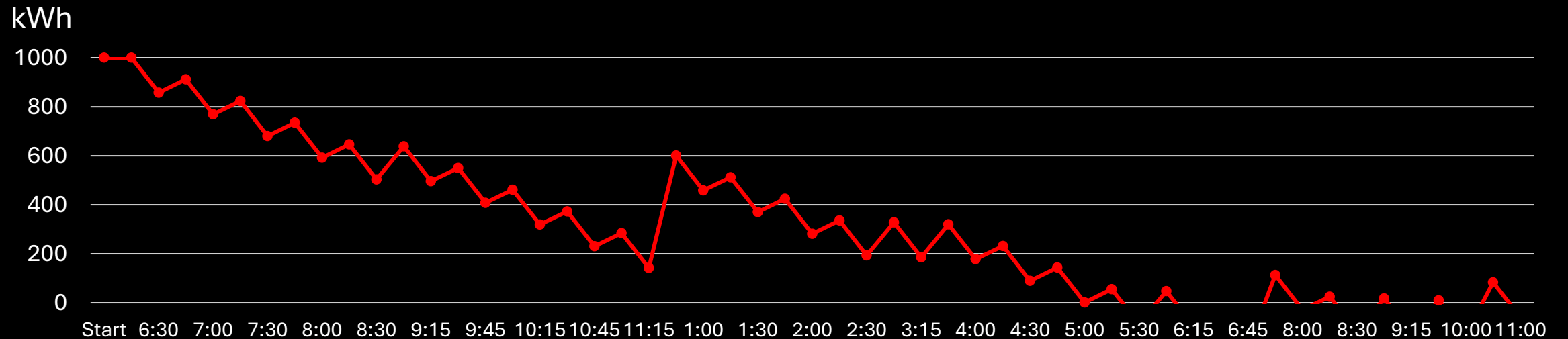
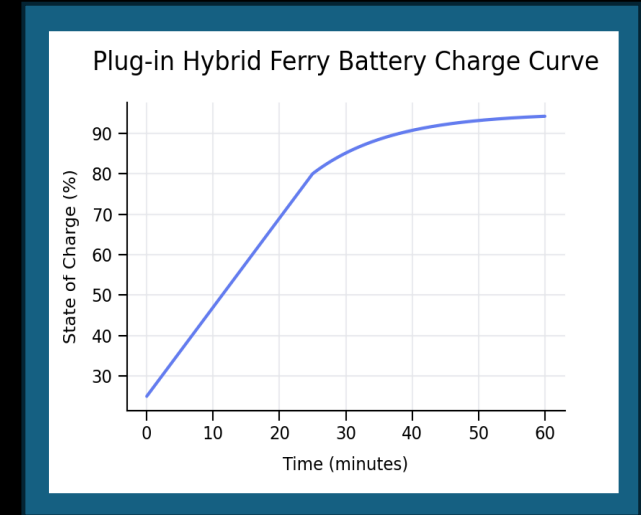
Operational Performance – Normal Run

Interval	Charge Time	Energy Added
30 minutes	10 minutes	54 kW
45 minutes	25 minutes	135 kW
60 minutes	40 minutes	216 kW
75 minutes (Dinner)	55 minutes	297 kW
105 minutes (Lunch)	85 minutes	459 kW



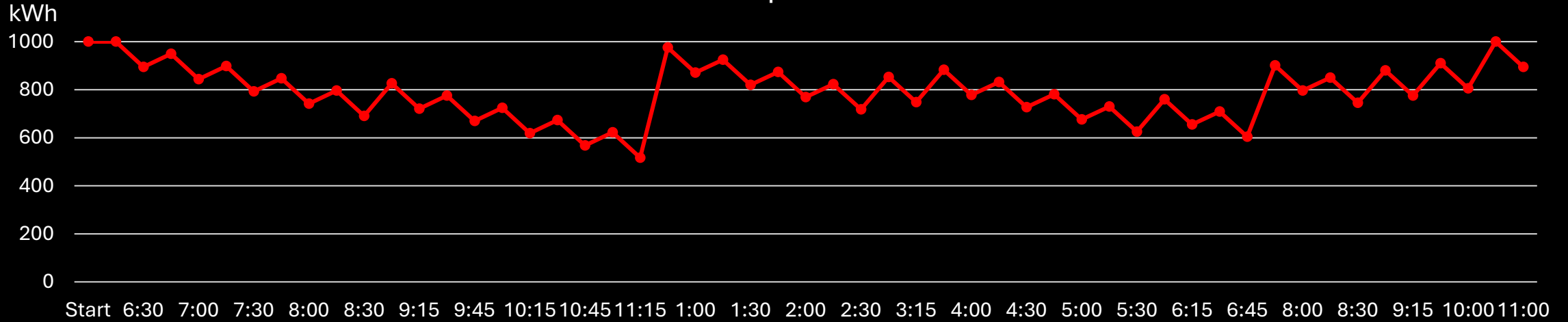
Operational Performance – Extreme Weather Run

Interval	Charge Time	Energy Added
30 minutes	10 minutes	54 kW
45 minutes	25 minutes	135 kW
60 minutes	40 minutes	216 kW
75 minutes (Dinner)	55 minutes	297 kW
105 minutes (Lunch)	85 minutes	459 kW

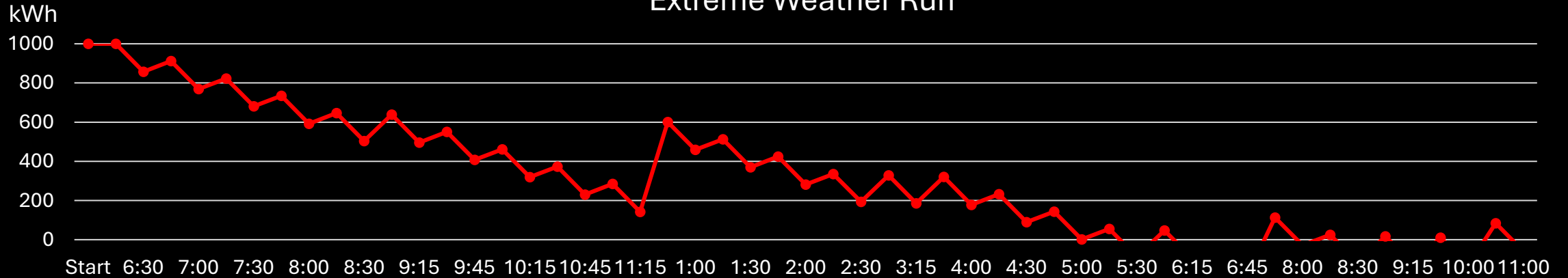


Operational Performance

Normal Operational Run

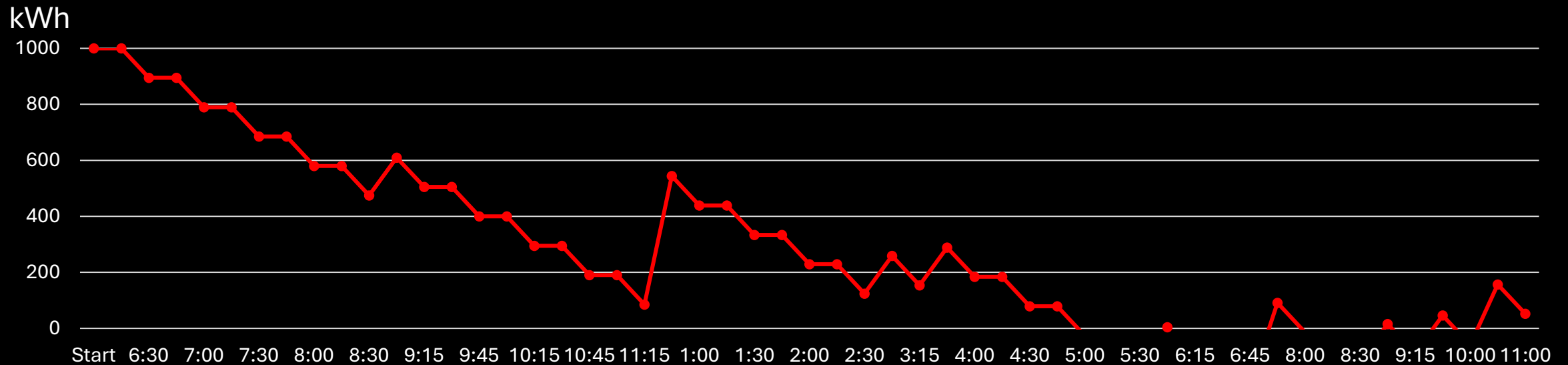
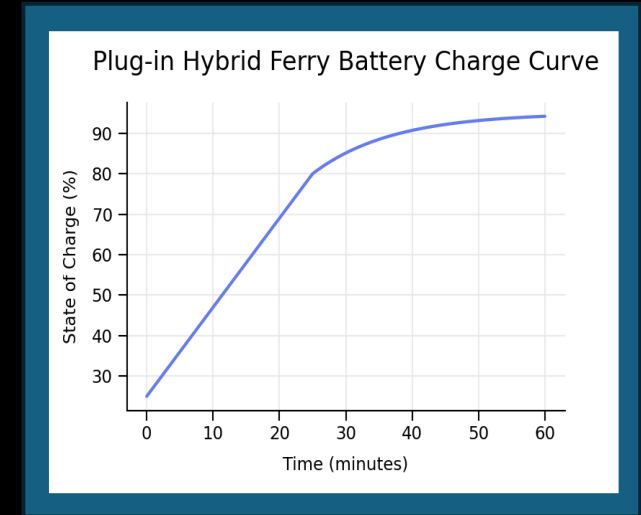


Extreme Weather Run



Operational Performance – Minimized Charging

Interval	Charge Time	Energy Added
30 minutes	10 minutes	54 kW
45 minutes	25 minutes	135 kW
60 minutes	40 minutes	216 kW
75 minutes (Dinner)	55 minutes	297 kW
105 minutes (Lunch)	85 minutes	459 kW



Realities of Building a Plug-In Hybrid Ferry for Guemes Island

- Long-Term Benefits

- Reduced Diesel Use, Emissions, and Noise
- Lower Exposure to Fuel Price Volatility Over Time
- Aligns with State Climate Goals and Grant Funding Priorities

- Upfront Challenges

- Higher Initial Vessel Cost Than a Conventional Diesel Ferry
- Requires New Shore-side Charging Infrastructure and Electrical Upgrades

- Operational Considerations

- More Complex Vessel Systems and Maintenance Requirements
- Additional Crew Training and Technical Expertise Needed
- Operational Savings Accrue Over Time, Not Immediately

- Risk Trade-off

- Trades Fuel and Environmental Risk For Capital And Technology Complexity Risk
- Hybrid Design Retains Operational Redundancy Compared To Fully Electric Options

Appendix

Plug-in Hybrid Ferry

Risks

- High Build Costs
- Increased Complexity
- Infrastructure Challenges
- Supplier Maturity

Opportunities

- Expanded Funding Options
- Reduced Operating Costs
- Environmental Benefits
- Technology is Advancing Quickly

3.5.5.4 Utility Connection

The connection to the utility is a critical aspect of providing adequate shore-power for the ferry battery banks at the Anacortes terminal. Discussions with Puget Sound Energy (PSE) have indicated peak power loading associated with charging the batteries is a major concern for their electrical infrastructure. Due to the vessel's possible operation during heavy winds and tidal currents, required energy per round trip varies greatly. Table 13 below summarizes the power and energy required for battery charging during average and peak conditions.

Table 13 Round trip power comparison

	Power		Total Shore Energy (kWh)	Vessel Battery Energy (kWh)
	No Shore-side Batteries (kW)	Shore-side Batteries (kW)		
All-Electric Average	1458	389	194	148
All-Electric Peak	3939	1051	525	352
Plug-in Hybrid Average	1393	372	186	142
Plug-in Hybrid Peak	2610	696	348	190

Installing shore-side batteries substantially reduces average and peak loading on the utility connection. PSE has stated based on initial modelling of their system, shore-side batteries will be required.

Peak power during each month of utility connection is also used by PSE to set the demand charge during that month. Reducing frequency and aggregate peak power will provide lower demand charges, reducing the cost per kWh.

3.5.4.4 Plug-in Hybrid

A plug-in hybrid propulsion system uses electrical power to supply all propulsion and ship service electrical loads while providing diesel generator sets for use during high energy demand operation. Typical operation is identical to the all-electric propulsion system.

A diesel generator provides additional power when energy loads become too high for the batteries, such as during maneuvering in heavy weather. The plug-in hybrid will reduce the load on the batteries and allows optimized sizing for charging apparatus and battery banks.

Benefits of Plug-in Hybrid:

In addition to the benefits of an all-electric plant, the series hybrid configuration also has the following benefits:

- *Capital Cost:* Generators can be used to reduce loads in bad weather conditions, limiting the necessary shore-power components size. This provides greater operational flexibility of the vessel.

Drawbacks of Plug-in Hybrid:

Due to the very low operating time of the diesel generators, most benefits of an all-electric system are still realized. Additional drawbacks include:

- *Complexity:* The vessel will incorporate both diesel generator sets and battery banks while requiring shore-power infrastructure. This configuration has the most components of any option.

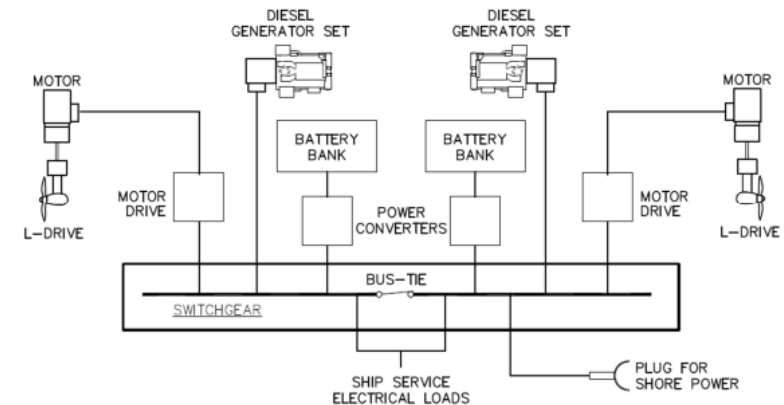


Figure 27. Plug-in hybrid configuration

The replacement vessel plug-in hybrid configuration includes two battery banks with a total 850kWh capacity and two 599kW generator sets. The vessel combines the auxiliary system requirements of all-electric and diesel-electric configurations, providing the most complex vessel systems arrangement. Section 3.5.5 discusses details required for shore-power infrastructure to accommodate this propulsion configuration.

3.6.1.3 Worst-Case Run

Due to the nature of the M/V *Guemes* operation, large variations in energy consumption can be seen when tidal currents and winds are combined to form specific wave conditions. As discussed in Section 3.2, the vessel must be capable of operating each 725 kW thruster at full power to account for maneuvering in heavy currents. Each propulsion configuration was provided with enough installed power to meet this requirement, even if some engines are not required to operate during typical runs.

For simplicity the worst-case run was taken as the 95 percentile winds, or approximately 20 mph, from Table 31 discussed in Section 4.3.3. This means the worst-case run will occur 5% of the time annually. In order to approximate the round-trip energy consumption; an approximate worse case run was developed for powering, as seen in Table 17.

Table 17 Worst case one-way trip delivered power

Operation	Time (min)	Delivered Power, Pd (kW)	Notes
Load / Unload	10.35	800	Current vessel maximum observed
Maneuver	0.85	834	1.5 multiplier on average power
Accelerate	0.78	1,196	1.5 multiplier on average power
Cruise	1.17	1,114	1.5 multiplier on average power
Decelerate	0.78	786	1.5 multiplier on average power
Maneuver	1.07	1,450	Max installed power

The worst-case run is a particular challenge for an all-electric vessel and plug-in hybrid vessel. All shore-power infrastructure and charging apparatus must be sized to accommodate the worst-case run as previously outlined. The plug-in hybrid propulsion system assumed an on-board generator could be run during the worst-case run, providing a maximum shore-power transfer requirement of 2.6 MW. The all-electric vessel worst-case run provides a maximum shore-power transfer requirement of 4.0 MW.

The power transfer required through the shore-side charging apparatus is crucial for design feasibility. As stated in Section 3.5.5.1, current charging technology pilot projects are rated at or below 2.0 MW. Scaling this technology significantly poses a major engineering challenge, increasing design risk substantially.

3.6.1.4 Emergency Services Premium

Emergency scenarios are described in Section 4.8. The existing vessel is capable of providing a variety of response scenarios, and it is assumed that the replacement vessel must also be able to do so.

The all-electric and plug-in hybrid propulsion systems make this requirement difficult to meet. These vessel configurations rely on connection to a shore-side utility to charge every round trip under the current assumptions. As described in Scenario 2 and Scenario 3 (Section 4.8), continuous 24-hour ferry operation with limited charging and rendering assistance to distressed vessel or person in Bellingham Channel.

The all-electric system includes a large generator set on shore to charge the shore-side batteries during utility down time. This generator set would be run during Scenario 2 in order to provide power if utility connection is limited. Calculations for Scenario 3 indicate a battery DOD of approximately 50%. This is well within allowable margin of battery discharge for an extremely rare occurrence.

The plug-in hybrid system requires one additional small generator set onboard for a total of two generator sets to provide additional power when vessel cannot be charged from shore. Scenario 2 and 3 can be accomplished by running both of these generators. Adequate transit power is achieved but total maneuvering power will exceed 1000 kW. The vessel batteries will function similar to a series hybrid configuration to make-up the additional power necessary for maneuvering.

Operational costs were not calculated for supporting an emergency services scenario as they are unplanned events.

Plug-in Hybrid Fuel & Electric Power Consumption

Assumptions:

1. Assumed 24 runs per day, 350 days per year
2. 675 kW required power for 11.5 knots transit
3. All operating loads were based on scaling power data (from torque monitoring) up from 425 to 675
4. 10% additional power is used for front end to makeup resistance during transit
5. All durations based on throughput model
6. Bad weather operational frequency based on climatology report, greater than 20 mph winds
7. Bad weather power requirements were assumed 1.5 times average operation; except maneuver into dock was assumed full power, and pushing was assumed 800 kW to match existing operations
8. Pushing power during Normal Operation was scaled to equal total kWh required during the average run

	time			Propulsion Power		Ship Service Load eKW	Total Power Req WBD ekW	Genset 1 power @90% MCR ekW	Battery Power Required		Engine Load % MCR	SFC* lb/(bhp-hr)	Duration hours/yr	Fuel Consumption		Shore		Battery		
	%	min	Total (min)	Pd (kW)	SWBD ekW				ekW	ekW				ekW	kWh	gal/yr	kW	kWh	kWh	%
Normal Operation																				
Maneuver	6%	0.85	0.00	556	612	40	652	0.00	661.97	9.38	0.00	0.811	113	0				850	100%	
Ramp Up	5%	0.78	0.85	798	878	40	918	0.00	932.04	12.17	0.00	0.811	104	0				841	99%	
Cruise	8%	1.17	1.63	743	818	40	858	0.00	870.56	16.93	0.00	0.811	155	0				828	97%	
Ramp Down	5%	0.78	2.80	524	577	40	617	0.00	626.46	8.18	0.00	0.811	104	0				812	95%	
Maneuver	7%	1.07	3.58	476	525	40	565	0.00	573.20	10.19	0.00	0.811	142	0				803	95%	
Unload/Load	69%	10.35	4.65	99	109	40	149	0.00	150.78	26.01	0.00	0.811	688	0				793	93%	
Maneuver	6%	0.85	0.00	556	612	40	652	0.00	661.97	9.38	0.00	0.811	113	0				767	90%	
Ramp Up	5%	0.78	0.85	798	878	40	918	0.00	932.04	12.17	0.00	0.811	104	0				758	89%	
Cruise	8%	1.17	1.63	743	818	40	858	0.00	870.56	16.93	0.00	0.811	155	0				746	88%	
Ramp Down	5%	0.78	2.80	524	577	40	617	0.00	626.46	8.18	0.00	0.811	104	0				729	86%	
Maneuver	7%	1.07	3.58	476	525	40	565	0.00	573.20	10.19	0.00	0.811	142	0				720	85%	
Unload/Load	69%	10.35	4.65	99	109	40	149	0.00	150.78	26.01	0.00	0.811	688	0	1329	177		710	84%	
			30.00							139.70								850	100%	
Bad Weather Operation																				
Maneuver	6%	0.85	0.00	834	918	40	958	495.00	463.05	6.56	90.00	0.347	6	213				850	100%	
Ramp Up	5%	0.78	0.85	1,196	1,317	40	1,357	495.00	862.09	11.26	90.00	0.347	5	197				843	99%	
Cruise	8%	1.17	1.63	1,114	1,226	40	1,266	495.00	771.26	15.00	90.00	0.347	8	293				832	98%	
Ramp Down	5%	0.78	2.80	786	866	40	906	495.00	410.59	5.36	90.00	0.347	5	197				817	96%	
Maneuver	7%	1.07	3.58	1,450	1,596	40	1,636	495.00	1141.48	20.29	90.00	0.347	7	268				812	96%	
Unload/Load	69%	10.35	4.65	800	881	40	921	495.00	425.81	73.45	90.00	0.347	36	1,299				792	93%	
Maneuver	6%	0.85	0.00	834	918	40	958	495.00	463.05	6.56	90.00	0.347	6	213				718	84%	
Ramp Up	5%	0.78	0.85	1,196	1,317	40	1,357	495.00	862.09	11.26	90.00	0.347	5	197				712	84%	
Cruise	8%	1.17	1.63	1,114	1,226	40	1,266	495.00	771.26	15.00	90.00	0.347	8	293				700	82%	
Ramp Down	5%	0.78	2.80	786	866	40	906	495.00	410.59	5.36	90.00	0.347	5	197				685	81%	
Maneuver	7%	1.07	3.58	1,450	1,596	40	1,636	495.00	1141.48	20.29	90.00	0.347	7	268				680	80%	
Unload/Load	69%	10.35	4.65	800	881	40	921	495.00	425.81	73.45	90.00	0.347	36	1,299	2610	348		660	78%	
			30.00							190.38								850	100%	
			30.00		0.908				0.985				Total:	4,933		0.900				

All-Electric Power Consumption

Assumptions:

1. Assumed 24 runs per day, 350 days per year
2. 675 kW required power for 11.5 knots transit
3. All operating loads were based on scaling power data (from torque monitoring) up from 425 to 675
4. 10% additional power is used for front end to makeup resistance during transit
5. All durations based on throughput model
6. Battery life was assumed 8 years
7. Worst case run was based on power assumptions from "Plug-in Hybrid" sheet
8. Demand power for utility was taken as the average of Poweravg and Powerworst

Round-Trip Charging

Battery Information		kWh	Notes								
Battery Size		1050									
Pushing	Time		Propulsion Power		Ship Service	Battery Power		Shore		Battery	
	min	Total min	Pd kW	SWBD ekW	eKW	kW	kWh	kW	kWh	kWh	%
Maneuver	0.85	0.00	556	603	40	653	9			1050	100%
Ramp Up	0.78	0.85	798	865	40	919	12			1041	99%
Cruise	1.17	1.63	743	805	40	858	17			1029	98%
Ramp Down	0.78	2.80	524	568	40	618	8			1012	96%
Maneuver	1.07	3.58	476	517	40	565	10			1004	96%
Unload/Load	10.35	4.65	150	163	40	206	35			994	95%
Maneuver	0.96	15.00	556	603	40	653	10			958	91%
Ramp Up	0.79	15.95	798	865	40	919	12			948	90%
Cruise	1.17	16.75	743	805	40	858	17			936	89%
Ramp Down	0.79	17.91	524	568	40	618	8			919	88%
Maneuver	0.96	18.70	476	517	40	565	9			911	87%
Unload/Load	10.34	19.66	150	163	40	206	35	1458	194	902	86%
		30.00								1050	100%
Total				0.92		0.99	147.93	0.90	194.39		
										SOC from 100%	86%
										DOD	14%

4.8 Range and Emergency Services

The *Guemes* presently refuels every two weeks during normal operation and travels as far as Seattle, 66 nm away, for periodic maintenance (Reference 7). Seattle is easily reachable with a fuel capacity sized for two weeks of normal operation. Larger fuel tanks are not advised, because it is costly to carry extra weight. Endurance and range are also important for meeting the emergency response scenarios outlined below. These response scenarios were developed in the Transportation System Assessment (Reference 7).

1. A catastrophic event requires evacuation of the island and the electrical grid is disabled. The island population varies seasonally, ranging from approximately 750 to 2,750 persons. This could significantly increase in the next 40 years. The duration of

continuous operation would be up to 24 hours. The ferry would have to provide power to the ramp and apron on each side.

2. Significant fire/emergency on the island requiring continuous operation of the ferry for up to 24 hours. The vessel must be able to complete two round trips without charging.
3. Rendering assistance to a distressed vessel or person in Bellingham Channel. Approximately 2-nm distance from ferry route to site of assistance. On station for 1 hour in 18 kts of wind (95th percentile), with associated waves, and 1 knot of current.
4. Man overboard recovery of a ferry passenger. On station for ½ hour in 32 kts of wind (99.9th percentile), with associated waves, and 2 kts of current. Man overboard recovery is a required operation of all USCG inspected ferries.

All five propulsion systems discussed in Section 3 meet these scenarios.

3.8 Sensitivity Analysis

The life cycle cost analysis accounted for energy price forecasts developed by the Energy Information Administration (EIA) of the US Department of Energy. The escalation is included in the discount factors applied to NPV calculation. Sensitivity analysis was performed by varying the price of fuel or electricity and subsequently the annual cash amount of each. The discount factors and forecasts were not changed.

Diesel and electrical prices in the Pacific Northwest region were gathered from EIA data ranging from 2011 to present. The maximum and minimum deviation from the current price of fuel and electricity are presented below in Table 30. The current price paid by Skagit County is also included for reference.

Table 30 Fuel and electricity price deviation as a percentage of current price since 2011

	Skagit County Price	Minimum Price	Maximum Price
Diesel	2.09 \$/gallon	25.0%	52.0%
Electricity	0.554 \$/kWh	16.9%	15.2%

Diesel fuel is much more volatile than electricity as seen by the minimum and maximum price deviation since 2011. In order to account for this, sensitivity analysis conducted utilized the percentages in Table 30 as the variance in current price.

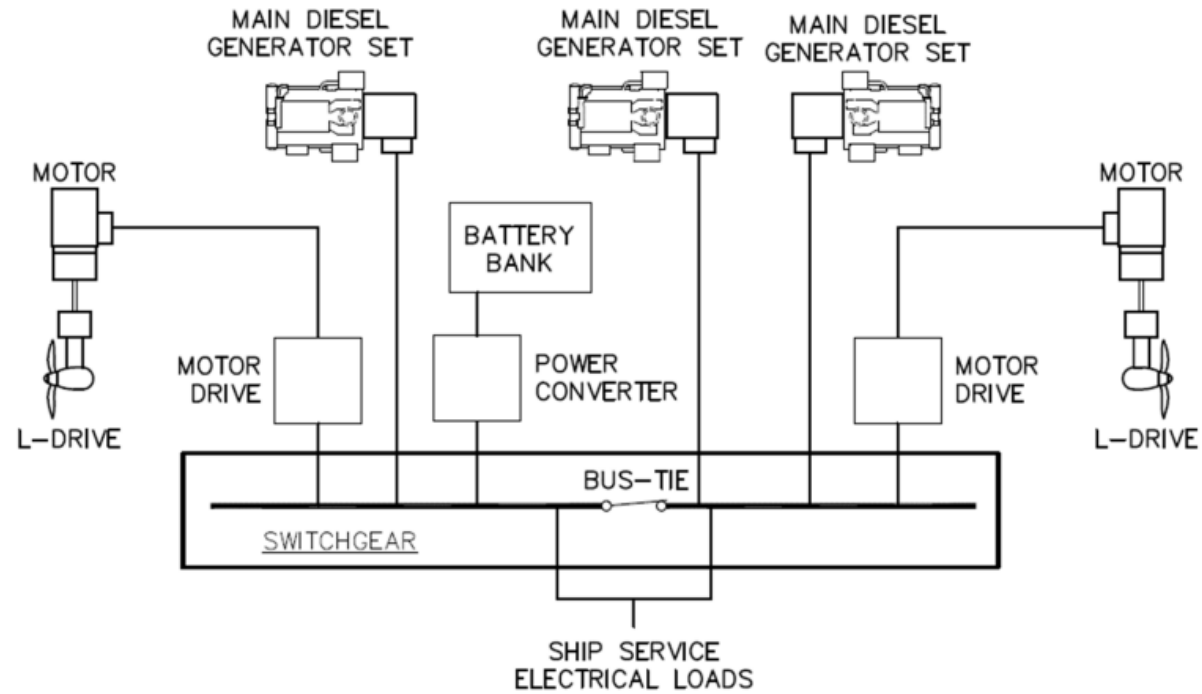


Figure 25 Series hybrid configuration

The replacement vessel series hybrid configuration includes three Tier 3 599kW diesel generator sets and a 300kWh battery bank. The vessel auxiliary systems are identical to diesel-electric with additional complexity associated with power management and battery pack safety systems.