Elliott Bay Design Group

5/13/2022

NEW VEHICLE FERRY
M/V WOODS HOLE EQUIVALENT

Hybrid Propulsion Study

Prepared for: Steamship Authority |Falmouth, MA

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REVISIONS

REV	DESCRIPTION	DATE	APPROVED
-	Initial Issue	4/14/22	LGB 51201
A	Revised to align shore power electricity costs with KPFF memo.	5/13/22	LGB 51201

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1. PURPOSE

This study presents a comparison of alternative propulsion options for a New Vehicle Ferry. The vessel considered in this study is an equivalent of the M/V WOODS HOLE with alterations for alternative propulsion configurations. This equivalent vessel is 235 ft. x 64 ft. x 18.5 ft. passenger ferry intended for service on two routes operated by the Steamship Authority (SSA): Woods Hole to Martha's Vineyard and Hyannis to Nantucket.

2. PROCEDURE

2.1 OVERVIEW

SSA provided operational vessel data from the M/V WOODS HOLE from the past five years while operating on the two routes. This data was reviewed and sorted to construct propulsion and hotel load profiles for each route. Five different propulsion configurations were identified as options for this vessel and each configuration was evaluated in terms of three evaluation criteria: capital cost, operating cost, and emissions.

2.2 CANDIDATE PROPULSION SYSTEMS

Preliminary discussions between EBDG and SSA led to the selection of five different propulsion arrangements for evaluation over two different routes. See Appendix C for system arrangement sketches.

2.2.1 OPTION 1: DIESEL MECHANICAL

The diesel mechanical option is meant to represent an updated version of the M/V WOODS HOLE installation and act as the baseline for all the other options. The configuration is a standard diesel mechanical propulsion system with two independent propulsion trains each with a high-speed diesel engine driving a single controllable pitch propeller (CPP) via a reduction gear and conventional shaft line. Electrical ship service power is provided by three diesel generators.

For this option the following equipment was considered:

- Two MTU 16V4000 M65L EPA Tier IV propulsion engines, rated for 2560 kW
- Two Hundested CPP Systems, including marine gear boxes and propeller units
- Three John Deere 6135 AFM85 diesel generators, rated for 310 ekW

2.2.2 OPTION 2: BERTH BATTERY

The second configuration is a diesel hybrid propulsion system with electric propulsion motors, generators, and battery banks. Three high-speed diesel propulsion generators are provided to charge batteries, provide hotel power, or power electric propulsion motors. Two variable speed propulsion motors would then drive fixed pitch propellers. Electrical ship service power is provided by the battery bank and the propulsion generators. Note that the third propulsion generator is included in this option, and all other hybrid options, in order to provide operational redundancy similar to the M/V WOODS HOLE configuration with three ship service generators.

This configuration is sized such that the diesel generators provide for propulsion and hotel loads during the crossing while charging batteries. In berth at either end of the crossing all diesel generators are shut down and hotel loads are provided by the battery banks.

For this option the following equipment was considered:

- Three MTU 16V4000 M65L EPA Tier IV generators, rated for 2450 ekW
- Two fixed pitch propellers
- Two 1,000 kW electric propulsion motors
- A DC propulsion switchboard, AC distribution switchboard and all interfacing equipment
- 180 – 190 kWh batteries

2.2.3 OPTION 3: PEAK SHAVE

The third configuration is a diesel hybrid propulsion system similar to Option 2 with an increased battery capacity. This configuration is optimized to level load the generators throughout the route, removing any peak demands from the generators operational profile and increasing the overall efficiency of the generator. Batteries are charged and discharged to support the level loading of the generators. The generators operate while in the berth.

For this option the following equipment was considered:

- Three MTU 16V4000 M65L EPA Tier IV generators, rated for 2450 ekW
- Two fixed pitch propellers
- Two 1,000 kW electric propulsion motors
- A DC propulsion switchboard, AC distribution switchboard and all interfacing equipment
- 1500 – 1900 kWh Batteries

2.2.4 OPTION 4: 50% BATTERY (MANUEVERING AND BERTH BATTERY)

The fourth configuration is yet another diesel hybrid propulsion system with additional batteries beyond those provided in Option 2 and Option 3. In this configuration diesel generators provide for propulsion and hotel loads and charge batteries during the transit portion of the crossing. The batteries are then used to provide for propulsion and hotel loads when the vessel is maneuvering in and out of the terminals. Additionally, batteries are used for hotel loads while in the terminal. The diesel generators will not operate while in berth.

For this option the following equipment was considered:

- Three MTU 16V4000 M65L EPA Tier IV generators, rated for 2450 ekW
- Two fixed pitch propellers
- Two 1,000 kW electric propulsion motors
- A DC propulsion switchboard, AC distribution switchboard and all interfacing equipment
- 1800 – 2500 kWh Batteries

2.2.5 OPTION 5: ALL ELECTRIC

The fifth propulsion option is an all-electric arrangement sized to provide all propulsion and hotel loads for the entire crossing. Batteries are sized assuming they are charged to their full capacity after each one-way crossing. The batteries would be charged at both the Woods Hole and Martha's Vineyard docks. The Hyannis to Nantucket route is not being considered for all-electric propulsion at this time. A high-speed diesel generator is provided to charge batteries or drive electric motors should shore power be unavailable.

For this option the following equipment was considered:

- One MTU 16V4000 M65L EPA Tier IV generators, rated for 2450 ekW
- Two fixed pitch propellers
- Two 1,000 kW electric propulsion motors
- One DC propulsion switchboard, one AC distribution switchboard, and interfacing equipment
- One shore power terminal and interfacing equipment
- 5380 kWh Batteries

2.3 EVALUATION CRITERIA

2.3.1 CAPITAL COST

Capital costs consist of the purchase price of all major equipment for each propulsion option. Budgetary estimates from vendors along with cost data from prior studies were used to develop the capital cost estimates, with all costs presented in 2022 dollars.

Installation, shipyard, and engineering labor costs are not included. Installation materials such as structural steel, cables, system piping, and shafting are not included. These costs are expected to be similar across all options. The diesel hybrid options do require additional systems as compared to diesel mechanical, but in the scope of a new vessel construction these additional systems are not large enough to make a significant cost difference. The relevant costs for the hybrid systems are accounted for in the overall cost of the propulsion package.

2.3.2 OPERATING COST

The operating costs consist of a 10-year life cycle maintenance and energy costs.

The maintenance cost includes the parts, consumables and labor for the recommended maintenance practices provided by the major equipment vendors. Maintenance activities were determined based upon engine and gear operating hours. For the hybrid options, battery replacement is included and based upon a 10-year battery life. Minimal maintenance costs for standby equipment is also included; annual time to verify the functionality of equipment and maintenance materials is estimated.

The energy cost is based upon an estimated annual fuel consumption and annual shoreside electricity consumption. Energy consumption is based upon the route profiles described in Section 3.1. Shoreside electricity consumption is considered for the all-electric Option 5 with rapid charging connections available at the Martha's Vineyard terminal and the Woods Hole terminal.

2.3.3 EMISSIONS

Once annual fuel consumption and operating hours for each arrangement is calculated the estimated annual Carbon Dioxide (CO_2), Nitrous Oxide (NOx), Carbon Monoxide (CO), and Particulate Matter (PM) emissions can be calculated. This study only considered the vessel emissions and does not account for offsite emissions such as those associated with electrical power generation. Emission rates at various engine/generator loadings were used along with the calculated vessel power demand to generate a total amount of emissions per cycle.

3. GIVEN AND ASSUMED PARAMETERS

3.1 VESSEL ROUTE AND POWER REQUIREMENTS

Two routes were studied to determine propulsion system configurations and sizing. Operational engine data from the Woods Hole to Martha's Vineyard and Hyannis to Nantucket routes was analyzed to determine powering requirements for each route. The M/V WOODS HOLE operated on three distinct routes for the time frame analyzed: Woods Hole to Martha's Vineyard, Hyannis to Nantucket, and Woods Hole to Oak Bluff. The Woods Hole to Oak Bluff route was omitted from the analysis, as it is similar in powering to the Martha's Vineyard route and was not within the scope of study.

Port and starboard main engine data was submitted by MTU as a percentage of the engine's Maximum Continuous Rating (MCR). Figure 1 is an example of the data provided; this figure shows a single engine load as a percent MCR over a single run on the Martha's Vineyard Route.

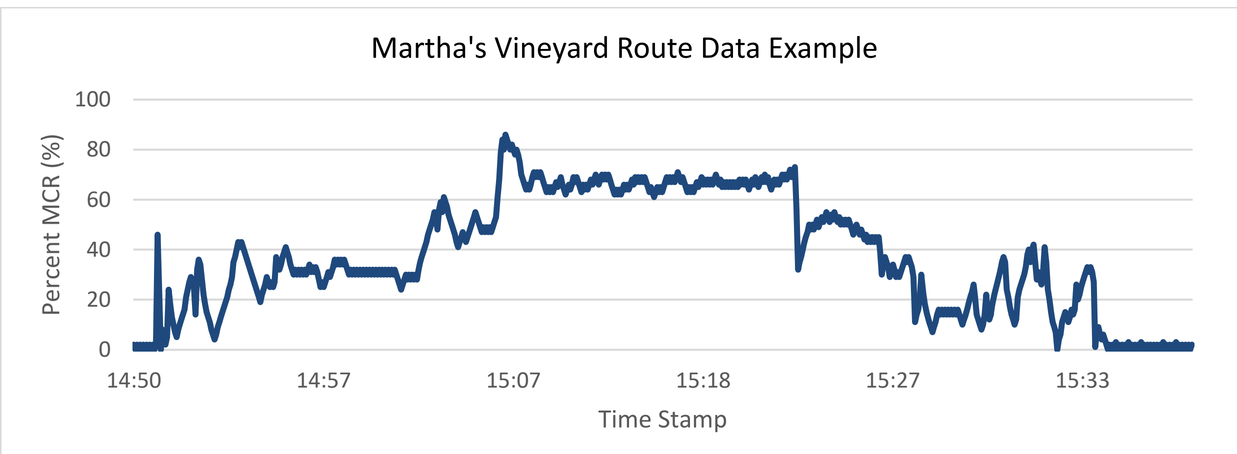

Figure 1: Example Propulsion Engine Data

The propulsion engine data was filtered to a representative day per month for each engine to account for differences in wind, wave, and loading conditions. SSA provided the approved vessel schedule as well as out of service dates for the vessel which was used to align the vessel activity with the data provided.

The values of the percentage load were averaged together as a piecewise function highlighting the different maneuvering and transiting conditions of the vessel during a typical voyage. The results of the data analysis were an average time and power spent at each operating condition for both the Woods Hole to Martha's Vineyard route and the Hyannis to Nantucket route.

3.1.1 WOODS HOLE TO MARTHA'S VINEYARD

The Woods Hole to Martha's Vineyard route has three distinct operating conditions: maneuvering out of the terminal, transit speed, and maneuvering into the new terminal. For annual calculations the vessel is assumed to operate on this route about 285 days per year with an average of 7 round trips per day. Figure 2 and Table 1 summarize the nominal Woods Hole to Martha's Vineyard route profile.

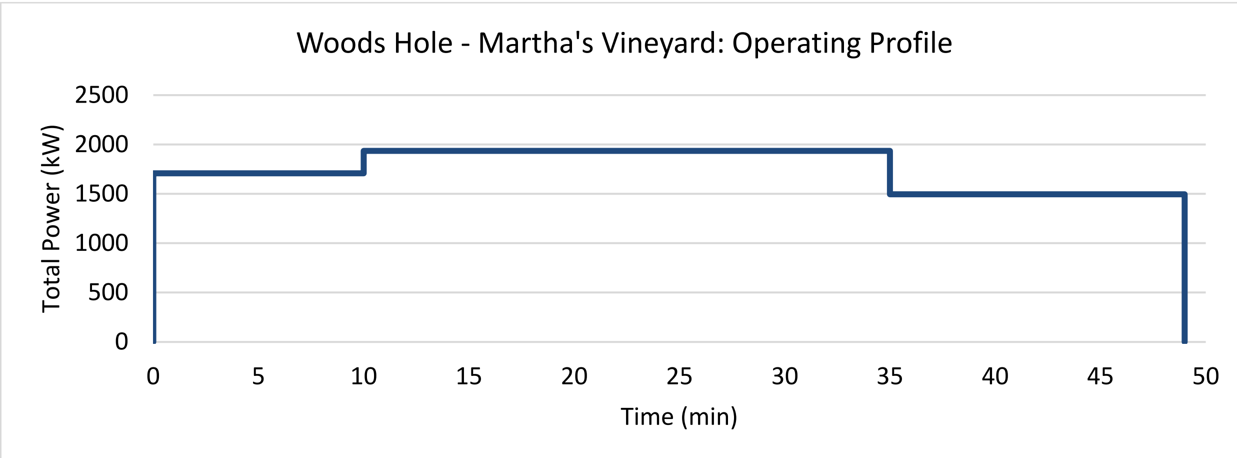

Figure 2: Woods Hole to Martha's Vineyard Profile

Table 1: Operational Profile - Woods Hole to Martha's Vineyard

OPERATING CONDITION	TIME (MIN)	COMBINED ENGINE POWER (KW)
Maneuvering 1	10	1707
Transit 1	25	1935
Maneuvering 2	13	1494

3.1.2 HYANNIS TO NANTUCKET

The Hyannis to Nantucket route has a secondary transit loading where additional power is required to maintain the transit speed. For annual calculations the vessel is assumed to operate on this route 200 days per year, 3 round trips per day. Figure 3 and Table 2 summarize the Hyannis to Nantucket nominal route profile.

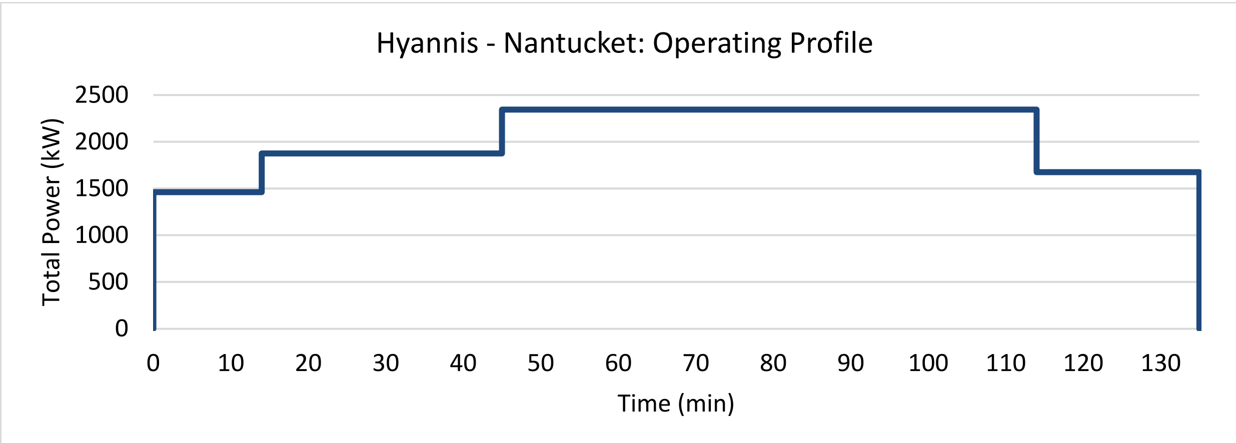

Figure 3: Hyannis to Nantucket Profile

Table 2: Operational Profile - Hyannis to Nantucket

OPERATING CONDITION	TIME (MIN)	COMBINED ENGINE POWER (KW)
Maneuvering 1	14	1460
Transit 1	31	1875
Transit 2	69	2344
Maneuvering 2	20	1674

3.2 SHIPS SERVICE ELECTRICAL AND HVAC REQUIREMENTS

Hotel loads of the existing vessel were analyzed in a similar fashion to the propulsion engine loads. After reviewing a collection of generator load data across a variety of dates for each route analyzed a conservative estimate was made.

For the purpose of this study, the assumed ships service electrical load is route dependent, with the Woods Hole to Martha's Vineyard route requiring 95 kW and the Hyannis to Nantucket route requiring 120 kW. These hotel loads account for lighting, ventilation, fluid pumping, and other normal operation loads.

All arrangements assume heat is supplied by a hot water boiler system and the propulsion arrangement will not affect the heat required by the vessel. Boiler fuel consumption is not included in the calculations.

3.3 FINANCIAL ASSUMPTIONS

For the capital and operating cost estimates, the following assumptions were used:

- Major equipment costs are based on quotes and costs derived from equipment vendors.
- Where current quotes were not obtained, equipment costs were estimated using a parametric approach, using that system's main design driver as the scaling factor.
- For the life cycle cost estimation, all costs were estimated as annual costs and inflation is accounted for using an annual 3% inflation rate.
- Electricity Rates were obtained from a study performed by KPFF, an engineering firm specializing in shoreside infrastructure. See Reference [1]. A single electric vessel was assumed to be charging directly from the grid.
- The consumables in Table 3 were assumed for the life cycle and fuel cost comparisons.

Table 3: Cost of Consumables

ITEM	COST	UNITS
Fuel (ULSD)	2.15	$/gal
Lube Oil	8.00	$/gal
Batteries	750	$/kWh
Urea	3.23	$/gal

Ultra-Low Sulfur Diesel (ULSD) price was sourced from the 2021 actual expenses for the M/V WOODS HOLE. While this may not be reflective of the current spike in fuel costs, it is reflective of the highest cost per gallon since 2016. The cost per kWh for batteries was confirmed with a battery vendor.

4. DISCUSSION

4.1 CAPITAL COST

The capital cost estimates for each different propulsion configuration are provided in Table 4 and Table 5. Additional details of the Capital Cost Calculations are shown in Appendix A.

Only the high-level costs related specifically to the propulsion system were addressed. In the diesel mechanical configuration, the capital costs accounted for the engines, the CPP system and reduction gears, and the ship service generator. Each of the diesel hybrid options had similar cost estimating, with the main differences in the costs being quantity of batteries required.

Of the diesel hybrid options, the 50% battery option required the most batteries and as such was the highest cost of the hybrid options. The all-electric configuration was the most expensive of all the configurations. This can be attributed to its large battery storage requirements, its shore power charging connections, and the general powering redundancy necessary for regulatory approval.

The costs for the Martha's Vineyard route configurations are more expensive than the Nantucket configurations for Peak Shave and 50% Battery, as the number of annual cycles affects battery aging and increases the required battery capacity.

Table 4: Martha's Vineyard Capital Cost Summary

OPTION	DESCRIPTION	COST
1	Diesel Mechanical	$ 4,467,000
2	Berth Battery	$ 8,691,000
3	Peak Shave	$ 10,236,000
4	50% Battery	$ 10,786,000
5	All Electric	$ 12,237,000

Table 5: Nantucket Capital Cost Summary

OPTION	DESCRIPTION	COST
1	Diesel Mechanical	$ 4,467,000
2	Berth Battery	$ 8,737,000
3	Peak Shave	$ 9,924,000
4	50% Battery	$ 10,209,000

4.2 OPERATING COST

Each propulsion configuration was projected out to a 10-year span, with estimates for the major costs incurred during that 10-year period. The major drivers of the operating costs were diesel consumption, shore power, urea consumption, battery replacement, and engine/generator maintenance. A 3% inflation rate in line with the maritime industry's inflation trends was assumed and used to calculate the future costs incurred for each recurring operating expense. The operating costs over a 10-year period, in 2022 dollars, are shown in Table 6 and Table 7. Additional details of the operating cost calculation are provided in Appendix B.

Table 6: Martha's Vineyard Operating Cost Summary

OPTION	DESCRIPTION	COST
1	Diesel Mechanical	$ 12,533,000
2	Berth Battery	$ 11,488,000
3	Peak Shave	$ 12,928,000
4	50% Battery	$ 13,332,000
5	All Electric	$ 17,728,000

Table 7: Nantucket Operating Cost Summary

OPTION	DESCRIPTION	COST
1	Diesel Mechanical	$ 11,662,000
2	Berth Battery	$ 10,766,000
3	Peak Shave	$ 11,698,000
4	50% Battery	$ 12,136,000

4.3 EMISSIONS

Utilizing the power profiles presented in Section 3.1 and ship service electrical requirements presented in Section 3.2, each route's emission generation was calculated.

It is standard practice to measure emissions in metric units. CO_2 generation is a function of the diesel fuel burned; one metric ton of CO_2 is generated for every 99.4 gallons of diesel burned. All other emissions (NOx, CO, and PM) were calculated based upon load-weighted EPA emissions certification data provided by the engine manufacturers. NOx, CO, and PM emissions from marine engines are already controlled by EPA regulations and all engine manufacturers are required to provide documentation of their engines meeting the EPA regulations. Table 8 and Table 9 show the total annual emissions produced by each configuration option.

The all-electric configuration was assumed to produce approximately 5% of the emissions of the diesel mechanical arrangement. This was to account for occasional operation of the installed diesel generator. It is expected that the generator may be required for vessel propulsion, and it is good marine practice to ensure the generator is operable.

Table 8: Martha's Vineyard Emissions Summary

OPTION	DESCRIPTION	CO_2 (MT/YR)	NOX (MT/YR)	CO (KG/YR)	PM (KG/YR)
1	Diesel Mechanical	3849	22	909	175
2	Berth Battery	3565	14	258	87
3	Peak Shave	3538	13	467	82
4	50% Battery	3544	11	2118	101
5	All Electric	187	1.1	45	8.7

Table 9: Nantucket Emissions Summary

OPTION	DESCRIPTION	CO_2 (MT/YR)	NOX (MT/YR)	CO (KG/YR)	PM (KG/YR)
1	Diesel Mechanical	3619	20	936	155
2	Berth Battery	3355	13	364	79
3	Peak Shave	3317	11	1782	92
4	50% Battery	3336	12	968	81

5. CONCLUSIONS

Of the five options considered, Option 1 (diesel mechanical) produced the most emissions and was the cheapest propulsion configuration. Option 5 was the closest to zero emission (wake-side) configuration and was also the most expensive to procure. The diesel hybrid options (Options 2-4) produced emissions similar to, but less than the diesel mechanical option with CO_2 emission reductions ranging from 7% - 8% depending on the load conditions of the propulsion generators.

Capital costs for the propulsion systems were higher the more emissions were reduced. The increase in cost amongst the hybrid and all electric options was largely related to the quantity of batteries needed in each powering scenario.

Future studies and analyses could be performed to better define a vessel optimized for an all-electric or hybrid option. There is likely a sweet-spot design that would work well on both routes. An all-electric configuration for the Hyannis – Nantucket route was not considered in this study, and the quantity of batteries for that application would likely be prohibitive. An evaluation of the existing M/V WOODS HOLE hold space for fit of a diesel hybrid propulsion configuration is recommended.

This study did not consider any alternate fuels such as methanol, hydrogen, or ammonia as potential vehicles for emissions reduction relative to diesel. To do so would require an in-depth analysis of the supply chain of such fuels.

6. REFERENCES

[1] KPFF, "2100492.001 Martha's Vineyard and Nantucket Steamship Authority Shoreside Electrification Feasibility Study".

APPENDIX A

Capital Cost

MARTHA'S VINEYARD

Diesel Mechanical

Item	Cost Per Unit		Unit	Total
Engines	$ 401	per kW	5120	$ 2,050,865
CPP System & Gears	$ 398	per kW	5120	$ 2,035,319
Ship Service Generator	$ 423	per kW	900	$ 381,000
Total Investment Cost				**$ 4,467,184**

Battery Power at Berths

Item	Cost Per Unit		Unit	Total
Batteries	$ 750	Qty	181	$ 135,731
DC Grid / Drive System	$ 2,899,004	Qty	1	$ 2,899,004
Motors, Propulsion	$ 155,811	Qty	1	$ 155,811
Switchgear and Transformer	$ 248,685	Qty	1	$ 248,685
Integrator Execution, Commissioning, Engineering	20%	% of Ele. Equip.	$ 3,439,231	$ 687,846
Generators	$ 1,304,698	Qty	3	$ 3,914,093
Propellers	$ 50,000	Qty	2	$ 100,000
Reduction Gear	$ 200,000	Qty	2	$ 400,000
Systems, etc.	$ 150,000	per room	1	$ 150,000
Total Investment Cost				**$ 8,691,169**

Peak Shaving

Item	Cost Per Unit		Unit	Total
Batteries	$ 750	Qty	1897	$ 1,423,011
DC Grid / Drive System	$ 2,899,004	Qty	1	$ 2,899,004
Motors, Propulsion	$ 155,811	Qty	1	$ 155,811
Switchgear and Transformer	$ 248,685	Qty	1	$ 248,685
Integrator Execution, Commissioning, Engineering	20%	% of Ele. Equip.	$ 4,726,511	$ 945,302
Generators	$ 1,304,698	Qty	3	$ 3,914,093
Propellers	$ 50,000	Qty	2	$ 100,000
Reduction Gear	$ 200,000	Qty	2	$ 400,000
Systems, etc.	$ 150,000	per room	1	$ 150,000
Total Investment Cost				**$ 10,235,906**

50 Percent Battery Operation

Item	Cost Per Unit		Unit	Total
Batteries	$ 750	Qty	2509	$ 1,881,559
DC Grid / Drive System	$ 2,899,004	Qty	1	$ 2,899,004
Motors, Propulsion	$ 155,811	Qty	1	$ 155,811
Switchgear and Transformer	$ 248,685	Qty	1	$ 248,685
Integrator Execution, Commissioning, Engineering	20%	% of Ele. Equip.	$ 5,185,059	$ 1,037,012
Generators	$ 1,304,698	Qty	3	$ 3,914,093
Propellers	$ 50,000	Qty	2	$ 100,000
Reduction Gear	$ 200,000	Qty	2	$ 400,000
Systems, etc.	$ 150,000	per room	1	$ 150,000
Total Investment Cost				**$ 10,786,163**

All Battery with Shore Charging

Item	Cost Per Unit		Unit	Total
Batteries	$ 750	Qty	5380	$ 4,035,319
DC Grid / Drive System	$ 2,899,004	Qty	1	$ 2,899,004
Shore charging modifications	$ 1,105,128	Qty	1	$ 1,105,128
Motors, Propulsion	$ 155,811	Qty	1	$ 155,811
Switchgear and Transformer	$ 248,685	Qty	1	$ 248,685
Integrator Execution, Commissioning, Engineering	20%	% of Ele. Equip.	$ 8,443,947	$ 1,688,789
Generators	$ 1,304,698	Qty	1	$ 1,304,698
Propellers	$ 50,000	Qty	2	$ 100,000
Reduction Gear	$ 200,000	Qty	2	$ 400,000
Systems, etc.	$ 150,000	per room	2	$ 300,000
Total Investment Cost				**$ 12,237,434**

NANTUCKET

Diesel Mechanical

Item	Cost Per Unit		Unit	Total
Engines	$ 401	per kW	5120	$ 2,050,865
CPP System & Gears	$ 398	per kW	5120	$ 2,035,319
Ship Service Generator	$ 423	per kW	900	$ 381,000
Total Investment Cost				**$ 4,467,184**

Battery Power at Berths

Item	Cost Per Unit		Unit	Total
Batteries	$ 750	Qty	191	$ 143,386
DC Grid / Drive System	$ 2,899,004	Qty	1	$ 2,899,004
Motors, Propulsion	$ 187,048	Qty	1	$ 187,048
Switchgear and Transformer	$ 248,685	Qty	1	$ 248,685
Integrator Execution, Commissioning, Engineering	20%	% of Ele. Equip.	$ 3,478,123	$ 695,625
Generators	$ 1,304,698	Qty	3	$ 3,914,093
Propellers	$ 50,000	Qty	2	$ 100,000
Reduction Gear	$ 200,000	Qty	2	$ 400,000
Systems, etc.	$ 150,000	per room	1	$ 150,000
Total Investment Cost				**$ 8,737,841**

Peak Shaving

Item	Cost Per Unit		Unit	Total
Batteries	$ 750	Qty	1509	$ 1,131,855
DC Grid / Drive System	$ 2,899,004	Qty	1	$ 2,899,004
Motors, Propulsion	$ 187,048	Qty	1	$ 187,048
Switchgear and Transformer	$ 248,685	Qty	1	$ 248,685
Integrator Execution, Commissioning, Engineering	20%	% of Ele. Equip.	$ 4,466,592	$ 893,318
Generators	$ 1,304,698	Qty	3	$ 3,914,093
Propellers	$ 50,000	Qty	2	$ 100,000
Reduction Gear	$ 200,000	Qty	2	$ 400,000
Systems, etc.	$ 150,000	per room	1	$ 150,000
Total Investment Cost				**$ 9,924,003**

50 Percent Battery Operation

Item	Cost Per Unit		Unit	Total
Batteries	$ 750	Qty	1826	$ 1,369,142
DC Grid / Drive System	$ 2,899,004	Qty	1	$ 2,899,004
Motors, Propulsion	$ 187,048	Qty	1	$ 187,048
Switchgear and Transformer	$ 248,685	Qty	1	$ 248,685
Integrator Execution, Commissioning, Engineering	20%	% of Ele. Equip.	$ 4,703,879	$ 940,776
Generators	$ 1,304,698	Qty	3	$ 3,914,093
Propellers	$ 50,000	Qty	2	$ 100,000
Reduction Gear	$ 200,000	Qty	2	$ 400,000
Systems, etc.	$ 150,000	per room	1	$ 150,000
Total Investment Cost				**$ 10,208,747**

APPENDIX B

Operating Cost

MARTHA'S VINEYARD

System Properties

System Property	Unit	Diesel Mechancial	Battery Power at Berths	Peak Shaving	50 Percent Battery Operation	All Battery with Shorepower
Engine Size	kW	2560.00	0.00	0.00	0.00	0.00
No. Engines	-	2	0	0	0	0
Engines Operating	-	2	0	0	0	0
Vessel Operating Hours	hr	5187	0	0	0	0
Annual Engine Hours (ea.)	hr	3192	0	0	0	0
Generator Size	kW	300	2450	2450	2450	0
No. Generators	-	3	3	3	3	0
Generators Operating	-	1	2	1	2	0
Annual Generator Hours (ea.)	hr	1729	2128	1729	1108	0
Battery Bank	kWh	n/a	181	1897	2509	5380
Cycle Life	yr	n/a	10.00	10.00	10.00	10.00
Fuel Consumption	gal/trip	95.87	88.78	88.11	88.26	0.00
Shore Power Consumption	kWh/trip	0.00	0.00	0.00	0.00	1533.08

Annual Fluid / Shore Power Consumption

Fluid	Unit	Diesel Mechancial	Battery Power at Berths	Peak Shaving	50 Percent Battery Operation	All Battery with Shorepower
Diesel	gal	382506	354237	351571	352164	0
Urea	gal	19125	17712	17579	17608	0
Lube Oil (Consumption)	gal	593	354	352	352	0
Shore Power	kWh	0	0	0	0	6116979

Annual Costs

Annual Cost Item	$/unit	Diesel Mechancial	Battery Power at Berths	Peak Shaving	50 Percent Battery Operation	All Battery with Shorepower
Diesel	$ 2.15	$822,388	$761,609	$755,878	$757,152	$0
Shore Power	$ 0.16	$0	$0	$0	$0	$972,600
Urea	$ 3.23	$61,775	$57,209	$56,779	$56,874	$0
Lube Oil	$ 8.00	$4,745	$2,834	$2,813	$2,817	$0
Batteries	$ 750.00	$0	$13,573	$142,301	$188,156	$403,532
Engine Maintenance		$80,539	$0	$0	$0	$0
Reduction Gear Maint.		$4,000	$4,000	$4,000	$4,000	$4,000
Generator Maint.		$5,112	$53,693	$43,625	$27,965	$0
Motor Maint.		$0	$4,000	$4,000	$4,000	$4,000
Total Annual Cost		$978,559	$896,917	$1,009,395	$1,040,965	$1,384,132

Net Present Value of Annual Costs

Annual Cost Item	Inflation Rate	Diesel Mechancial	Battery Power at Berths	Peak Shaving	50 Percent Battery Operation	All Battery with Shorepower
Diesel	3.00%	$10,532,978	$9,754,528	$9,681,125	$9,697,450	$0
Shore Power	3.00%	$0	$0	$0	$0	$12,456,858
Urea	3.00%	$791,198	$732,724	$727,210	$728,436	$0
Lube Oil	3.00%	$60,778	$36,296	$36,023	$36,084	$0
Batteries	3.00%	$0	$173,841	$1,822,564	$2,409,862	$5,168,354
Engine Maintenance	3.00%	$1,031,525	$0	$0	$0	$0
Reduction Gear Maint.	3.00%	$51,231	$51,231	$51,231	$51,231	$51,231
Generator Maint.	3.00%	$65,478	$687,683	$558,743	$358,168	$0
Motor Maint.	3.00%	$0	$51,231	$51,231	$51,231	$51,231
Total Annual Cost		$12,533,188	$11,487,534	$12,928,127	$13,332,463	$17,727,674

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System Properties

System Property	Unit	Diesel Mechanical	Battery Power at Berths	Peak Shaving	50 Percent Battery Operation
Engine Size	kW	2560.00	0.00	0.00	0.00
No. Engines	-	2	0	0	0
Engines Operating	-	2	0	0	0
Vessel Operating Hours	hr	3280	0	0	0
Annual Engine Hours (ea.)	hr	2680	0	0	0
Generator Size	kW	300	2450	2450	2450
No. Generators	-	3	3	3	3
Generators Operating	-	1	2	1	2
Annual Generator Hours (ea.)	hr	1093	1787	1093	1333
Battery Bank	kWh	n/a	191	1509	1826
Cycle Life	yr	n/a	10.00	10.00	10.00
Fuel Consumption	gal/trip	299.72	277.78	274.70	276.28
Shore PowerConsumption	kWh/trip	0.00	0.00	0.00	0.00

Annual Fluid / Shore Power Consumption

Fluid	Unit	Diesel Mechanical	Battery Power at Berths	Peak Shaving	50 Percent Battery Operation
Diesel	gal	359663	333340	329642	331540
Urea	gal	17983	16667	16482	16577
Lube Oil (Consumption)	gal	537	333	330	332
Shore Power	kWh	0	0	0	0

Annual Costs

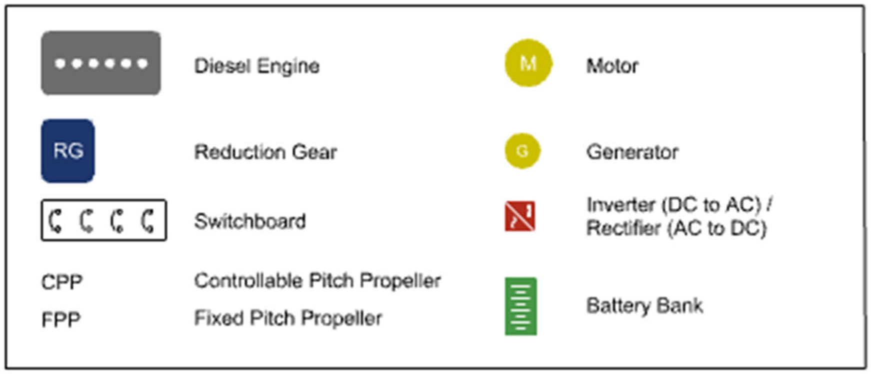
Annual Cost Item	$/unit	Diesel Mechancial	Battery Power at Berths	Peak Shaving	50 Percent Battery Operation
Diesel	$ 2.15	$773,275	$716,682	$708,731	$712,810
Shore Power	$ 0.12	$0	$0	$0	$0
Urea	$ 3.23	$58,086	$53,834	$53,237	$53,544
Lube Oil	$ 8.00	$4,292	$2,667	$2,637	$2,652
Batteries	$ 750.00	$0	$14,339	$113,186	$136,914
Engine Maintenance		$67,620	$0	$0	$0
Reduction Gear Maint.		$4,000	$4,000	$4,000	$4,000
Generator Maint.		$3,233	$45,080	$27,586	$33,642
Motor Maint.		$0	$4,000	$4,000	$4,000
Total Annual Cost		$910,506	$840,602	$913,377	$947,563

Net Present Value of Annual Costs

Annual Cost Item	Inflation Rate	Diesel Mechancial	Battery Power at Berths	Peak Shaving	50 Percent Battery Operation
Diesel	3.00%	$9,903,947	$9,179,113	$9,077,278	$9,129,531
Shore Power	3.00%	$0	$0	$0	$0
Urea	3.00%	$743,948	$689,501	$681,851	$685,776
Lube Oil	3.00%	$54,975	$34,155	$33,776	$33,970
Batteries	3.00%	$0	$183,646	$1,449,657	$1,753,569
Engine Maintenance	3.00%	$866,067	$0	$0	$0
Reduction Gear Maint.	3.00%	$51,231	$51,231	$51,231	$51,231
Generator Maint.	3.00%	$41,405	$577,378	$353,321	$430,879
Motor Maint.	3.00%	$0	$51,231	$51,231	$51,231
Total Annual Cost		$11,661,573	$10,766,255	$11,698,345	$12,136,188

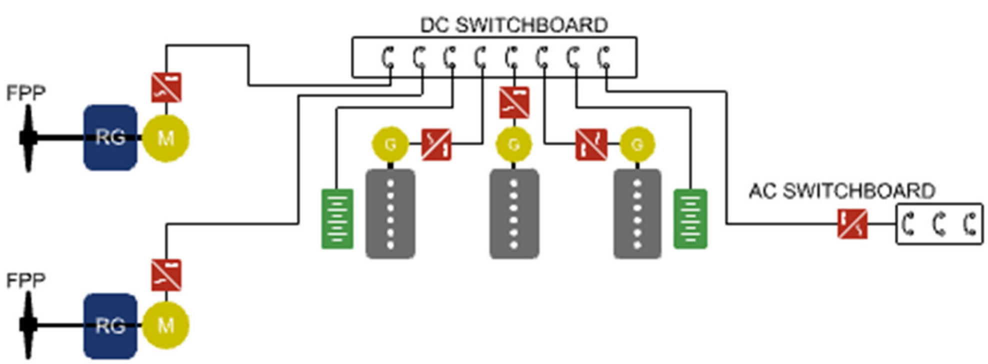
APPENDIX C

System Sketches



DIESEL MECHANICAL, CPP

DIESEL HYBRID, FPP



Note that Options 2-5 are each a variation of the Diesel Hybrid arrangement with the quantity of batteries, generators and a shore power connection as variables.