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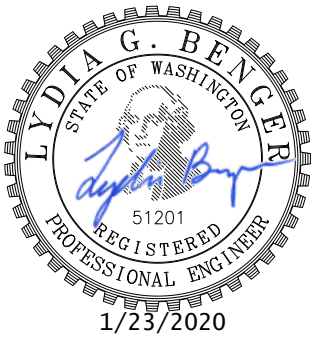
MEMORANDUM

Vessel:	New Vehicle Ferry
Engineer:	Lydia Benger, PE
Reference:	18045-100-062-3A
Date:	January 22, 2020
Subject:	Battery Optimization for Capital Expense



REVISION

Revision A incorporates further explanation of the Central Maine Power Company Rate and how the electricity cost was calculated for each option. Other minor corrections are also made.

PURPOSE

Elliott Bay Design Group (EBDG) completed a propulsion selection study, [1], for Casco Bay Lines (CBL) as a component of the preliminary design process. The recommendation of that study was to design the vessel with a diesel electric hybrid propulsion system. The specific hybrid system considered in that study is essentially a battery electric vessel with a diesel engine provided for use when shore power is unavailable. CBL has indicated that the recommended propulsion system is desirable, but that the capital cost of the system, $3.4 million, may exceed the allowable budget. Of this capital cost, $1.4 million is assumed to be batteries.

The Central Maine Power Company (CMP) rate schedule for Large General Service, [2], has very high demand costs during peak operating periods. As a result, the battery bank considered in the propulsion study was sized at 1800 kWh to avoid charging during the peak periods and thus target lower operating costs. It is possible to reduce the battery bank size and thereby reduce the capital cost of the system.

Reducing the battery bank size will either require charging during undesirable peak periods or increased reliance on the diesel generator. This memo explores different battery bank sizes to reduce the capital cost of the system and identifies the impacts of those different bank sizes.

PROCEDURE

EBDG contacted a supplier of marine rated energy storage systems, to discuss different options for the New Vehicle Ferry. This vendor was aware of the project as they were included in system integrator quotes utilized in the propulsion selection study.

EBDG provided the vendor with round trip power requirements, operating schedule and utility rate schedule and requested the vendor propose different battery bank options. EBDG directed the vendor to allow for use of the diesel engine during the transit portion of the route and require battery operation during maneuvering and while in port.

The vendor provided three battery bank options ranging in size from 452 kWh to 1809 kWh [3]. These options were evaluated for their impact on capital cost and energy cost.

GIVEN AND ASSUMED PARAMETERS

The following assumptions are used in this memo:

- The New Vehicle Ferry will operate on battery power while maneuvering and while at the dock on either side of the route.
- The summer Wednesday to Saturday schedule is the most demanding schedule the New Vehicle Ferry will serve. For conservative battery aging considerations, the Friday timetable, with 16 round trips, is assumed to be repeated 7 days per week, 365 days per year.
- The Friday summer schedule is considered for daily energy consumption as it has the most round trips. The quantity of transits on diesel and transits on electric power are varied to suit the size of battery bank proposed and to best align with the shoulder and off-peak demand charge times.
- The following equation is used to estimate the annual energy consumption:

$$Annual\ Energy = \frac{12.1}{16} * E_f * 365$$

  Where E_f represents the energy consumed on a Friday, whether diesel or electricity. This is to best represent the annual consumption as there are an average of 12.1 trips per day, 365 days per year.

- The monthly electricity cost is calculated as follows:

$$Electricy\ Cost = CE + SD + Service\ Charge$$

  Where

  C is the monthly electricity consumption in kWh

  $E$is the electricity rate in dollars per kWh

  S is the shore power charging rate in kW, and

  D is the demand charge in dollars per kW.

- The electricity rate is comprised of the Delivery Service and Electric Supply rates because CMP is not a supplier of electricity but instead maintains the delivery system. CMP provides billing services for the standard suppliers in the region. EBDG used $0.073829 for the Electric Supply rate based upon historical data provided by Reference [4]. The Delivery Service rate is stated on Reference [2].
- The demand charge is associated with the highest 15-minute integrated kW demand. This cost ranges from $2.24 / kW during the shoulder period in the winter to $14.24 / kW during peak periods in the Summer, Reference [2].
- The shore power rate required to recharge batteries during the 12 minutes available at the Portland Terminal is approximately 1200 kW.

- The batteries are expected to have a 10-year life. For simplicity, the cost of replacing the batteries at the end of life is evenly distributed over the 10 years and included as part of the annual energy cost for each battery bank option. A 10-year life is standard in the industry at this time, and the energy storage system provider stated that reducing the battery life to 5 years does not significantly reduce the quantity of batteries needed.
- The costs in Table 1 are assumed for energy cost comparisons:

Table 1: Energy Costs

Item	Cost	Units
Fuel (ULSD)	3.00	$/gal
Batteries	800	$/kWh
Electricity - Supply	0.073829	$/kWh
Electricity - Delivery	0.004008	$/kWh
Electricity - Shoulder Demand (July/Aug)	2.67	$/kW/month
Electricity - Shoulder Demand (Sept - Jun)	2.24	$/kW/month
Electricity - Peak Demand (July/Aug)	14.24	$/kW/month
Electricity - Peak Demand (Sept -Jun)	13.81	$/kW/month
Electricity Service Charge	592.06	$/month

DISCUSSION

Energy Requirements

EBDG calculated the power required for a single round trip, utilizing the power profile from [5]. The route was analyzed two ways: once assuming all electric propulsion throughout the trip, and again assuming the diesel generator provided the propulsion power and hotel loads during the 15.5-minute transit portion of the route. The complete calculations are provided in the Calculations section, but Table 2, summarizes the energy required for each type of crossing.

Table 2: Round Trip Energy Consumption

Transit Type	Diesel (gal)	Electric (kWh)
Battery Transit	0.0	219
Diesel Transit	9.6	59

Battery Electric Vessel – 1809 kWh

The largest proposed battery bank correlates best with what was proposed in the propulsion selection study. This bank is sized to allow for battery transit all day and charging at shoulder and off-peak periods. The estimated capital cost for the diesel electric hybrid system as discussed in the propulsion study is $3.4 million. Of this cost, $1.4 million is assumed to be batteries.

Table 3 shows the anticipated daily energy use, if this battery bank is used for the New Vehicle Ferry.

Table 3: Daily Energy Expenditures - BEV

Transit Type	Transit Qty	Day - 16 Trips		Day - 12.1 Trips	
		Diesel (gal)	kWh	Diesel (gal)	kWh
Battery Transit Count	16	0.0	3505	0.0	2651
Diesel Transit Count	0	0.0	0	0.0	0

The anticipated annual energy cost for this battery bank is approximately $260,000, as shown in Table 4. This cost includes the cost of charging the batteries daily and replacing the batteries after 10 years. The complete annual energy cost calculations are provided in the Calculations section below.

Table 4: Annual Energy Cost - BEV

Annual Fuel Cost	$	-
Annual Electric Cost	$	115,315
Annual Battery Replacement Cost	$	144,720
Total Annual Cost	$	260,035

Plug-In Hybrid Battery Electric Vessel Flex – 904 kWh

The next largest battery bank is 904 kWh. This bank is sized for diesel transit during the peak charging periods and electric transit and charging at shoulder and off-peak periods. This battery bank is estimated to cost approximately $725,000, bringing the overall system capital cost down to $2.7 million.

Table 5 shows the anticipated daily energy use, if this battery bank is used for the New Vehicle Ferry.

Table 5: Daily Energy Expenditures – PHEV Flex

Transit Type	Transit Qty	Day - 16 Trips		Day - 12.1 Trips	
		Diesel (gal)	kWh	Diesel (gal)	kWh
Battery Transit Count	9	0.0	1972	0.0	1479
Diesel Transit Count	7	67	414	50.3	310

The anticipated annual energy cost for this battery bank is approximately $218,000, as shown in Table 6. This cost includes the cost of charging the batteries daily, replacing the batteries after 10 years, and providing diesel for the generator. The annual energy cost calculations are provided in the Calculations section below.

Table 6: Annual Energy Cost - PHEV Flex

Annual Fuel Cost	$	55,030
Annual Electric Cost	$	90,835
Annual Battery Replacement Cost	$	72,320
Total Annual Cost	$	218,184

This option is of particular interest, because if CBL can negotiate lower peak demand charges, this is the desired bank size for an all-electric operation with charging every round trip.

Plug-In Hybrid Battery Electric Vessel – 452 kWh

The smallest battery bank is 452 kWh. This bank is sized only to provide electric propulsion and hotel loads during the maneuvering process and while at dock. All transit would be done on diesel. Batteries are recharged with shore power during shoulder and off-peak periods. This battery bank is estimated to cost approximately $362,000, bringing the overall system capital cost down to $2.4 million.

Table 7 shows the anticipated daily energy use, if this battery bank is used for the New Vehicle Ferry.

Table 7: Daily Energy Expenditures - PHEV

Transit Type	Transit Qty	Day - 16 Trips		Day - 12.1 Trips	
		Diesel (gal)	kWh	Diesel (gal)	kWh
Battery Transit Count	0	0.0	0.0	0.0	0.0
Diesel Transit Count	16	153	946	115	709

The anticipated annual energy cost for an installation with this battery bank is approximately $222,000, as shown in Table 8. This cost includes the cost of charging the batteries daily and replacing the batteries after 10 years. The annual energy cost calculations are provided in the Calculations section below.

Table 8: Annual Energy Cost - PHEV

Annual Fuel Cost	$ 125,782
Annual Electric Cost	$ 60,160
Annual Battery Replacement Cost	$ 36,160
Total Annual Cost	$ 222,101

RESULTS

Table 9 summarizes the three different battery banks considered to demonstrate the flexibility of the capital cost for a diesel electric hybrid installation. It is possible to vary the size of the battery bank by adjusting the number of trips that rely on batteries for the transit portion of the route. In all cases, the maneuvering and time at dock are assumed to be on battery power.

Table 9: Battery Bank Summary

Battery Bank	Percent of Transits on Battery	Perscent of Transits on Diesel	Battery Capital Cost	System Captial Cost	Annual Electricity / Fuel Cost	Annualized Battery Replacement Cost
Battery Electric Vessel - 1809 kWh	100%	0%	$ 1,447,200	$ 3,447,200	$ 115,000	$ 144,000
Plug-in Hybrid Vessel, Flex - 904 kWh	56%	44%	$ 723,200	$ 2,723,200	$ 145,000	$ 72,000
Plug-in Hybrid Vessel - 452 kWh	0%	100%	$ 361,600	$ 2,361,600	$ 186,000	$ 36,000

CALCULATIONS

Diesel Transit Energy Consumption

Operational Profile		Power Demand				Power Supply		Engine Usage		Fuel Burn
Loading Condition	**Duration**	**Prop. Load**	**Hotel Load**	**Other**	**Total**	**Generator Power**	**Battery Power**	**Eng Pwr**	**Eng Time**	**Eng. BSFC**
	min	kW	kW	kW	kW	kW	kW	%	min	lb/hp-hr
Included Efficiency		Motor	Gen			Gen	Disch			
Value		0.976	0.98			0.98	0.97			
Load	6	26.0	40.8		66.8	0.0	68.9	0%	0.0	0
Maneuvering	1.13	397.5	40.8		438.3	0.0	451.8	0%	0.0	0
Transit	15.48	265.2	40.8		306.0	312.2	0.0	57%	15.5	0.321
Maneuvering	0.89	397.5	40.8		438.3	0.0	451.8	0%	0.0	0
Tie Up	0.5	26.0	40.8		66.8	0.0	68.9	0%	0.0	0
Unload	6	26.0	40.8		66.8	0.0	68.9	0%	0.0	0
Load	6	26.0	40.8		66.8	0.0	68.9	0%	0.0	0
Maneuvering	1.13	397.5	40.8		438.3	0.0	451.8	0%	0.0	0
Transit	15.48	265.2	40.8		306.0	312.2	0.0	57%	15.5	0.321
Maneuvering	0.89	397.5	40.8		438.3	0.0	451.8	0%	0.0	0
Tie Up	0.5	26.0	40.8		66.8	0.0	68.9	0%	0.0	0
Unload	6	26.0	40.8		66.8	0.0	68.9	0%	0.0	0
	60 min				215 kWh	161 kWh	59 kWh		31 min	9.6 gal

Battery Transit Energy Consumption

Operational Profile		Power Demand				Power Supply		Engine Usage		
Loading Condition	**Duration**	**Prop. Load**	**Hotel Load**	**Other**	**Total**	**Generator Power**	**Battery Power**	**Eng Pwr**	**Eng Time**	**Eng. BSFC**
	min	kW	kW	kW	kW	kW	kW	%	min	lb/hp-hr
Included Efficiency		Motor	Gen			Gen	Disch			
Value		0.976	0.98			0.98	0.97			
Load	6	26.0	40.8		66.8	0.0	68.9	0%	0.0	0
Maneuvering	1.13	397.5	40.8		438.3	0.0	451.8	0%	0.0	0
Transit	15.48	259.9	40.8		300.7	0.0	310.0	0%	0.0	0
Maneuvering	0.89	397.5	40.8		438.3	0.0	451.8	0%	0.0	0
Tie Up	0.5	26.0	40.8		66.8	0.0	68.9	0%	0.0	0
Unload	6	26.0	40.8		66.8	0.0	68.9	0%	0.0	0
Load	6	26.0	40.8		66.8	0.0	68.9	0%	0.0	0
Maneuvering	1.13	397.5	40.8		438.3	0.0	451.8	0%	0.0	0
Transit	15.48	259.9	40.8		300.7	0.0	310.0	0%	0.0	0
Maneuvering	0.89	397.5	40.8		438.3	0.0	451.8	0%	0.0	0
Tie Up	0.5	26.0	40.8		66.8	0.0	68.9	0%	0.0	0
Unload	6	26.0	40.8		66.8	0.0	68.9	0%	0.0	0
	60 min				213 kWh	0 kWh	219 kWh		0 min	0 gal

BEV Annual Energy Cost – 1809 kWh

Period	Charge	Fee		Power (kW)	Energy (kWh)	Fee (USD)	Frequency per year	Subtotal Cost
July/August	Demand - On-Peak	$ 14.24	per kw	0	-	$ -	2	$ -
	Demand - Shoulder	$ 2.67	per kw	1186	-	$ 3,166.62	2	$ 6,333
	Supply Charge	$ 0.073829	per kWh	-	2651	$ 195.71	61	$ 11,906
	Delivery Charge	$ 0.004008	per kWh	-	2651	$ 10.62	61	$ 646
	Service Charge	$ 592.06		-	-	$ 592.06	2	$ 1,184
September-June	Demand - On-Peak	$ 13.81	per kw	0	-	$ -	10	$ -
	Demand - Shoulder	$ 2.24	per kw	1186	-	$ 2,656.64	10	$ 26,566
	Supply Charge	$ 0.073829	per kWh	-	2651	$ 195.71	304	$ 59,528
	Delivery Charge	$ 0.004008	per kWh	-	2651	$ 10.62	304	$ 3,232
	Service Charge	$ 592.06		-	-	$ 592.06	10	$ 5,921
							Annual Electric Cost	$ 115,315

Battery Qty (kWh)	Battery Cost ($/kWh)	Battery Life (years)	Annual Cost ($)
1809	800	10	$ 144,720

Diesel (gal/day)	Diesel (gal/year)	Annual Cost ($)
0.00	0	$ -

Annual Energy Cost $ 260,035

PHEV Flex Annual Energy Cost – 904 kWh

Period	Charge	Fee		Power (kW)	Energy (kWh)	Fee (USD)	Frequency per year	Subtotal Cost
July/August	Demand - On-Peak	$ 14.24	per kw	0	-	$ -	2	$ -
	Demand - Shoulder	$ 2.67	per kw	1186	-	$ 3,166.62	2	$ 6,333
	Supply Charge	$ 0.073829	per kWh	-	1789	$ 132.09	61	$ 8,035
	Delivery Charge	$ 0.004008	per kWh	-	1789	$ 7.17	61	$ 436
	Service Charge	$ 592.06		-	-	$ 592.06	2	$ 1,184
September-June	Demand - On-Peak	$ 13.81	per kw	0	-	$ -	10	$ -
	Demand - Shoulder	$ 2.24	per kw	1186	-	$ 2,656.64	10	$ 26,566
	Supply Charge	$ 0.073829	per kWh	-	1789	$ 132.09	304	$ 40,177
	Delivery Charge	$ 0.004008	per kWh	-	1789	$ 7.17	304	$ 2,181
	Service Charge	$ 592.06		-	-	$ 592.06	10	$ 5,921
							Annual Electric Cost	$ 90,835

Battery Qty (kWh)	Battery Cost ($/kWh)	Battery Life (years)	Annual Cost ($)
904	800	10	$ 72,320

Diesel (gal/day)	Diesel (gal/year)	Annual Cost ($)
50.29	18357	$ 55,070

Annual Energy Cost $ 218,225

PHEV Annual Energy Cost – 452 kWh

Period	Charge	Fee		Power (kW)	Energy (kWh)	Fee (USD)	Frequency per year	Subtotal Cost
July/August	Demand - On-Peak	$ 14.24	per kw	0	-	$ -	2	$ -
	Demand - Shoulder	$ 2.67	per kw	1186	-	$ 3,166.62	2	$ 6,333
	Supply Charge	$ 0.073829	per kWh	-	709	$ 52.38	61	$ 3,186
	Delivery Charge	$ 0.004008	per kWh	-	709	$ 2.84	61	$ 173
	Service Charge	$ 592.06		-	-	$ 592.06	2	$ 1,184
September-June	Demand - On-Peak	$ 13.81	per kw	0	-	$ -	10	$ -
	Demand - Shoulder	$ 2.24	per kw	1186	-	$ 2,656.64	10	$ 26,566
	Supply Charge	$ 0.073829	per kWh	-	709	$ 52.38	304	$ 15,931
	Delivery Charge	$ 0.004008	per kWh	-	709	$ 2.84	304	$ 865
	Service Charge	$ 592.06		-	-	$ 592.06	10	$ 5,921
							Annual Electric Cost	$ 60,160

Battery Qty (kWh)	Battery Cost ($/kWh)	Battery Life (years)	Annual Cost ($)
452	800	10	$ 36,160

Diesel (gal/day)	Diesel (gal/year)	Annual Cost ($)
114.95	41958	$ 125,875

Annual Energy Cost $ 222,194

REFERENCES

[1] Elliott Bay Design Group, "Propulsion Selection Study, 18045-100-062-1, Rev -," 12/18/2019.

[2] Central Maine Power Company, "Electric Delivery Rate Schedule: Large General Service-Primary-Time," 7/1/2019.

[3] Spear Power Systems, "Casco Bay Lines PHEV Ferry Optimization," 11/15/2019.

[4] Office of the State of Maine, "Maine Public Utilities Commission," [Online]. Available: https://www.maine.gov/mpuc/electricity/standard_offer_rates/standardoffer_cmpmedium.htm. [Accessed Jan 2019].

[5] Elliott Bay Design Group, "18045-070-0, Vessel Configuration Comparison," 10/31/19.