# Vessel Electrification Feasibility Study for the New York State Canals

Final Report

Prepared for

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# NOTICE



# DISCLAIMER

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16. Abstract:
The objective of this study was to determine the technical and economic feasibility of repowering a diesel-fueled New York State Canal Corporation (NYSCC) work boat with a diesel hybrid-electric or full-electric powertrain. The project team instrumented a NYSCC dredge tender to capture in-use data to determine the vessel's duty cycle. A comprehensive evaluation of commercially-available hybrid-electric and full-electric marine powertrains was performed. The results revealed that only one full-electric system met NYSCC's performance and cost targets. A cost-effective electric powertrain system is expected to handle approximately 95% of the dredge tender's typical duties. The remaining high energy use cases that are not met will be handled by NYSCC dispatching a diesel boat. An evaluation of the available electric recharging infrastructure on shore and using excess power from mobile work platform generators was also performed. The investigation revealed that shore power was available at many, but not all, locations where the boat frequently visits. The project concluded that hybrid-electric and full-electric powertrains are a potentially viable technology option for NYSCC to consider to reduce its operating costs, carbon footprint, and energy use. Thus, NYSCC and New West Technologies proposed a Phase II field demonstration project to NYSERDA and NYSDOT to install a full-electric powertrain and perform a long-term field demonstration project to validate the electrically-powered boat's performance. The Phase II project was awarded and is expected to be completed in early 2014.


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# ABSTRACT

This study presents a technical and economic feasibility assessment for repowering New York State Canal Corporation (NYSCC) diesel work boats with hybrid-electric and full-electric powertrains. Over the next decade, NYSCC will need to rebuild or replace many of the work boat vessel engines. The vessels themselves are historical so will likely remain in service, so upgrading the powertrain is the most probable path. The results of this Phase I project are intended to provide NYSCC with the technical and economic information needed to develop electric boat fleet deployment and charging infrastructure expansion plans.

A data acquisition system and measurement sensors (e.g., propeller torque, propeller speed, fuel rate, and global positioning system) were used to capture in-use real-world on a NYSCC dredge tender. The instrumented boat works exclusively on the Utica Section of the New York State Canal (Canal). The data were analyzed to characterize the dredge tender's duty cycle and to quantify the daily power and energy requirements for the boat. The analysis revealed that roughly 95% of the dredge tender's normal use could be met with a powertrain with 100 bhp of shaft power and 55 kWh of energy. Data collected and analyzed from a NYSCC work platform (a derrick boat) showed that ample spare generator power exists to provide a battery charging option during the day. This option could be used either to increase the daily electrically-driven range, or to allow downsizing of the battery pack. A shorepower electric charging infrastructure evaluation was also done for the length of the Utica Section of the Canal. The study revealed that many locks along the Canal have shorepower available. Others likely could have shorepower added; however a thorough analysis of this was not done.

An exhaustive evaluation of commercially-available hybrid-electric powertrain system was done first to determine which systems could meet the performance and cost targets for NYSCC. Only one hybrid-electric system (ReGen Nautic USA) met the performance requirements and had a price that was within reason for both a demonstration project and for hopeful future NYSCC funded deployment. Project Team discussions revealed the system was still too expensive for NYSCC to consider, so the project was refocused on a full-electric system. Moving to a full-electric system raises the concern that the boat could be left stranded if it did not make it back to dock or another charging location before the battery pack was "empty". This was acceptable to NYSCC and will be dealt with by changes to boat work scheduling to ensure the electric boat is deployed on appropriate jobs.

A simulation model was developed that incorporated the performance of the baseline diesel and the conceptual electrically-powered vessels and was used to estimate the energy, emissions, and cost savings of the hybrid-electric and full-electric powertrain options. The lowest battery capacity system option (52 kWh) was selected to meet 95% of NYSCC duties. The simulations showed that this system was the most cost-effective. The higher capacity systems (76 kWh and 92 kWh) were much higher cost due to the battery cost, but were not able to capture much more of the tender's duties, so only saved a small amount more fuel (7% and 10% respectively). The 52 kWh system is estimated to payback the initial investment in 12 years and will result in a net savings of $71,000 (assuming a 15-year battery replacement interval) or $45,000 (assuming a 10-year battery replacement interval). Both are very positive results.

**Keywords:** marine hybrid, electric powertrain, electric vessel, electric tug, electric boat, canal, waterway

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# EXECUTIVE SUMMARY

## BACKGROUND

The New York State Canal Corporation (NYSCC) is continually searching for opportunities to improve the environmental profile and operating cost of their New York State Canal System (Canal) maintenance vessel fleet. In this joint New York State Energy Research and Development Authority (NYSERDA)/New York State Department of Transportation (NYSDOT)-funded project, NYSCC and engineering consultant firm, New West Technologies (NEW WEST), performed a technical and economic feasibility assessment of hybrid-electric and full-electric powertrain options for NYSCC's vessel fleet. At the start of this Phase I feasibility project the NYSCC vessel fleet included: 11 tugboats, 11 dredge tenders (small tugs), four (4) hydraulic dredges, seven (7) self-propelled scows, five (5) derrick boats, two (2) Gradall (excavator) boat, 20 buoy boats, and four (4) quarter boats. The Project Team decided the focus should be on the dredge tenders (referred to from here on as simply "tenders") since they are heavily used and all of the boats have nearly the same powertrain (many use the same engine). The decision will facilitate the deployment of electrically-powered tenders using the same system across a relatively large number of boats.

Tender 4 was selected for duty cycle monitoring. The 1929 boat is powered with a 1980s-era Detroit Diesel 6-71 two-stroke diesel engine. The engine was originally rated to produce 174 brake horsepower (bhp) and 500 ft-lbs of torque at 1,800 rpm at the crankshaft. A 2:1 reduction gearbox is installed between the engine and the 30 inch propeller. The maximum engine performance values recorded at the propeller shaft during the project were approximately 150 bhp and 1,000 ft-lbs of torque. NEW WEST installed a comprehensive data acquisition (DAQ) system on Tender 4 to monitor the boat's activities and record the in-use operational data. Discrete sensors for torque and fuel flow were needed because the engine does not have an electronics control unit to connect to access and record the data as modern engines would. The DAQ system included several components to collect and store this data, including: a SoMat eDAQ*lite* rugged field data acquisition system; a Sierra Wireless Raven X wireless modem (for remote communication and data downloads); a Binsfield Engineering TorqueTrack Revolution torque sensor to measure propeller shaft torque and speed; a Technoton DFM 250D differential fuel flow meter (DFM) to measure instantaneous fuel consumption; and a GPS antenna to measure position. A DAQ system schematic is shown in Figure 1.

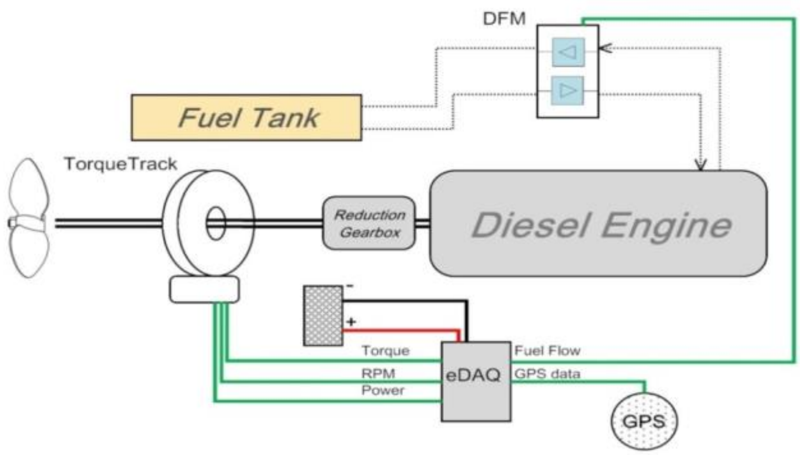


**Figure 1: Data Acquisition System Schematic**

## BASELINE DIESEL BOAT DUTY CYCLE DATA COLLECTION AND ANALYSIS

The goal of the vessel monitoring period was to collect operational data for all of the vessel's activities for an entire NYSCC operating season (typically mid-April through mid-November; depending on weather conditions) to gather a typical year's operational data. Equipment failures (presumably from old vessel battery), limited access to vessel while working, and other unforeseen issues led to a reduction in overall data collected. Vessel mechanical issues, including a faulty alternator and battery system and an oil leak (near the end of the season, assumed to be an oil cooler issue but was identified as head gasket issue), led to additional days when the boat was inactive and not able to record duty cycle data. Ultimately, the monitoring period extended from June 21, 2012 to early October when mechanical issues removed the vessel from service. Overall, only 25 days of high-quality operational data were collected. The duty cycle data showed that daily tender operations on the Utica Section of the Canal can effectively be split into three intensity levels depending on the type of work that the tender did for each day, including:

- Low intensity– Supplies and personal movement, light barge transport, light dredge support, and other light canal maintenance work); approximately 20% of the instrumented tender's daily duties
- Medium intensity – Relatively constant barge movements to move dredged material to dumping areas; approximately 75% of the instrumented tender's daily duties
- High intensity – Heavy-duty extended dredge movements; approximately 5% of the instrumented tender's daily duties

The overall compilation of the low-, medium, and heavy-duty days was combined to create the overall NYSCC tender duty cycle profile shown in Figure 2.

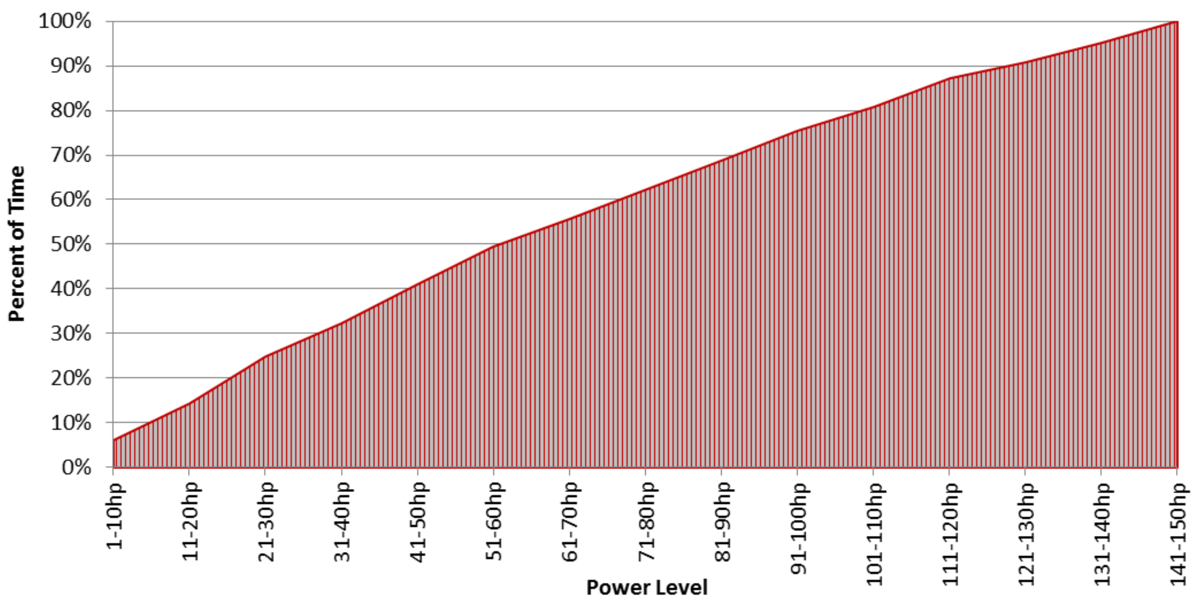


**Figure 2: NYSCC Tender 4 Duty Cycle Profile (% of Time at or Below Power Level)**

## EVALUATION OF CHARGING POTENTIAL FROM STATIONARY EQUIPMENT

The potential to recharge the electrically-powered tender onsite during the workday using excess generator capacity on work boats (e.g., derrick boats and dredges) to either extend the boat's range/work capability or to minimize the battery pack capacity was evaluated. To do this, a DAQ system (including a SoMat eDAQ*lite* data acquisition system, a Continental Control Systems WattNode electrical energy meter, and a Sierra Wireless broadband cellular modem wireless modem) was installed on the main generator of a NYSCC derrick boat.

Several months of operational data were collected and analyzed. The result was that only a fraction of the generators full power capacity was ever used. The genset was rarely operated at over 25% load and spent the majority of its operation time at 5-10% of its total power output (65 kW).The generator was operated for an average of 6.6 hours per work day to produce an average of 22.3 kWh of energy, while consuming 6.7 gallons of fuel. This extended operation time at loads well below the rated power of the genset provide a charging opportunity for the electrified tender at the dredge during daily operations. The increased load due to charging would result in increased overall fuel consumption, but the brake specific fuel consumption (BSFC) (i.e., the fuel consumed per energy output) decreases because of increased engine efficiency at higher loads. However, to maximize the overall fuel reduction benefits, it is suggested that charging from equipment mounted generators only be used for supplemental power when utility grid electricity is not available to complete the required operations.

## ELECTRICAL CHARGING INFRASTRUCTURE STUDY

Independent of the type of electrical propulsion system chosen and the duty cycle of the specific vessel, the need for a suitable electrical infrastructure available to charge the electrically-powered tender is imperative. NEW WEST conducted a comprehensive charging location inventory of all shore-side electrical infrastructure utilized by NYSCC in the Utica Floating Plant section of the canal to determine all the charging locations that would be available to the electrically-powered tender. The focus area of this inventory includes locations from Sylvan Beach (on Oneida Lake) to Lock 16 in Minden, NY (Lock 16 is not part of the Utica Floating Plant Section; however, their vessels may occasionally visit this location). The majority of the charging locations are at locks along the Canal which NYSCC employees often use as a mooring location for the vessels when the vessels are not actively being used. However, additional locations with electrical infrastructure are available including Sylvan Beach and a location near the Utica Floating Plant headquarters location. Others likely could have shorepower added; however a thorough analysis of this was not done. The overall layout of the Utica Section of the Erie Canal, showing canal infrastructure and resting locations recorded from the tender, are shown in Figure 3.


**Figure 3: Canal Electrical Infrastructure Layout and Tender Resting Locations**

Shorepower charging pedestals are available at most lock locations and at the Utica Floating Plant where the boat will likely be docked at night. Three-phase 208 VAC outlet rated at 50 amps was the predominantly available type of power. This power type will be the type required for the battery charger specified for the follow-on demonstration.

**ELECTRIC PROPULSION SYSTEM EVALUATION**

The goal of the evaluation was to identify all of the commercially-available potential electric powertrain options and then narrow the list to determine the best option to determine the economic and environmental savings. The project's initial focus was on a hybrid-electric system because NYSCC required that the vessel could operate for a whole day (10 hours for the Utica Section) at full power if needed. A NYSCC tender application and duty cycle summary document was developed and was shared with component and system providers to aid them in developing a conceptual sub-component or complete powertrain system and cost estimate.

The evaluation began with an investigation of components (e.g., batteries and electric motors). Several battery chemistries were evaluated and discussions were held with battery providers. Lead-acid (many manufacturers), nickel metal hydride (Cobasys, Saft), sodium-metal halide (General Electric Durathon), and lithium-ion batteries (many manufacturers) were included in the evaluation. Lithium-ion were recommended by all of the powertrain companies for the lowest total cost of ownership. Nickel metal hydride has similar cost and lower performance than lithium-ion so was not recommended by any powertrain provider. The General Electric Durathon batteries (manufactured in Schenectady, NY) were not yet available for mobile applications. Lead-acid was only recommended by electric propulsion providers if minimizing initial system cost was the driving factor.

After discussing the NYSCC tender application with component manufacturers, it became clear that it was necessary that the optimized NYSCC tender powertrain system had to be developed as a system by a powertrain provider company to ensure the system was high-quality, reliable, efficient, and capable of performing its duty in the NYSCC tender. The commercially-available powertrain system options included a range of powertrain architectures and a wide range of electric motor output power from partial-power (on the order of 10 kW [13 bhp]) to full-power capability (>200 kW [268 bhp]). The hybrid-electric powertrain options and the companies fell into three groups:

- Electric Power Too Low – Elco Motor Yachts (Athens, NY), Mastervolt (Netherlands), Propulsion Marine (Santa Barbara, CA), Nanni (France), and Steyr Motors (Germany)
- Electric Power Suitable, but System Price Too High – American Traction System (Fort Meyers, FL), Ecomarine Propulsion Systems Corp. (U.S.), Northern Lights (Seattle, WA), and Siemens Marine (Germany)
- Suitable for NYSCC tender application – ReGen Nautic USA (Fort Lauderdale, FL)

ReGen Nautic was the only company who met the system capabilities and had a price that was within reason for both a demonstration project and for hopeful future NYSCC funded deployment. ReGen Nautic has developed hybrid-electric and full-electric propulsion systems for various marine vessels including yachts, trawlers, and sailboats, mainly for applications over 50 feet. The company uses robustly designed automotive-grade electric drive and control components. This approach eliminates duplicated development effort/cost and also results in lower part costs since the combined component sales volumes are higher. ReGen Nautic designs and produces the unique components needed for system function, including the high-voltage boxes and the software for integration and safety systems that control the system operation. The automation control systems are customized for each vessel design to maximize efficiency. The tender hybrid powertrain system quote was $155,000, so was considerably less expensive than all of the other systems. This cost will make payback based on fuel and maintenance alone difficult, but was closer to what NYSCC could realistically consider deploying in the fleet. ReGen Nautic does not install the system; installation is the fleets' responsibility (either with full-time staff or a third-party installer). ReGen Nautic will assist with the system integration design to determine where the components will be located and how all of the wiring and cabling will be routed. All cables, wires, and components are packaged on shipping pallets along with detailed installation procedures. ReGen Nautic claims that all of the power and signal wire connections are plug-and-play and should be straightforward during installation. The fleet is also responsible for designing and fabricating the mounting racks and brackets for the batteries and for the electric motor. ReGen Nautic requires that the first installation by each fleet or installer does be inspected and verified by a ReGen Nautic engineer (for an additional $15,000) before the vessel can be commissioned. The fee includes one week of onsite support. The engineer will also make the high-voltage cable connections to ensure they are done properly. This factory-certified inspection is only needed for the first installation.

## FULL-ELECTRIC VERSUS HYBRID-ELECTRIC POWERTRAIN

The Project Team (NEW WEST, NYSCC, NYSERDA, and NYSDOT) discussed the available hybrid-electric system options and the high cost for systems suitable for the NYSCC tender application. All of the systems, except the ReGen Nautic system, were significantly too expensive. The ReGen Nautic system is much less expensive, but is still too expensive ($155,000) for NYSCC to realistically consider for deployment once the demonstration project is completed using NYSCC funds. Because of these findings, NYSCC made the decision to change the powertrain design focus to a full-electric system instead. The change actually better fits NYSCC's long-term goal to eliminate diesel fuel use and thus eliminate the cost and variability in cost for their fleet. Moving to a full-electric powertrain reduces the system cost because the generator and the associated mounting and other hardware are not required. Depending on the original hybrid-electric battery capacity, a larger battery pack may be needed to meet the range requirement which would increase the cost. The duty cycle analysis of the collected data and discussions with NYSCC staff showed that approximately 95% of the tender's typical duty on the Utica Section of the Canal could be met with a full-electric system with a reasonably sized (and thus cost) battery pack. Mr. Gritsavage understands this limitation and stated that the fleet would have to be managed in a slightly different way to ensure that a diesel tender was assigned to the 5% of the duties that the electric boat cannot handle.

Moving to a full-electric system raises the concern that the boat could be left stranded if it did not make it back to dock or another charging location before the battery pack was "empty". Mr. Gritsavage agreed this was a concern, but would have to be incorporated into how the boats' duties were scheduled. The option of including an emergency/standby generator in the system was discussed by NYSCC and New West, but was dismissed because of the increased system complexity and because retrieving a stranded tender is not difficult since the boat would never be stranded on open waters and that the canal at its widest is only several hundred yards wide. (Also, the electric powertrain control systems generally are configured to discharge the down to 20% state-of-charge [i.e., 20% capacity remaining in the pack] for battery life reasons. The result is the pack would have enough charge to move the boat to the side of the canal to not interfere with Canal traffic and so it could be accessed by shore if necessary.) Several options are available to remedy this issue if/when it occurs. One option is that another tender could be deployed to tow the electric tender back to dock or another charging location. This is not ideal because the rescue tender would increase its diesel fuel use for the trip to meet up with and then to tow the electric tender. Depending on the location of the rescue boat when it was deployed and the location of the electric tender large quantity of fuel could be used, effectively decreasing the electric tender's payback. Another option would be to send a pickup truck with an emergency generator in the bed to the shoreline nearest to the tender to charge the pack enough to get the boat back to the dock. This option would also use fuel for the rescue truck, but the fuel consumption of a truck is much lower than for a boat, so would impact the fuel use and payback less.

With this revised direction, New West reconnected with ReGen Nautic to have them revise the system design and quote for a full-electric powertrain. New West also contacted BAE Systems' HybriDrive division (Endicott, NY) directly since earlier discussions with Northern Lights indicated that BAE Systems was interested in the project for business reasons and also because it supports New York state business. BAE Systems was interested in the project and even though HybriDrive has no commercialized full-electric system. BAE stated that the drive and control components and software is used in other applications so can be relatively easily modified for the tender application. Ultimately, BAE did not provide a cost quote and did not reply to numerous attempts to contact the to discuss the system quote. None of the other powertrain provider companies were contacted for a full-electric system quote because it was clear from the earlier discussions that the powertrain architecture change would not dramatically reduce the system prices to a point that would provide an acceptable payback for NYSCC.  Only ReGen Nautic provided a quote response for the full-electric system.

ReGen Nautic USA –ReGen Nautic revised the original hybrid-electric system design to develop a full-electric system. The generator and related hardware were removed and the battery pack capacity was increased from 53 kWh to 76 kWh. The total hardware costs for this system was quoted to be $106,000. ReGen Nautic also quoted additional battery capacity moving from 76 kWh to 92 kWh for an additional $10,300 if it was needed/requested. The total cost for this system would be $116,300.

**POTENTIAL SYSTEM BENEFITS**

A simulation model was developed that incorporates the performance of the baseline diesel and the conceptual electrically-powered vessels to estimate the energy, emissions, cost, and other benefits of the electric-powered tender compared to the current diesel tender.. The data recorded by the DAQ system was post-processed to convert the various sensors' outputs (in the form of frequencies, voltage measurements, and pulse counts) to useable duty cycle data that reflected the vessel's duties and to filter out erroneous data points (e.g., torque spikes, vibrations, and signal noise). The duty cycle data parameters (shaft power, shaft torque, fuel consumption rate, and GPS data) were inputs to the model. The model architecture incorporated component (e.g., electric motor, electric motor controller, and battery pack) efficiencies. The power, torque, and shaft rotational speed duty cycle data were collected directly from the vessel's output shaft. This allowed the propulsion system to be treated as a "black box" to allow various combinations of system components to be modeled. The model initially included an onboard generator, which required runtime logic. The energy modeling method provided flexibility for evaluating propulsion system configurations. To account for the days not monitored, the collected data was extrapolated, using weighting factors that were derived through discussions with NYSCC staff and review of the vessel's operational logs to reflect the total annual operation. Published vessel's emission data from a U.S. Department of Transportation, Maritime Administration emission factors study of similar engines in marine applications were used to develop representative emissions for all engine loads and speeds. The amount of diesel fuel the electrically-powered vessel eliminates is directly related to the vessel's battery energy storage capacity and the amount of vessel operation time that it can offset. For modeling purposes, it was assumed that the electric vessel's daily operational profile would be modified slightly by NYSCC fleet management to maximize the electric vessel usage and capitalize on all potential charging opportunities while the vessel was not active. The analysis assumed that NYSCC will allocate a diesel-powered tender for the extremely heavy-duty operational days (roughly 5% of work days) to minimize the battery storage capacity/costs. Larger battery capacities would allow for longer operation times between charging and thereby potentially offset more diesel tender operation. However, the significant initial cost associated with increased battery capacity can easily offset the potential savings. To quantify the ideal energy storage capacity to achieve the most economical success of the system, various sized energy storage, including 52, 76, and 92 kWh capacities were evaluated and a comprehensive economic analysis completed. (The capacity values were selected based on available battery capacity levels from ReGen Nautic.) Further daily vessel operation optimization to maximize the available battery capacity per day can be accomplished by NYSCC by scheduling vessel duties that can be completed with ample charging times between. The potential benefits discussed in this section are based on the vessel operational data recorded throughout the 2012 NYSCC operating season for diesel-powered Tender 4.

**Energy Savings**

The energy savings resulting from the electrified propulsion system are in the form of decreased diesel fuel use, less the electrical energy required to recharge the batteries. The costs and environmental impacts associated with the electricity are significantly lower than the eliminated diesel fuel. The estimated overall energy offsets from a diesel tender retrofit with an electrified propulsion system are shown in Figure 4. This figure shows the expected diesel fuel reductions as well as the required electrical energy (in diesel gallon equivalent [DGE] units).[1] The chart also shows that the additional fuel savings from the larger battery pack capacities (i.e., 76 and 92 kWh) are small. Given the high cost for batteries, this limits the payback potential for higher battery capacities.

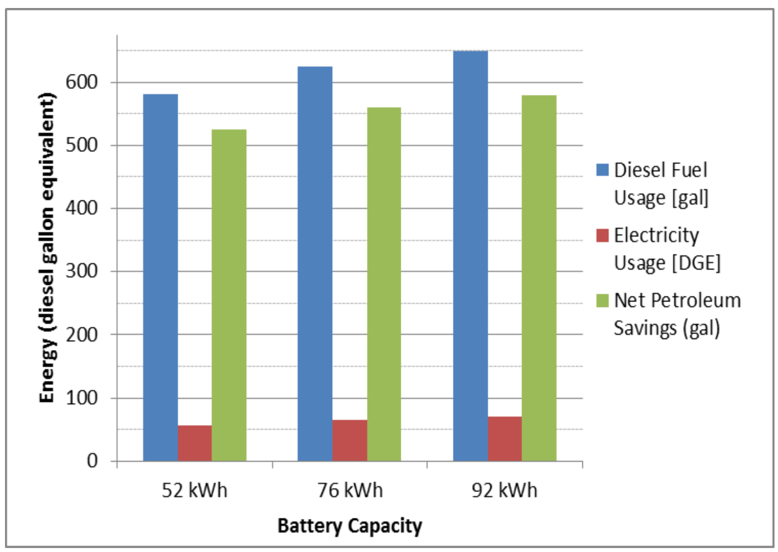


**Figure 4: Electrified Tender Energy Savings**

[1] Diesel gallon equivalents calculated with information taken from http://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf

### Emissions Savings

The electrified tender's potential emission savings are directly related to the fuel offset benefits and to the clean electrical energy available in New York State. The vessel's current Detroit Diesel 6-71 diesel engine is relatively fuel efficient, however considering the engine's two-stroke design, the lack of an exhaust aftertreatment system, its age, and duty cycle, it emits a significant amount of pollutant emissions. While the emissions produced are generally correlated to the amount of diesel fuel used, the specific emission rates also vary with engine load and speed. To account for all varying and transient emission factors, emission estimates were modeling using second by second data collected throughout the season and then combined to provide a yearly emission offset that could be realized from the electrified vessel. The annual potential emission savings (shown in mass and percent savings) compared to the baseline diesel vessel are shown in Figure 5.

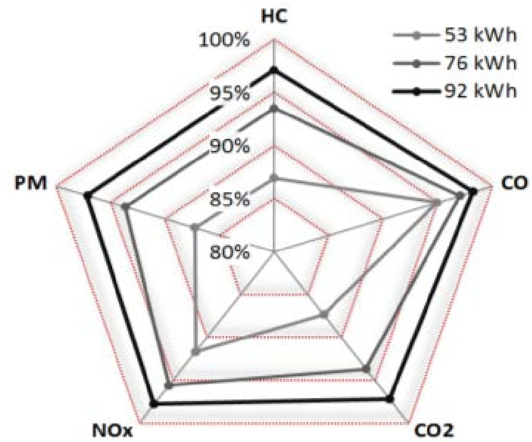


**Figure 5: Potential Electrified Vessel Emission Savings**

### Cost Savings

Annual operating cost savings during the operation of the electrified tender would be realized from reductions in both energy costs and vessel maintenance. Electric powertrains only have a few moving parts and are typically very reliable and require little maintenance. Battery packs require little or no maintenance, but will require replacement(s) during the vessel lifetime which adds cost. The modeling showed that approximately $140 of grid-supplied electricity is able to eliminate over $2,000 of diesel fuel costs per year (at current rates). NYSCC provided diesel fuel cost ($4.00/gal) and electricity cost ($0.06/kWh) data for current costs. Future fuel and electricity cost variations were accounted for by using future fuel cost data taken from the U.S. Energy Information Administration's Annual Energy Outlook to calculate energy cost variability as accurately as possible. Significant yearly cost savings would also be potentially seen from the reduction in vessel maintenance pertaining to its current diesel engine including engine fluids, filters, labor, and misc. components. NYSCC Utica Floating Plant Maintenance staff estimated that each tender requires approximately $2,000 worth of engine maintenance each year (including parts and labor).

Table 1 provides a summary of the initial system cost and the estimated annual savings for each battery capacity variant. The higher battery capacity variants are estimated to only save a small amount of fuel and cost above the base (52 kWh) system assuming the electric tender will be used for the light- and medium-duty uses (roughly 95% of tender duties). The higher capacity systems will be able to operate for longer periods to handle some of the heavier duty demands on tenders; however will only incrementally improve the tender's utility to NYSCC and impedes the system payback.

**Table 1: Summary of System Variant Performance**

| | | | |
|---|---|---|---|
| Battery Pack Capacity (kWh) | 52 kWh | 76 kWh | 92 kWh |
| Incremental System Cost | $50,425 | $64,225 | $73,825 |
| Fuel Offset [gal] | 582 | 625 | 650 |
| Diesel Fuel Cost ($) (@ $4/ gallon) | $2,328 | $2,500 | $2,600 |
| Electrical Energy Use [kWh] | 2,278 | 2,639 | 2,849 |
| Electrical Energy Use [DGE*] | 57 | 66 | 71 |
| Electricity Cost ($) (@ $0.06/ kWh) | $137 | $158 | $171 |
| Annual Energy Savings | $2,191 | $2,342 | $2,429 |
| Maintenance Savings | $2,000 | $2,000 | $2,000 |
| Total Annual Savings | $4,191 | $4,342 | $4,429 |
| Savings Over Base System | n/a | $150 | $238 |

Overall, the system is predicted to provide a payback of the initial investment in 12 years (52 kWh, 14 years (76 kWh), and 16 years (92 kWh). NYSCC repowers tenders infrequently. NYSCC currently has tenders with engines that are 30-42 years (1980s-1971) old. Assuming a 35 year useful life between engine repowers, the different system levels will save NYSCC $114,000, $107,000, and $100,000 respectively. These calculations, however, assume the battery pack is not replaced, so are not realistic projections.

Battery replacement is a significant factor that must be included. This is especially true for Li-ion batteries which are currently very expensive. The ReGen Nautic supplied battery pack replacement costs (in 2012) for the different capacity levels are $30,000, $43,200, and $53,600 respectively. The cost of replacement Li-ion batteries are expected to be much lower when the pack needs to be replaced given the R&D emphasis supporting the plug-in electric vehicle and renewable power industries, so the analysis included this assumption.

The initial capital cost payback is unaffected by the battery replacement costs. Assuming a 15 year battery replacement schedule, the vessel reaches a net positive savings in Year 17 (52 kWh), Year 22 (76 kWh), and Year 25 (92 kWh) respectively. Over the 35 year useful life between engine repowers, the different system levels will save NYSCC $71,000, $45,000, and $26,000 respectively. Assuming a 10 year battery replacement schedule, the vessel reaches a net positive savings in Year 23 (52 kWh), Year 32 (76 kWh), and roughly reaches breakeven (92 kWh) over the engine useful life respectively. Over the 35 year useful life between engine repowers, the different system levels will save NYSCC $45,000, $17,000, and roughly breakeven respectively.

The payback and savings are summarized below in Table 2.

**Table 2: Summary of Payback and Savings**

| Battery Pack Capacity (kWh) | 52 kWh | | | 76 kWh | | | 92 kWh | | |
|---|---|---|---|---|---|---|---|---|---|
| Battery Pack replacement Interval | None | 15 year | 10 year | None | 15 year | 10 year | None | 15 year | 10 year |
| Initial Capital Cost Payback (years) | 12 | 12 | 12 | 14 | 14 | 14 | 16 | 16 | 16 |
| Years to Net Positive Cash Flow | 12 | 17 | 23 | 14 | 22 | 32 | 16 | 25 | n/a |
| Total Savings over Diesel Engine Useful Life | $114,000 | $71,000 | $45,000 | $107,000 | $45,000 | $17,000 | $100,000 | $26,000 | $- |

**Other Benefits**

The noise level on the vessel for NYSCC crew and onshore for Canal users and residents along the canal is expected to be significantly lower.

## POTENTIAL CHALLENGES

### Daily Operation

The tender's limited daily operating time is one of the challenges to the economic payback of electrified propulsion system for NYSCC's vessels. The typical daily run time for the current tender is less than two hours a day, which limits the fuel reduction potential offset. (As mentioned earlier, this includes 95% of typical daily operation, but does not include heavy-duty operations and extended towing requirements.) To maximize the annual fuel savings and improve the payback, the electrically-powered tender should be operated as much as possible. This will require a NYSCC Operations to ensure the vessel is deployed every work day for a job it is capable of completing. This will require NYSCC Operations Managers to work with vessel operators to promote understanding and interest in the system and its benefits throughout the vessel crew. This could also mean that the electric tender is deployed to locations where it could charge from shorepower or from mobile equipment generators to increase the daily range. Preliminary interest from the dredging crews, gauged by NEW WEST through informal discussions when onsite and gathering operational information, is extremely high and all parties were motived to utilize this technology. This interest, along with the significantly more favorable operational characteristics (e.g., significantly reduced powertrain noise, vibration, fumes) should prove very successful for the deployment and usage of this technology.

### Seasonal Operation

The tender's annual operating time is further restricted because of NYSCC's limited operating season for Canal maintenance and dredging activities. The season is limited because of icing on the Canal, so most NYSCC vessels are removed from the water between early-November and mid-April (depending on weather). This results in the vessels only operating six to seven months out of the year which slows the economic payback.

## RECOMMENDED PERFORMANCE SPECIFICATIONS

Based on the analysis of the collected duty cycle data, even the lowest battery capacity variant (52 kWh) full-electric system is capable of handling roughly 95% of the tender's typical duties. The analysis also showed that this variant is the most cost-effective. Since the data collection was limited due to the various issues discussed in Section 3, to ensure that the demonstration boat is not battery capacity limited, it is recommended to move up to the next capacity system (76 kWh). The 76 kWh system is still cost-effective and reaches a net positive value within the vessel's engine repower timeframe. This will increase the demonstration system cost by roughly $14,000. The goal will be to validate that the lower capacity (52 kWh) system would have been sufficient to support the most cost-effective system for future NYSCC deployments.

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# SECTION 1
# INTRODUCTION AND BACKGROUND

The New York State Canal Corporation's (NYSCC) goal is to transform the New York State Canal System (Canal) into a world-class recreation way, with clustered development to foster recreation, tourism and economic development, while preserving the natural and historical environment of the system and its adjacent communities. By incorporating efficient propulsion technology that significantly reduces its petroleum fuel usage and greenhouse gas emissions (GHG) to improve the sustainability of the Canal, NYSCC vessels will serve as a model for the vision they are promoting. Electric propulsion systems with onboard energy storage and the capability to recharge on utility grid power are viewed as a technology that could be used with NYSCC vessels, because the vessels typically only have single day duties and return to base nightly. By incorporating this efficient propulsion technology, which minimizes fossil fuel usage (even in the electricity generation), emissions, and operational expenses, NYSCC's electric boats will serve as a model for the vision NYSCC is promoting. Although the potential for electric boat use appears very strong, a proper thorough investigation is required to ensure that the electric powertrain meets, or exceeds, current and projected NYSCC operational performance requirements. New West Technologies, LLC's (NEW WEST) extensive staff experience and expertise were contracted by NYSERDA (NYSERDA Agreement Number 25735) and NYSDOT (Task Assignment Number C-11-10) to evaluate the technical and economic feasibility of electric powertrain options in the Phase I feasibility study presented here. Using a project-tested data collection and analysis approach, the NEW WEST worked with NYSCC staff to collect the necessary in-use data to specify an electric propulsion system that provides necessary vessel performance for its operational functions. The energy, environmental, and economic benefits of the specified electric propulsion system were determined or estimated to quantify the impacts and to determine the cost-effectiveness of the system.

Another important consideration in addition to the vessel's electric propulsion system is the electrical infrastructure needed to charge the onboard battery system. Existing charging infrastructure capable of, and accessible to, NYSCC vessels along the section of the canal being studied were evaluated. NEW WEST also investigated the potential of charging the vessel's batteries from dredges or other floating equipment already equipped with generators as an option to increase the available battery power during the work day since the vessels are often stationary for a considerable amount of the day. The use of lock generated hydroelectric power was also considered.

Shipping freight through the Canal is economically-viable in certain situations to replace truck traffic. However, while marine transport is generally more efficient than trucking, NYSCC's fleet of vessels used to operate and maintain the Canal is wholly-dependent on fossil fuels. In addition, many of the vessels have very old engines (>30 years) which are neither fuel-efficient, nor clean running. Without action, the NYSCC fleet is fully exposed to the volatile and increasing petroleum fuel prices. The dredge tender (referred to as a "tender" for the remainder of the report), is the most common vessel in the NYSCC fleet (Figure 6). Tenders are used extensively to provide transit for personnel and materials to job sites and also provide light towing. One solution to address the NYSCC fleet's reliance on petroleum fuels is a full-electric propulsion system to replace the engines operating on either diesel or gasoline. The electrically-powered vessel would connect to utility grid power to recharge its batteries when docked at shore, or potentially draw excess electrical power from the floating equipment it is working beside, such as the dredges, derrick boats, or excavators. Electric propulsion systems have the capability to meet power requirements, because they conserve energy when the boats are idling, operate more efficiently, and generally have more power for the short typical intervals of acceleration and steering. Increased efficiency reduces the overall consumption of energy and electricity obtained from the utility grid displaces petroleum since the majority of electricity in New York State comes from nuclear, natural gas, and hydropower as shown in Figure 7.[2] The improved powertrain efficiency and lower energy cost of electricity over petroleum can have significant economic benefits to NYSCC by lowering operational costs. Additionally, electrifying NYSCC vessels sup ports Governor Paterson's Executive Order No. 4 which was approved for continuation under current Governor Andrew Cuomo, which requires that state agencies, public authorities, and public benefit corporations must consider green alternatives for their new procurements and take steps to implement sustainable initiatives. A successful project resulting in a reduction of greenhouse gases and the overall emissions produced from burning fossil fuels within New York State corresponds with the continuing Governor Pataki's Executive Order No. 40 that orders state agencies to register emission reduction credits.

**Figure 6: Typical NYSCC Tender**

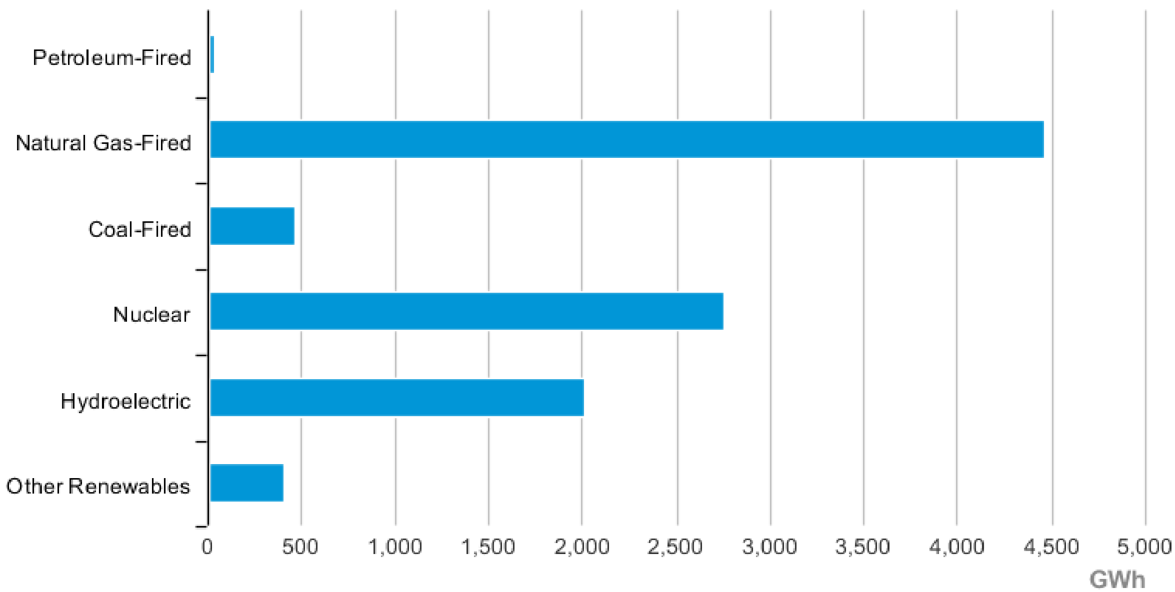


**Figure 7: New York Electricity Generation by Source, November 2012**

2 (2012) U.S. Energy Information Administration. New York Electricity Generation by Source. Retrieved January 24, 2013 from http://www.eia.gov/beta/state/?sid=NY#tabs-4

As mentioned earlier, the Canal has an untapped electric energy resource through the use of hydroelectric power at each of the locks that could complement the use of electricity in their fleet in later stages. Use of lock-generated hydroelectric power would represent an even greater potential for fossil fuel and emission reductions. With lock-generated hydroelectric, or other renewable power (e.g., solar or wind), as the electricity source for these vessels the fleet would be virtually carbon-free. In addition, expanded shore-side electrical connections to support NYSCC vessels would bolster the infrastructure to support electrification of other electric ships or crafts that used the Canal. The Canal system, with regularly spaced locks, could be the ideal configurations for electric vessels to receive a charge during the time that is required to pass through the lock itself.

With the significant fuel consumption and rising costs to operate diesel powered workboats, many designers are investigating electric propulsion as a potential solution for certain applications. Marine architects generally develop the entire hybrid electrical system including electrical control systems, battery management systems, generator layout, electrical power distribution, and propulsion configuration. Some systems on the market for tug and work boats utilize many components and technology from diesel electric locomotives. These systems are discussed in detail in the *Electric Propulsion System Evaluation* section.

NEW WEST's extensive experience and expertise evaluating advanced technologies for fleets (e.g., electrification, hybrid-electric, idle reduction, hydraulic regenerative braking, series hydraulic hybrid, and hydrogen fuel cells) was used for the current NYSCC electric boat evaluation. In this Phase I feasibility study (NYSERDA Agreement Number 25735, NEW WEST collected and analyzed operational data from NYSCC vessels to determine the petroleum reduction, economic, environmental, and energy security benefits that could result from using a full-electric propulsion system in NYSCC tenders. Robust full-electric and hybrid-electric powertrain technology are available for the marine industry. NEW WEST conducted an evaluation of these commercially available systems that meet the required demand of the Canal fleet and down-selected the systems to identify the ones that were best suited for the NYSCC tender application. Over the next decade, it is highly likely that NYSCC will need to replace many of the vessel engines that will reach their end-of-life, while the vessels themselves will likely be around for another half century. The results of this Phase I project are intended to provide NYSCC with the technical and economic information needed to develop fleet deployment and charging infrastructure expansion plans.

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# SECTION 2
# THE NEW YORK STATE CANAL CORPORATION

In many towns and communities across New York State, the Canal System is a central element to establishing a livable community for both economic development and pristine recreational opportunities. From its origins, "Clinton's Ditch" was built to provide economic development to the State by creating a transportation route for freight from the Great Lakes to the Hudson River. This resulted in many towns and cities developing around the Canal to use it to import and export products. Today the Canal takes a secondary freight transport role to the New York State Thruway; however it plays a vital role in transporting large items, such as General Electric turbines, that would otherwise not be able to be shipped in their assembled state. With petroleum fuel costs rising, efficient transport modes such as marine via tug and barge will likely play an increasing freight transportation role, especially for products that are not critically time-sensitive. Having a properly maintained waterway infrastructure in place favorably positions the Canal for providing a lower cost shipping option that is less influenced by the rising fuel costs due to its inherently efficient characteristics.

The New York Canal Corporation, a subsidiary of the New York State Thruway Authority, controls all operations and conducts all maintenance on the NYS canal system. To effectively maintain the canal through dredging and overall maintenance (including lock maintenance), the canal is divided into seven sections, each with a specific operation (including vessels, equipment, and personnel). The layout of the western part of the Canal system, including the Utica Floating Plant Section (the focus area of this study), is shown in Figure 8.[3]

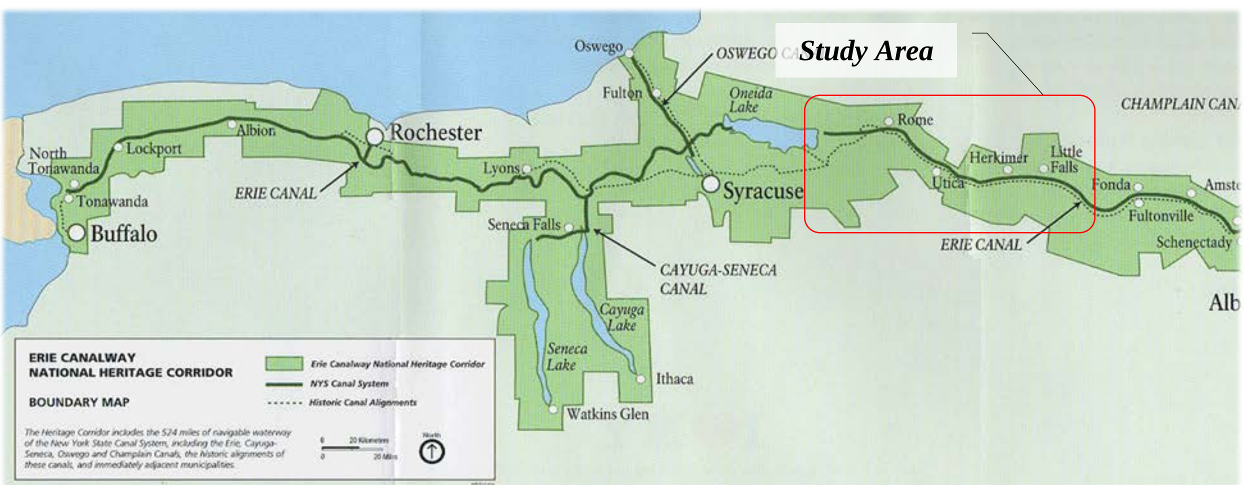


**Figure 8: Western Portion of the New York State Canal System**

NYSCC has begun efforts to improve the Canal's appeal for recreational and community development purposes. The New York State Thruway Authority and NYSCC launched a five-year, $32.3 million initiative in 1996 to preserve and develop the Canal System for the 21st century. The Canal Revitalization Program presented a realistic and achievable approach to Canal System development. The New York State Thruway Authority and NYSCC are committed to a new program of strategic investment in

[3] Graphic taken from http://www.shipsblog.com/images/maps/ecnhc_map.gif

partnership with businesses and local communities. One example of this is the Harbor Point Project in Utica where a 10 acre lot will be transferred to a city-run development corporation that will seek out developers that adhere to their vision of a mix of commercial, residential and recreational uses at the site. The state-mandated cleanup at this site has been mostly undertaken by National Grid, with NYSCC spending several months dredging the harbor and its neck to remove the accumulated silt for boats to sail through without fear of bottoming out. Utica's elected officials recognize a direct connection between water access, commerce, and economic development. Other similar examples can be found at Cornhill Landing (Rochester), Waterford, Sylvan Beach, among others. According to NYSCC, $380 million in economic development for the State can be attributed to the Canal's operation.

The tradition of navigation on New York's Canals continues uninterrupted, and the resurgence of development in the historic communities has begun again, as it did in the mid-1800s. NYSCC is committed to preserving the legacy of this marvelous waterway and the towpaths that now make up a portion of the Canalway Trail, a multi-use recreational network of trails. Numerous activities and attractions are available along the Canal System for visitors including boating at a leisurely pace along the waterways, cycling or hiking along the Canalway Trail, enjoying festivals in Canal side communities, or picnicking at lock-side parks. The Canal also provides recreational boats with access to reach many of the lakes throughout New York State right from their own community, so eliminating the need to tow the boat over the road. NYSCC's sustainability efforts, provides an enjoyable boating experience, to which reduces petroleum fuel consumption that would be needed to reach other destinations.

The U.S. and state economies rely on the freight transportation to maintain the flow of goods from manufacturers to consumers. Trucks are effective and generally reliable, however they are also energy inefficient compared to other freight transit methods. Marine freight methods, such as tug and barge, can be significantly more energy efficient for transporting large volumes of goods to or from a single location. Marine freight methods also permit large items, such as industrial turbines and assembled aircraft, to be transported fully-assembled. These items would not meet the roadway width and height restrictions. In addition, moving extremely heavy items via water does not damage the infrastructure (i.e., roads and bridges) like it would if hauled by trucks over the road. According to a U.S. Department of Transportation's Maritime Administration publication, one barge can transport 514 ton-miles per gallon of fuel while trucks can only transport 59 ton-miles per gallon of fuel.[4] Waterborne freight is not ideal for time-sensitive products because of the travel speed. Still, Canal freight movement serves a vital role in transporting specific freight today, with the realistic potential to increase as fuel prices continue to rise and have more impact on operational costs. This energy and cost efficiency disparity will make transport by water a more attractive option for shippers.

The price impact from fuel prices rising affects the State's economy that is dependent on imported energy for the transportation sector. Petroleum fuels, for which the transportation sector consumes over 72% of the State's total use, are a significant contributor to the State's total energy expenditures with $24.5 billion spent in 2009, or about 2.2% of the Gross State Product.[5, 6] Nearly 75% of this petroleum is

[4] (1994) U.S. Department of Transportation Maritime Administration, "Environmental Advantages of Inland Barge Transportation". Retrieved September 5, 2011 from www.ingrambarge.com/images/ingrambarge/pdf/environmental_advantages.pdf

[5] (2011) U.S. Energy Information Administration. U.S. States Notes and Sources (Data). Retrieved September 1, 2011, from http://www.eia.gov/state/state-energy-profiles-notes-sources-data.cfm

[6] (2011). USGovernmentRevenue.com. Government Revenue Details. Retrieved September 1, 2011, from http://www.usgovernmentrevenue.com/New_York_state_revenue_2009

imported from outside the U.S. This dependence is a serious consideration in the current economic climate, as it sends significant amounts of New York State dollars overseas. Petroleum fuel combustion represents the State's single largest contributor to GHGs, accounting for 55% of the total GHG emissions. Given the transportation system's petroleum dependence, it follows that transportation is a significant GHG emission contributor, with 39% of GHG coming from transportation fuel use (the largest portion of GHG emissions totals).[7] Governor Andrew Cuomo approved the continuation of Executive Order No. 24 (2009) which established a statewide goal to reduce greenhouse gas emissions by 80% by 2050. The Order also requires that a Climate Action Plan be developed and implemented, reiterating the importance of developing and deploying technologies that reduce GHG emissions.

The Canal is a critical component of a successful waterborne freight system in New York State, because it links the Port of New York and the Hudson River to the Great Lakes. The Canal is 524 miles long with 57 locks and 20 lift bridges. The operation and maintenance of this waterway is the responsibility of NYSCC. Their role is to ensure that the Canal is passable and easily navigated. At the start of the Phase I feasibility project the NYSCC vessel fleet included: 11 tugboats, 11 tenders, four (4) hydraulic dredges, seven (7) self-propelled scows, five (5) derrick boats, two (2) excavator boats, 20 buoy boats, and four (4) quarter boats. For some time, NYSCC has realized that its workboats are floating museums that the public wants to be retained. Canal vessels have been continuously and rigorously maintained since the inception of the Utica Floating Plant (the operation tasked with maintenance along the Utica section of the canal) in the 1930s, resulting in vessels that, while old, continue to perform the necessary tasks of placing, maintaining, and removing buoys, moving dredges, taking soundings, and myriad other jobs. The vessels are also an integral component of the historic New York State Canal System, which is eligible in its entirety for listing on the State and National Historic Registers.

[7] (2011) U.S. Energy Information Administration. Environment, State $CO_2$ Emissions. Retrieved September 1, 2011, from http://www.eia.gov/oiaf/1605/state/state_emissions.html

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# SECTION 3
# TENDER 4 REAL-WORLD DATA COLLECTION

## 3.1 AREA OF STUDY

The original project scope was to evaluate the entire NYSCC vessel fleet and design the electrically-powered vessel to handle all NYSCC tender duties. Jeff Gritsavage, P.E., AICP (NYSCC, Navigation Program Manager) described at the Project Kickoff meeting that each NYSCC Section operates semi-independently and may have a wide range of typical duties due to geography (e.g., having to cross lakes) or other reasons. As a result, vessels are not typically shared between Canal sections, although they can be temporarily transferred if needed. The result was that designing an electrically-powered vessel to handle all NYSCC operation would likely result in a more expensive vessel since the powertrain components would have to be oversized to meet the highest power and energy storage requirements. NEW WEST's office is located in Yorkville, NY which is outside of Utica, NY where the NYSCC Utica Section is headquartered. Mr. Gritsavage felt that the Utica Section's tender operation was a good representative of current and future NYSCC operation, and that the NYSCC Section staff would support the project. Based on this, the Project Team made the decision to narrow the project focus to the Utica Section.

## 3.2 SELECTED VESSEL DESCRIPTION

NYSCC utilizes 12 tenders for various duties including: dredging, light towing, barge pushing, personnel and equipment transport, and other Canal support tasks. During light-duty days, tenders may only be operated 20-40 minutes to transport the crew to the dredging operation. However, on many days tenders are used to transport barges loaded with dredge tailings and to reposition dredges. This type of operation represents a medium-duty day. Tenders are infrequently used to transport dredges over long distances (occasionally over 20 miles) along the canal. This type of operation represents a heavy-duty day. On the Utica section crews typically operate the tender for four, 10 hour days per week. Other Canal Sections have five, eight hour day weeks. Mr. Gritsavage selected Tender 4 as the suitable representative vessel to monitor because of powertrain similarity to many other tenders and because of its planned usage profile. This vessel, which is very similar in every way to the other tenders used throughout the canal system, is 40 foot long with a 10 foot beam and approximately 6 foot draft.

Tender 4 is powered with a 1980s-era Detroit Diesel 6-71 two-stroke diesel engine that was widely used in marine applications and even some older on-road heavy-duty applications. The engine was originally rated to produce 174 brake horsepower (bhp) and 500 ft-lbs of torque at 1,800 rpm at the crankshaft. A 2:1 reduction gearbox is installed between the engine and the 30 inch propeller. The maximum engine performance values recorded during the project (described later) at the propeller shaft were approximately 150 bhp and 1,000 ft-lbs of torque, although several spikes slightly above these values were recorded. The engine manufacturer, model, and build years in the other tenders vary, but they are all very similar engines. The vessel's 300 gallon fuel capacity allows it to only require refueling one to two times a month on average. This vessel is shown in active duty in Figure 9. The engine room of Tender 4, and the recorded engine/propeller power map, is shown in Figure 10. The power map shows that the majority of the power demand occurs at very low engine power (e.g., idling and maintaining position). The next largest area occurs in the 100 bhp range.

**Figure 9: NYSCC Tender 4**

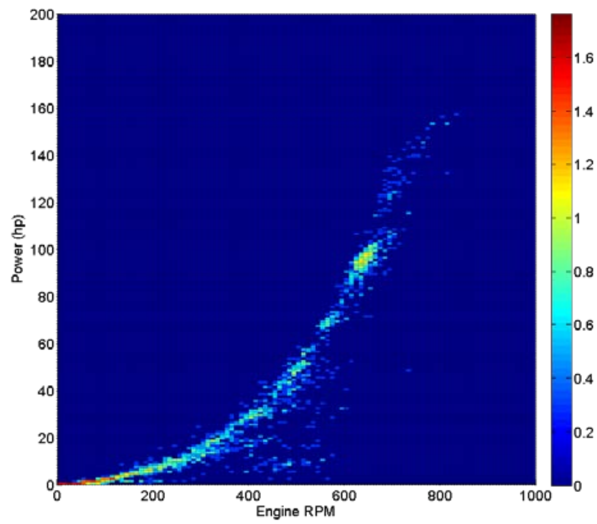


**Figure 10: Tender 4 Engine Room (showing the Detroit Diesel 6-71) and Recorded Propeller Power Curve**

## 3.3 DATA ACQUISITION EQUIPMENT AND METHODOLOGY

To accurately analyze the tender's daily activity and quantify its operational dynamics, the vessel was instrumented with a comprehensive data acquisition (DAQ) system to monitor its activities and record the in-use operational data. The DAQ system described below was installed by NEW WEST, with the assistance of NYSCC staff the week of June 18, 2012. Data gathered during the summer monitoring period included propeller shaft speed, propeller shaft torque, fuel flow, and vessel position (i.e., global positioning system [GPS]) data. Most parameters were sampled once per second (1 Hz) throughout the monitoring period. Some sensors required higher sampling rates to retrieve frequency and count (rising/falling edge) signals but were later reduced to a 1Hz rate once the required data was extracted. A DAQ system schematic is shown in Figure 11.

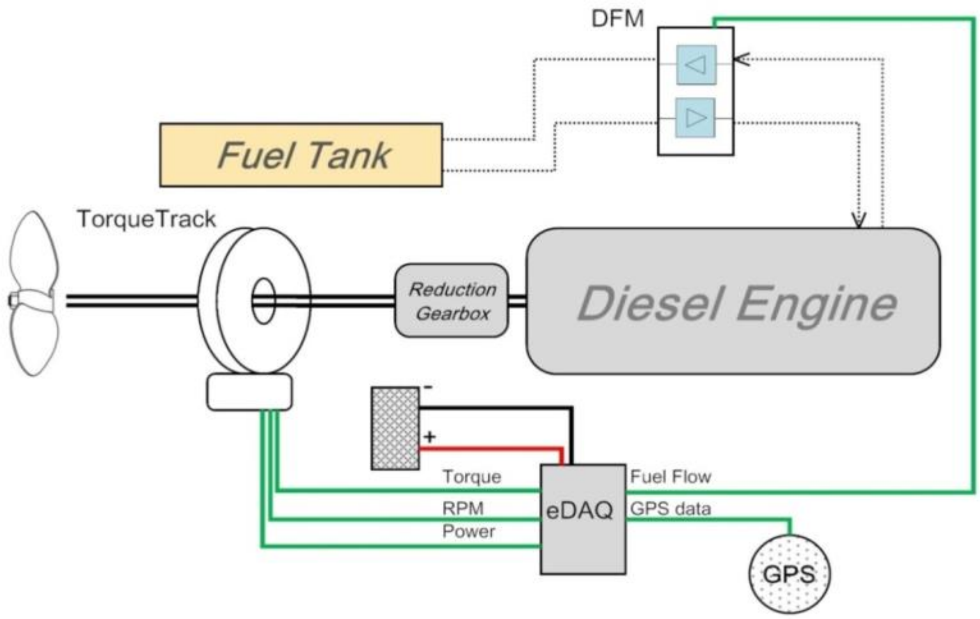


**Figure 11: Data Acquisition System Schematic**

The DAQ system included several components to collect and store this data, including: a SoMat eDAQ*lite* data acquisition system, a Sierra Wireless Raven X wireless modem (for remote communication and data downloads), a Binsfield Engineering TorqueTrack Revolution torque sensor, a Technoton DFM 250D differential fuel flow meter (DFM), and a GPS antenna. The discrete sensors for torque and fuel flow were needed because the engine does not have an electronics control unit to connect to access and record the data as modern engines would. This increased the data acquisition system cost well beyond the proposed level, due to the equipment cost itself as well as the time required to select, purchase, and learn how to use the new equipment.

The eDAQ*lite* data acquisition system is a compact, rugged field data logging solution that is widely used both in the industry and by NEW WEST for vehicle field testing and long-term data acquisition. This eDAQ records sensor (engine torque, engine speed, engine power, fuel flow, and position) data and stores it on internal non-volatile memory. The broadband cellular modem is provides access to the eDAQ to download the data remotely over the Internet. The eDAQ is designed to utilize different sensor input layers to accommodate various sensor types, numbers, and applications. Because of the type of sensors utilized, analog and digital data acquisition boards were used, allowing simple analog sensors and more complex inputs such as GPS to be recorded simultaneously. The DAQ hardware (eDAQ, wireless modem, 12 volts direct current [VDC] power wiring, and charge maintaining system) were installed in a fiberglass enclosure to protect the equipment. An exhaust cooling fan was used to remove the heat generated by the DAQ system from the inside of the enclosure. The enclosure was installed in the tender's engine room. The enclosure layout as mounted in Tender 4 is shown in Figure 12.

The DFM measured the instantaneous fuel flow rate of the diesel engine. The DFM was required because the engine does not have an electronics control unit to collect the data from. The DFM measures both the feed and return line flow rates, calculates the difference, and reports the result back to the eDAQ as a pulse count signal (80 pulses per liter). The DFM installation required modification of the fueling system to allow fuel to flow through the meter's supply side before entering the engine fuel rail and also through the meter's return side before returning to the fuel tank. The installed DFM is shown in Figure 13.


Figure 12: NYSCC Tender 4 DAQ System Layout

**Figure 13: Differential Fuel Flow Meter**

Engine power is typically reported by engine manufacturers at the crankshaft, but this power level is not seen by the propeller because of other system losses, such as in the reduction gearbox. Thus, an accurate power measurement at the propeller is critical for specifying the electrically-powered tender powertrain. A Binsfeld Engineering TorqueTrak Revolution non-contact torque measuring system was used provide this measurement between the reduction gearbox and the propeller. (The assumption is that there are negligible losses in the steel driveshaft itself). A steel bracket was fabricated and attached to the vessel's main structure and to both sides of the TorqueTrak unit to provide a rigid mount (Figure 14). The system requires attaching strain gauges to the driveshaft to measure the driveshaft torsional deflection. The TorqueTrak system stationary collar assembly inductively receives signals from the strain gages on the rotating driveshaft (which acts as the stator). The strain sensor measurements are translated into driveshaft torque measurements. The system also measures driveshaft rotational speed, which is then used with the torque measurements to calculate the power seen by the propeller. The calculated values were output as analog current signals (5-12 mA) for power and torque (a resistor was used to allow for measuring voltage) and a pulse count signal for driveshaft rotational speed.


**Figure 14: TorqueTrak Inductive Torque Meter**

It was noticed early in the data collection period that the tender's battery would be drained after sitting for periods of more than two days. (The Utica Section works four 10 hour days, so weekends are three days.)

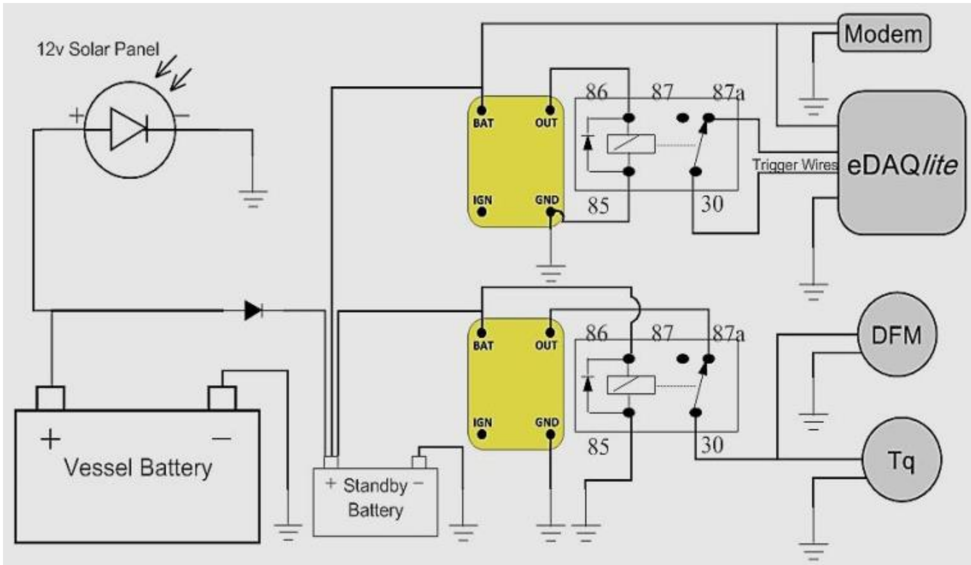


**Figure 15: Tender Battery Maintenance System**

The DAQ system requires a low power level even when not collecting data; however NEW WEST calculations showed that this power draw was not likely the cause of the low battery. Even so, to ensure the DAQ system was not the cause, a novel 12 VDC battery recharging/charge sustaining system was developed to power the DAQ system and to maintain the vessel's 12 VDC battery during downtimes. The system was designed to shut down the sensors and equipment as soon as possible after the tender's engine was shut down. The system utilized two Havis ChargeGuard units to monitor the system voltage and switch relays on when the system voltage is over 14 VDC (typical voltage while the engine is operating) and back off when it falls under 14 VDC. The system also uses a 15 watt photovoltaic solar panel to trickle charge the battery to maintain the battery charge, and a separate small 12 VDC standby battery. The tender's battery voltage typically drops below the eDAQ's low voltage threshold (9 VDC) during engine cranking to start the engine, so the secondary standby battery prevents unintended DAQ system shutdown during engine cranking. The overall electrical power system schematic is shown in Figure 15. NYSCC staff later discovered that the root cause of the battery charge problem was that the alternator was in the process of failing. The result was that these issues combined with limited operation, long waiting periods, and the additional small electrical requirements of the DAQ system led to the low battery charge issue.

## 3.4 OPERATIONAL SUMMARY

The goal of the vessel monitoring period was to collect operational data for all of the vessel's activities for an entire NYSCC operating season (typically mid-April through mid-November; depending on weather conditions) to gather a typical year's operational data. The time needed to specify, purchase, and learn how to use the fuel flow meter and torque sensor delayed the start of the data collection. Equipment failures (presumably from old vessel battery), limited access to vessel while working, and other unforeseen issues led to a reduction in overall data collected. Vessel mechanical issues, including a faulty alternator and battery system and an oil leak (near the end of the season, assumed to be an oil cooler issue but was identified as head gasket issue), led to additional days when the boat was inactive and not able to record duty cycle data. Ultimately, the monitoring period extended from June 21, 2012 to early October when mechanical issues removed the vessel from service. Overall, 25 days of high-quality operational data were collected.

The duty cycle data presented below was collected from Tender 4 from the collected data. It may not be widely applicable to other tenders in the Utica Section and more widely to other NYSCC sections. The data showed that daily tender operations can effectively be split into three intensity levels depending on the type of work that the tender did for each day, including:

- Low (typical for simple equipment and personnel movement)
- Medium (during typical small barge and scow movements)
- High (during dredge movements)

Low intensity, light-duty days included duties such as supplies and personal movement, light barge transport, light dredge support, and other light canal maintenance work. These light-duty days comprised approximately 20% of the instrumented tender's daily duties that were recorded throughout the season. As shown in the daily profile in Figure 16, the light-duty cycle is very similar to medium-duty cycle as they perform similar daily activities. Due to the typically low power demand levels during light-duty days, the tender consumes an average of two gallons of diesel fuel per day to generate the required 10 kWh of energy, while producing 0.06 kg of hydrocarbons (HC), 0.1 kg of carbon monoxide (CO), 16.7 kg of carbon dioxide ($CO_2$), 0.4 kg of nitrogen oxides ($NO_x$), and 0.01 kg of particulate matter (PM) of exhaust emissions.[8]

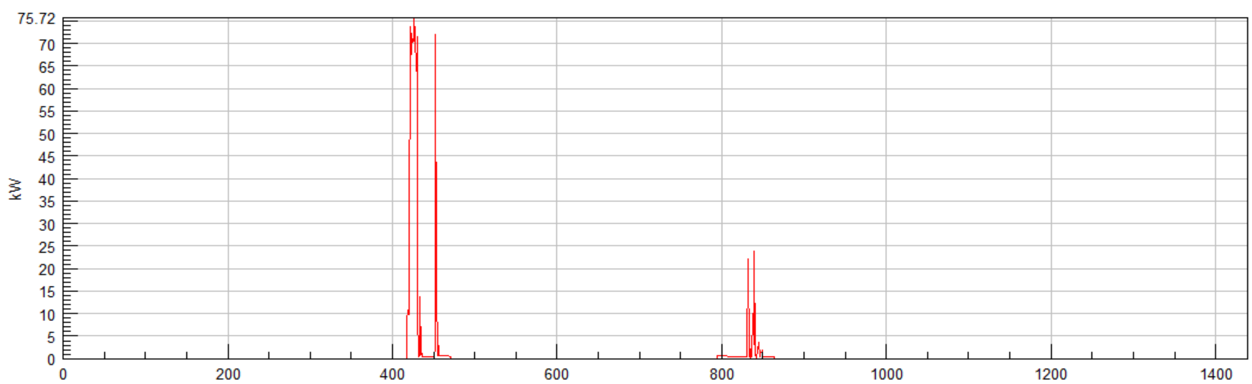


**Figure 16: Light-Duty Tender Daily Operation (X-axis = minutes)**

Medium intensity, medium-duty days included relatively constant barge movements to move dredged material to dumping areas. These medium intensity days accounted for approximately 75% of the instrumented tender's daily duties. The barges or scows used to haul this material are relatively small and are transported short distances. This resulted in a highly varied, but relatively low power round trip duty cycle. However, when dredge operations continue all day, as shown in Figure 17, the energy consumption can be significant. During days with this type of extended medium-duty duty cycle, the vessel consumed

[8] Emission data calculated from data taken from: (2003) U.S. Department of Transportation, Maritime Administration. Evaluation of Exhaust Emissions from Elizabeth River Ferries. Retrieved February 28, 2013 from http://www.ntis.gov/search/product.aspx?ABBR=PB2008108498

an average of 12 gallons of fuel to provide 95 kWh of energy while producing 0.2 kg of HC, 0.8 kg of CO, 100 kg of $CO_2$, 2.4 kg of $NO_x$, and 0.05 kg of PM of exhaust emissions.[8]

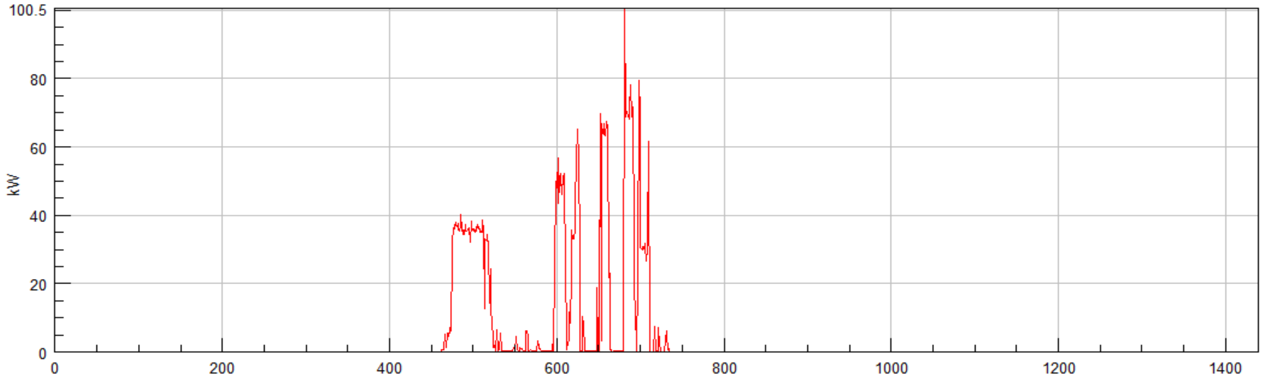


**Figure 17: Medium-Duty Tender Daily Operation (X-axis = minutes)**

High-intensity, heavy-duty extended dredge movements, accounted for only approximately 5% of the tenders' total use during the data collection period. However, when the tender was used this way the sustained high power operation resulted in a significant amount of fuel usage. Figure 18 shows a typical NYSCC tender power profile for a high intensity dredge transport day. For days with similar usage profiles, the tender used approximately 35 gallons of fuel while producing 0.5 kg of HC, 41 kg of CO, 296 kg of $CO_2$, 41 kg of $NO_x$, and 0.2 kg of PM of exhaust emissions.[8]

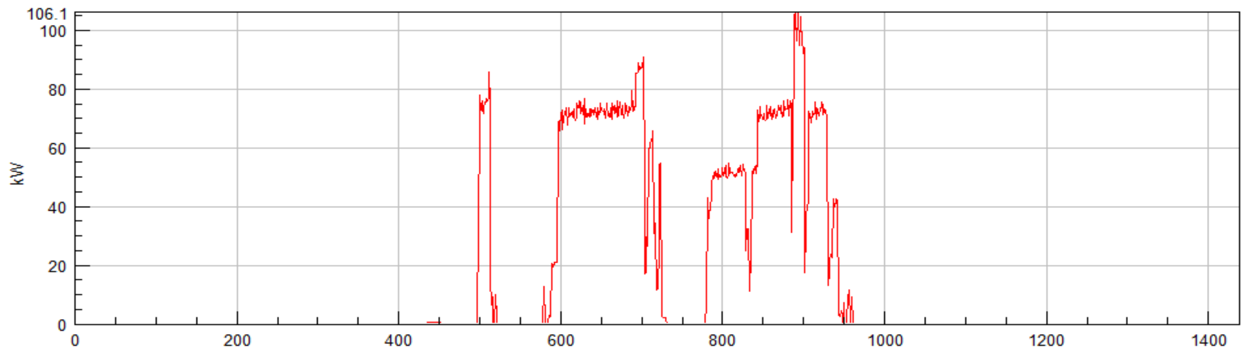


**Figure 18: Heavy-Duty Tender Daily Operation (X-axis = minutes)**

The overall compilation of the low-, medium, and heavy-duty days was combined to create the overall NYSCC tender duty cycle profile shown in Figure 19. The figure clearly shows the intensity of the vessel's overall duty cycle; however, it should be noted that the percent time is based on the amount of time that the engine is running and this graph does not represent the downtime that was experienced by the tender. It can be seen from the graph that the vessel spends approximately 7% of its operational time at ide (power levels below 1 bhp) resulting from NYSCC's efficient operating practices which minimized idle fuel consumption.

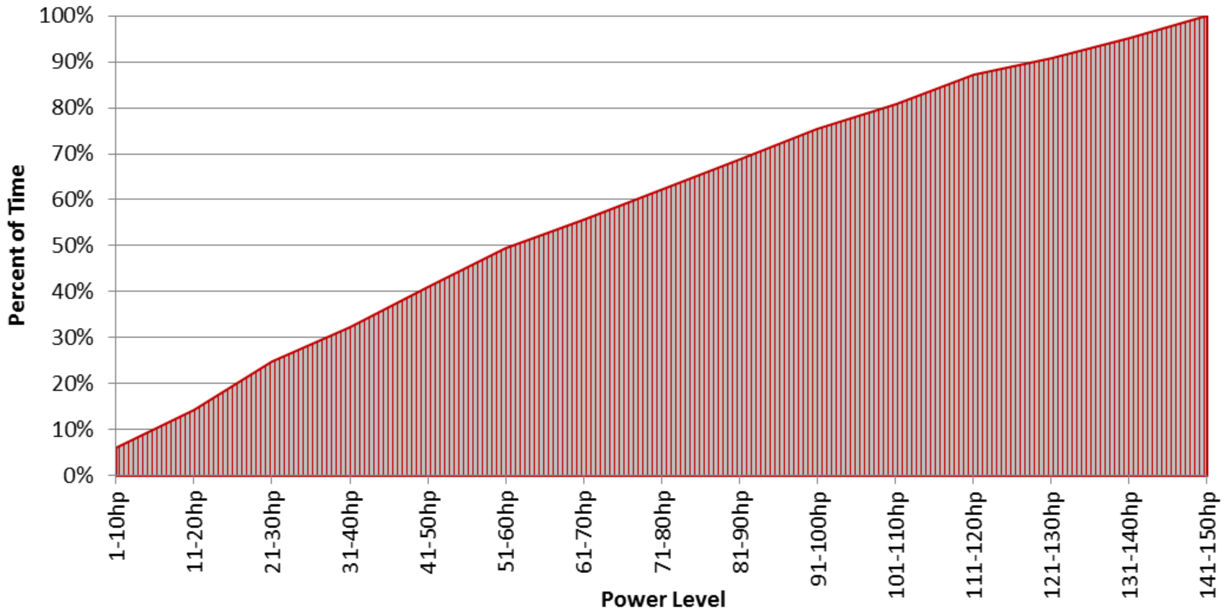


**Figure 19: NYSCC Tender 4 Duty Cycle Profile (% of Time at or Below Power Level)**

A comprehensive engine torque versus fuel map was developed using the fuel flow rate and the engine power output that were independently measured (Figure 20). The outlier data points are most likely erroneous, and area believed to have been caused by propeller cavitation due to the vessel's light ballast. This graphic also highlights that the current diesel vessel is relatively fuel efficient.

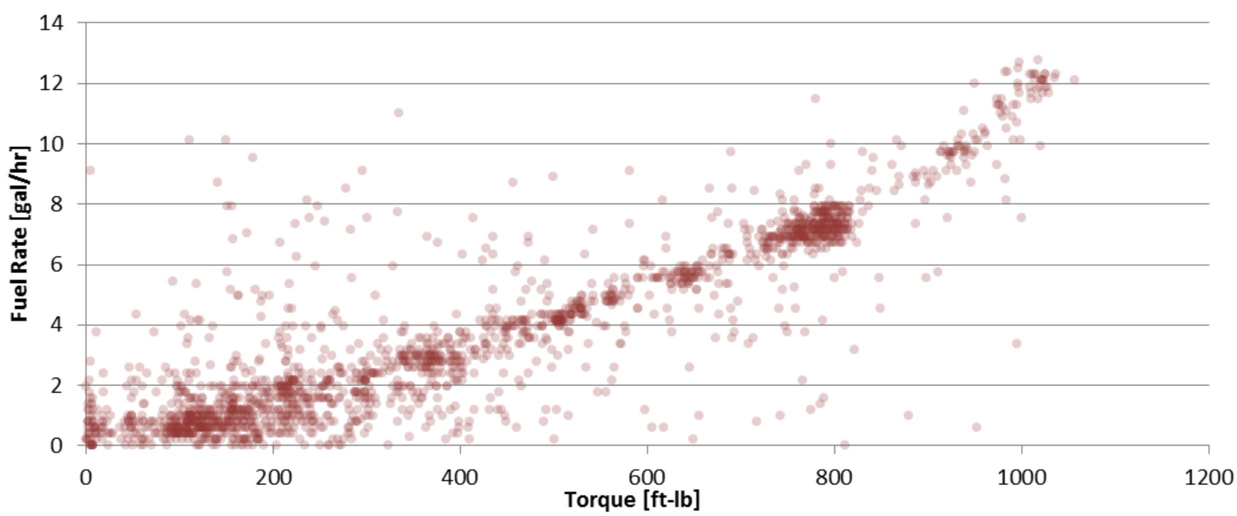


**Figure 20: NYSCC Tender 4 Fuel Consumption Rate versus Torque Output**

The fuel consumption rate was correlated to vessel speed to approximate the vessel's fuel consumption rate. This can be used as a way to understand the tender's operation, but should not be used as a detailed reference because the fuel consumption differs widely depending on whether the boat is in free transport or is moving a barge. This difference is operation is shown by the two separate curves shown in Figure 21. The graphic shows how vessel transit speed effects fuel consumption with the vessel using approximately 0.4 gallon per mile at slow speeds (<5 mph [4.35 knots]) and increasing 300% to approximately 1.2 gallons per mile at higher speeds (>8 mph [6.95 knots]) for free transit.

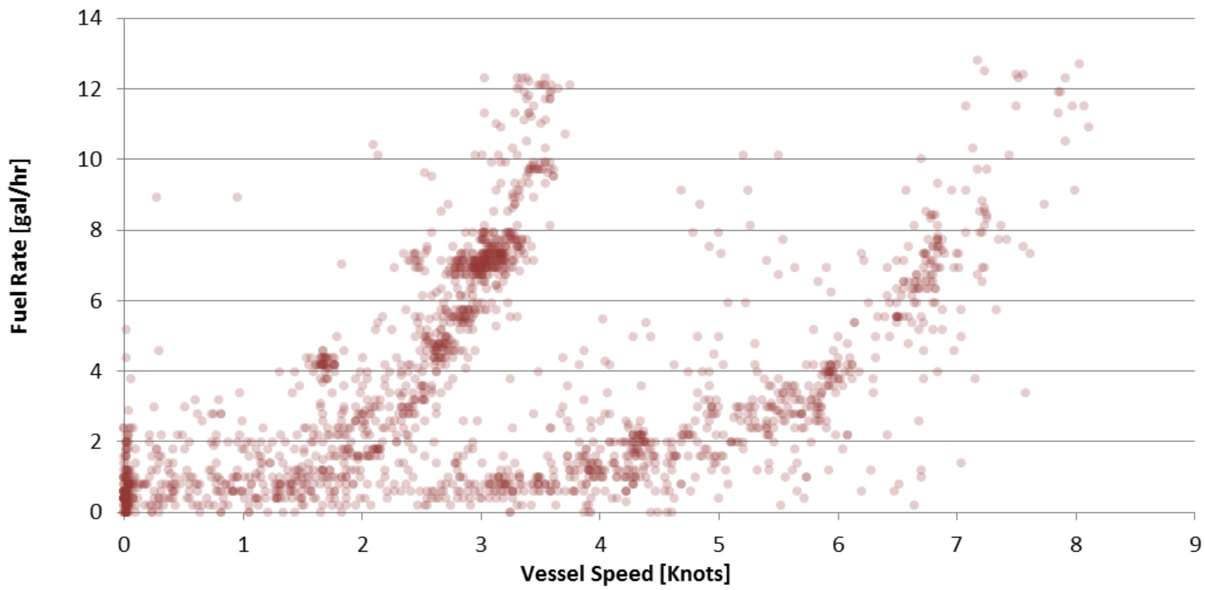


**Figure 21: Tender 4 Fuel Consumption Rate versus Vessel Speed**

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# SECTION 4
# DERRICK BARGE REAL-WORLD DATA COLELCTION

## 4.1 SELECTED VESSEL DESCRIPTIONS

To evaluate the potential to recharge the electrically-powered tender onsite during the workday in order to either extend the boat's range/work capability or to minimize the battery pack capacity, a data acquisition system was installed on the derrick boat (NYSCC DB1) to monitor generator power usage from the primary generator (Figure 22). During a typical work day, the derrick boat is operated for approximately 10 hours, less personnel/equipment transport periods and required breaks. Data acquisition equipment was used to monitor and record the electrical power output of the primary onboard generator that supplies the dredge with operational power. The 65 kW primary generator operates at or below 20% load in this usage so is significantly oversized for its intended purpose. (The derrick boat also has a secondary generator that was not evaluated because the primary generator had sufficient excess capacity.) The excess capacity provides a significant recharging potential if this approach is determined to be beneficial.

**Figure 22: NYSCC Derrick Boat DB1**

## 4.2 DATA ACQUISITION EQUIPMENT AND METHODOLOGY

The data acquisition system was installed near the dredge's electrical cabinet that the primary generator directly powers. Electrical power is distributed (both 220 volts alternating current [VAC] three-phase and 110 VAC single-phase) from the cabinet to equipment throughout the vessel. However, for the purpose of this study the power produced by the genset was of interest and not the final use of the power.

The data acquisition system hardware (SoMat eDAQ*lite* data acquisition system, a Continental Control Systems WattNode electrical energy meter, and a Sierra Wireless broadband cellular modem wireless modem) were installed in a fiberglass enclosure to protect the equipment. An exhaust cooling fan was used to remove the heat generated by the DAQ system from the inside of the enclosure. The enclosure was installed in the engine room. The enclosure layout is shown in Figure 23. The system was used to record primary generator power levels and energy usage throughout the day.

The eDAQ used for this application was identical to the one used in the tender, except that only digital input boards were used because of the signals being recorded. The system's power was controlled with a Havis ChargeGuard system to ensure the vessel's battery remained charged throughout the duration of the testing. The wireless modem allowed for remote downloading of data throughout the monitoring period. The WattNode meter output energy usage data via a digital pulse count signal. The pulse count signal was input into the eDAQ and was converted into numerical energy and instantaneous power measurements.

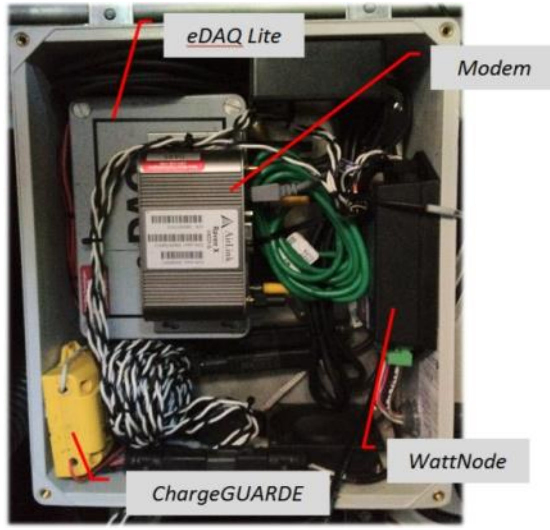


**Figure 23: DB1 Data Acquisition System**

The generator is wired using a three-phase, four-wire, wye configuration (also known as a wild-leg delta) because the dredge requires both 110 VAC single-phase and 220 VAC three-phase power. The WattNode connects directly to the three legs of the output wiring to measure voltage. Clamp-on hall-effect current transducers were installed on each leg to measure current. A wiring schematic of the data acquisition system used for the generator monitoring, including its connection to the vessel wiring, is shown in Figure 24.[9]

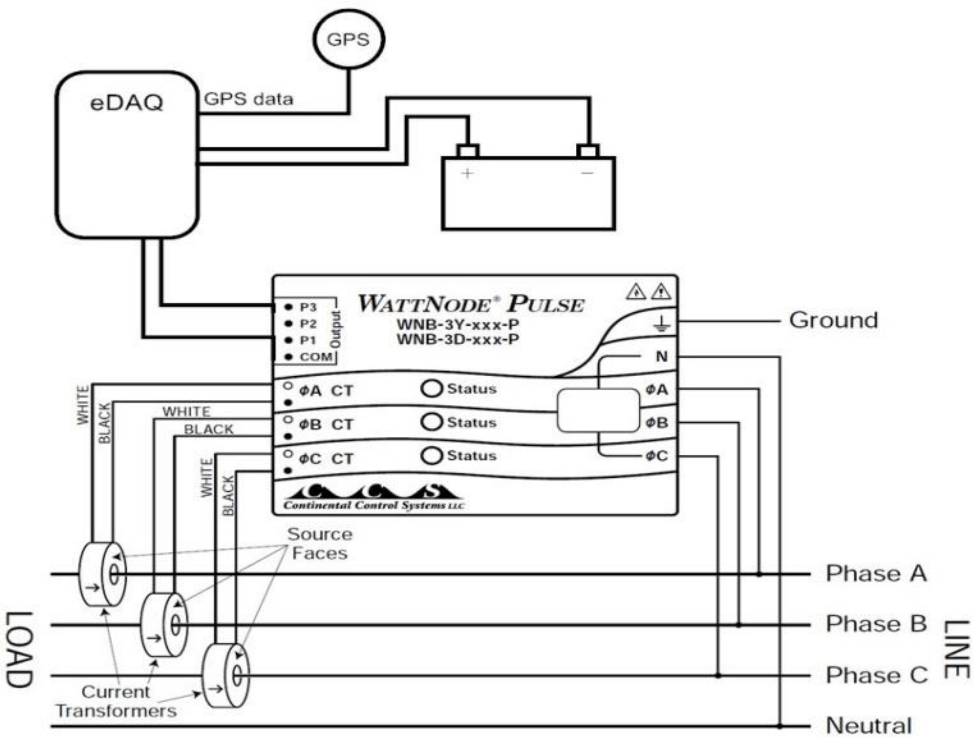


**Figure 24: WattNode Connection Schematic**

[9] Graphic created with information from http://www.ccontrolsys.com/ww/images/f/fb/Manual_WNB_Pulse.pdf

## 4.3 OPERATIONAL SUMMARY

Several months of operational data were collected and analyzed. The result was that only a fraction of the generators full power capacity was ever used. As shown in Figure 25, the vessel's genset was rarely operated at over 25% load and spent the majority of its operation time at 5-10% of its total power output (65 kW).The generator was operated for an average of 6.6 hours per work day to produce an average of 22.3 kWh of energy, while consuming 6.7 gallons of fuel. This extended operation time at loads well below the rated power of the genset provide a charging opportunity for the electrified tender at the dredge during daily operations. The increased load due to charging would result in increased overall fuel consumption, but the brake specific fuel consumption (BSFC) (i.e., the fuel consumed per energy output) decreases as shown in Figure 26 because of increased engine efficiency at higher loads. However, to maximize the fuel reduction benefits, it is suggested that charging from equipment mounted generators only be used for supplemental power when utility grid electricity is not available to complete the required operations.

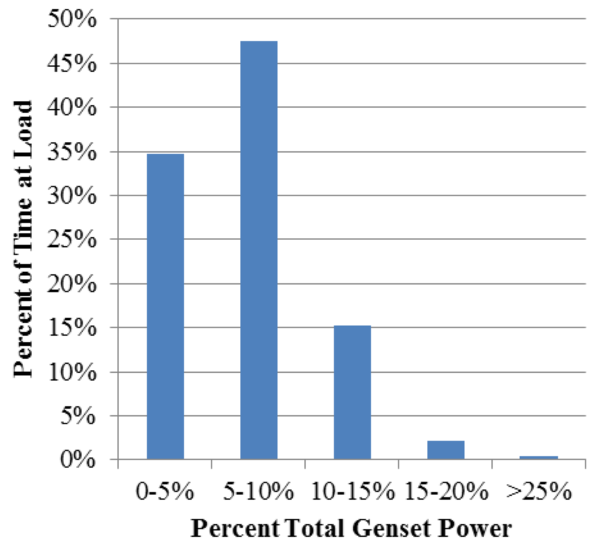


**Figure 25: DB1 Duty Cycle Profile**

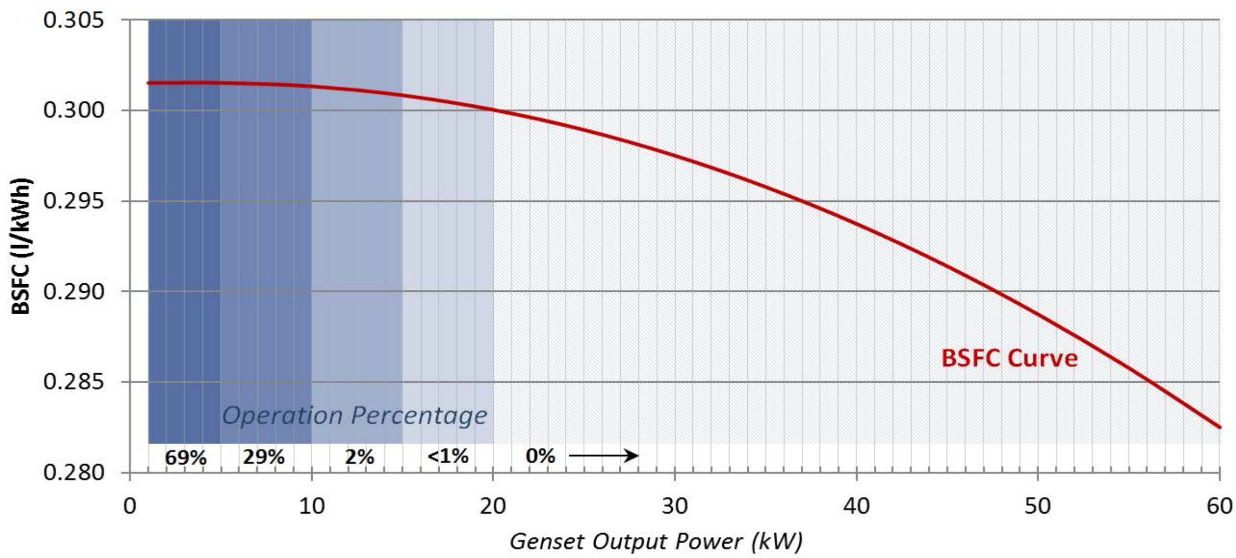


**Figure 26: DB1 Primary Generator Specific Fuel Consumption Curve**

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# SECTION 5
# ELECTRICAL CHARGING INFRASTRUCTURE

## 5.1 CANAL INFORMATION

Independent of the type of electrical propulsion system chosen and the duty cycle of the specific vessel, the need for a suitable electrical infrastructure available to charge the electrically-powered tender is imperative. NEW WEST conducted a comprehensive charging location inventory of all shore-side electrical infrastructure utilized by NYSCC in the Utica Floating Plant section of the canal to determine all the charging locations that would be available to the electrically-powered tender. The focus area of this inventory includes locations from Sylvan Beach (on Oneida Lake) to Lock 16 in Minden, NY (Lock 16 is not part of the Utica Floating Plant Section; however, their vessels may occasionally visit this location). The majority of the charging locations are at locks along the Canal which NYSCC employees often use as a mooring location for the vessels when the vessels are not actively being used. However, additional locations with electrical infrastructure are available including Sylvan Beach and a location near the Utica Floating Plant headquarters location. The overall layout of the Utica Section of the Erie Canal, showing canal infrastructure and resting locations recorded from the tender, are shown in Figure 27.


**Figure 27: Canal Electrical Infrastructure Layout and Tender Resting Locations**

## 5.2 LOCK 16

Lock 16 is located 7.9 miles east of Lock 17 in the town of Minden, NY and is not actually part of the Utica Floating Plant's section of the canal. However, vessels from Utica may occasionally be located at this lock to support the Fonda Section's work. This location is equipped with one electrical pedestal as designated by #1 in Figure 28. The electrical pedestal at this lock is equipped with one three-phase 208 VAC outlet rated at 50 amps and is located on the south wall on the western side of the lock, shown in detail in Figure 29. While this could be utilized to recharge an electrified vessel, it may be beneficial to install an additional pedestal farther from the opening of the lock to not impede Canal traffic. An NYSCC worker at Lock 16 mentioned that adding electrical infrastructure would be relatively simple to install due to extra wiring already installed at light posts along the wall.


**Figure 28: Lock 16 Electrical Infrastructure Layout**

## 5.3 LOCK 17

**Figure 29: Lock 16 Electrical Outlet**

Lock 17 is the last lock in the Utica Section of the Canal on the eastern boundary. The lock is located in the city of Little Falls, NY and is 4.1 miles east of Lock 18. This lock is the largest in New York State and raises and lowers vessels 40.5 feet and employs a much different technology from the others. The design of this lock includes an extremely large portion of dockage to the downstream (eastern) side of the lock. While Tender 4 was not recorded to have rested here during active duty, the vessel and many other NYSCC vessels occasionally tie-up here (the monitored vessel was indicated as being at this location several times for maintenance, but not during active use). The layout of this lock is shown in Figure 30 below. The lock currently does not have any shore-side electrical infrastructure. The large open dockage area to the east of the lock would provide an ideal location for electrical pedestals.


**Figure 30: Lock 17 Electrical Infrastructure Layout**

## 5.4 LOCK 18

Lock 18 is located in the town of German Flatts, NY and is 11.8 miles east of Lock 19. The layout is shown in Figure 31. This location is not currently equipped with shore-side electrical power; however, the location designated as #1 in Figure 31 could provide convenient charging for an electrified vessel.


**Figure 31: Lock 18 Electrical Infrastructure Layout**

## 5.5 LOCK 19

Lock 19, which is located in the town of Schuyler, NY, is six miles east of Utica and is 11.8 miles west of Lock 18 by water. This lock does not currently have any installed electrical infrastructure that could be utilized for recharging an electrified vessel. The layout of this lock is shown in Figure 32 below with the likely place for recharging infrastructure to be installed designated with the #1. This location would allow the vessel to recharge without interfering with vessel traffic and provide a location to tie-up. While the tender was not reported to have overnighted at this location during the monitoring period, if an electrified vessel was to be operated in this area, it would be advantageous to allow charging at this location to allow electrified vessels to be stationed here.


**Figure 32: Lock 19 Electrical Infrastructure Layout**

## 5.6 UTICA AREA

The primary headquarters for the Utica Floating Plant division of the Canal is located in Utica, NY off of Genesee Street and includes the Utica Harbor which is equipped with significant electrical infrastructure. Access to the harbor requires passing through a lock which reduces the convenience and use of the harbor as a resting and overnighting location for all vessels. However, NYSCC vessels do utilize a small docking location on the canal channel itself, which is equipped with electrical infrastructure, as an access and overnighting location (location designated by #1 in Figure 33).


**Figure 33: Utica Area Electrical Infrastructure Layout**

This location is equipped with two older style plugs used on the canal for 208 VAC three-phase power (50 amp) plugs to accommodate the frequent shore power requirements of tugs passing by. This type of plug is still utilized on the larger canal tugs and the canal has many adaptor cords, which could be used for an electrified vessel, that allow vessels not equipped with this type of plug to utilize these outlets. This existing infrastructure should be sufficient to provide recharging power for potential electrified vessels. Installing additional electrical infrastructure is not necessary because of the limited vessel docking space. The layout and detail of the existing electrical infrastructure is shown in Figure 34.

**Figure 34: Utica Area Electrical Infrastructure**

## 5.7 LOCK 20

Lock 20 is located in Marcy, NY 18.1 miles east of Lock 21. The lock doubles as a NYSCC vessel maintenance location and is equipped with a large workshop and ample electrical infrastructure along the Canal wall on the western side of the lock. While the Utica Floating Plant headquarters are located in the Utica Harbor, much of the vessel maintenance and short-term vessel storage (for between jobs) occurs at Lock 20 because it is conveniently located near dredging jobs. The layout of Lock 20 is shown in Figure 35 with the electrical pedestals indicated by #1, 2, 3, and 4.


**Figure 35: Lock 20 Electrical Infrastructure Layout**

Lock 20 is equipped with four electrical pedestals (as shown in Figure 35) which could prove applicable for recharging an electrified vessel. As with other locations, each pedestal is equipped with two 120/208 VAC 3-phase outlets, each rated at 50 amps. With a total of eight high-power electrical outlets near the water, this location offers sufficient electrical infrastructure to accommodate recharging duties without effecting current operations. Through discussions with onsite staff, it is thought that no additional infrastructure would be needed at this location to support the charging of an electrified vessel. The layout of the existing electrical pedestals and the outlet detail is shown in Figure 36.

**Figure 36: Lock 20 Electrical Infrastructure Detail**

## 5.8 LOCK 21

Lock 21 is located Rome, NY and was heavily utilized during the tender monitoring period for overnight resting periods and as an access point for crews during dredging operations. This lock is located 1.3 miles east of Lock 22 and 18.1 miles west of Lock 20 (by water). This location is currently equipped with one charging pedestal on the upper side of the lock (western side). No electrical infrastructure is available on the lower side (eastern side). The layout of the lock and the location of the existing (#1) electrical infrastructure are shown in Figure 37.


**Figure 38: Lock 21 Electrical Infrastructure Layout**

The pedestal is equipped with two 120/208 VAC 3-phase outlets rated at 50 amps each, so could be used for recharging an electrified vessel. This pedestal is often used when NYSCC vessel maintenance is done at the lock. The electrical pedestal and outlet detail is shown in Figure 38. While it would be possible to recharge an electrified vessel from this location, several NYSCC employees mentioned that the electric pedestal would be too close to the opening of the lock to provide unrestricted traffic flow if a charging vessel was located there. To avoid this potential problem the NYSCC employees and NEW WEST felt that a charging pedestal at location #2 was better suited for charging the vessel.


**Figure 37: Existing Electrical Pedestal at Lock 21**

## 5.9 LOCK 22

Lock 22 is also located in Rome, NY and is the lock the farthest west on the Utica Floating Plant's Section of the Canal. While the tender being monitored under this project was never recorded to have rested at this location, it does provide a convenient point of access and over-night location for crews working between Sylvan Beach and Lock 21. Lock 22 is equipped with electrical infrastructure at two areas that could be utilized to recharge an electrified vessel, one on the upper and lower sides of the lock. The layout of the lock, and the location of the charging infrastructure (designated by #1 and #2), is shown in Figure 39. Overall, this location should currently have sufficient electrical infrastructure to fully support the adoption of an electrical vessel in the canal system.


**Figure 39: Lock 22 Electrical Infrastructure Layout**

The charging infrastructure on the lower side of the lock (western side designated by the #1 above) consists of an electrical pedestal located off to the side of the main channel. This pedestal is equipped with two 120/208 VAC 3-phase outlets, rated at 50 amps each, and a 120 VAC single-phase outlet rated at 20 amps. The location and internals of this electrical pedestal is shown in Figure 40. The location of this infrastructure would allow the vessel to tie-up for extended periods without interfering with canal traffic.

**Figure 40: Lower Electrical Pedestal at Lock 22**

The electrical infrastructure on the upper side of Lock 22 includes a shore power outlet that is currently utilized by NYSCC vessels equipped with shore power capabilities (onboard equipment that allows the vessel to shut down onboard generators, currently is limited mostly to the large tugs and barges). This plug type (shown in Figure 41) is widely used throughout the canal system. To effectively make use of all available 208VAC three-phase electrical connections along the Canal, it is suggested that the electrified vessel employ a plug adaptor system to allow recharging from any electrical outlet type used on the canal system.

## 5.10 SYLVAN BEACH

The farthest west non-lock location operated by the Utica Floating Plant is a small docking area located in Sylvan Beach near the entrance to Oneida Lake. This small area is located under the bridge for Route 13 and is used by NYSCC vessels to dock overnight and when resting to assist operations in Oneida Lake and in the canal west of Lock 22. This location is equipped with three 208 VAC three-phase 50 amp shorepower charging outlets and an additional 208 VAC three-phase outlet for work taking place onsite. The electrical infrastructure (with a NYSCC tug connected) is shown in Figure 42. This location currently has sufficient electrical infrastructure to support an electrified vessel and would not require additional installs due to its relatively small area and sufficient electrical outlets. Figure 43 shows the area layout and its relation to the canal, Oneida Lake, and the electrical infrastructure location shown as #1.

**Figure 41: Upper Electrical Pedestal at Lock 22**

**Figure 42: Canal Infrastructure at Sylvan Beach**

**Figure 43: Sylvan Beach Electrical Infrastructure Location**

## 5.11 OTHER POTENTIAL CHARGING LOCATIONS

Tender 4 spent a considerable amount of time resting at locations other than the locks equipped with electrical infrastructure during the monitored period. These locations include docks, marinas, and other access points that NYSCC workers could use as access points to reduce travel requirements. Many of these locations may not be viable for the addition of electrical infrastructure because of their rural locations and inconsistent use. However, many of the marinas, including the Ilion Marina which saw significant use by Tender 4, have currently installed shore-side power for private boaters for overnight stays. NYSCC management decided that these charging points not be included in the electrical infrastructure inventory because they are privately-owned and some form of payment plan would be required. However, these locations could provide emergency recharging if an agreement can be reached. Other charging locations at locks that do not currently have shorepower likely could have shorepower added; however a thorough analysis of this was not done.

The tender also spent a considerable time stationary at the derrick boat (DB1) throughout the day while dredging operations were underway. The barge is outfitted with two onboard generators for operating equipment, which could provide boost or emergency recharging during the day (Figure 44). The additional electrical load on the generators requires some additional diesel fuel use and produces additional emissions so is not as cost-effective or clean an option as charging from the utility grid. Data acquisition equipment was installed on the dredge generator to monitor the energy usage to determine if/how much energy could be available for charging the vessel, if needed. The option was discussed in *Derrick Boat Real-World Data Collection* section of this report.


**Figure 44: Derrick Boat 1 Generators**

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# SECTION 6
# ELECTRIC PROPULSION SYSTEM EVALUATION

The goal of this task was to identify all of the commercially-available potential electric powertrain options and then narrow the list to determine the best option to determine the economic and environmental savings. The project scope called for “electric propulsion systems”, which implies a full-electric powertrain. The scope also discussed downsizing the diesel generator, which implies a hybrid-electric powertrain. Mr. Gritsavage (NYSCC) stated at the Project Kickoff Meeting that NYSCC wanted to maintain the base vessel’s generator power capacity (not necessarily the same engine) to ensure the boat could operate for a whole day (10 hours for the Utica Section) at full power if needed. Because of this requirement, the powertrain investigation focused only on hybrid-electric powertrains that were capable of providing full generator power continuously for long periods. Mr. Gritsavage also mentioned that the hardware for repowering a tender with a conventional diesel engine costs between $30,000 to $40,000. NYSCC understands that electric powertrain technology will have a higher initial cost. NYSCC had not determined what an acceptable payback period would be for an electric boat, but a rough estimate of between five and ten years was given. To provide a reference point, a new boat with comparable performance would cost between $150,000 to $200,000, if NYSCC was able to replace the tenders.

## 6.1 COMPONENT AND COMPLETE HYBRID-ELECTRIC POWERTRAIN OPTIONS

The investigation into potential component and system providers was started several months into the project once enough in-use data was collected to develop a reasonable picture of the tender’s typical duty cycle. An application and duty cycle summary document was developed in late July 2012 and was shared with component and system providers to aid them in developing a conceptual sub-component or complete powertrain system and cost estimate. The summary included a brief description of the current Phase I feasibility study, the planned Phase II demonstration, the major vessel relevant specifications, pictures of the boat (inside and outside), plots showing the distribution of engine load and torque, a schematic of the expected proposed system, and the information requested from the manufacturer. A copy of the application summary is located in Appendix B. The initial broad industry search included all commercially-available marine vessel battery manufacturers and electric propulsion system developers that potentially could be used for the NYSCC tender application.

### 6.1.1 Battery Options

A summary of the marine battery chemistries, manufacturers, and the pros/cons of each is summarized in Table 3:

**Table 3: Battery Options Summary**

| Battery Chemistry | Example Companies | Features | |
|---|---|---|---|
| | | Pro | Con |
| Lead-acid | Panasonic, Enersys, MasterVolt | 1) Low-initial cost and 2) established recycling infrastructure | 1) Heavy, 2) significant discharge rate effect, 3) low cycle life at deep discharges, 4) poor performance in low ambient temperature operation, and 5) high self-discharge rate |
| Nickel-metal hydride | Cobasys, Saft | 1) Energy capacity higher than lead-acid, 2) high-power density, 3) low discharge rate effect, 4) moderate cycle life at deep discharges, 5) long calendar life, and 6) established recycling infrastructure | 1) Energy capacity lower than lithium-ion, 2) cycle life lower than lithium-ion, 3) poor performance in low ambient temperature operation, and 4) moderately high self-discharge, |
| Sodium-metal halide | General Electric (Durathon) | 1) New York developed and manufactured, 2) high energy capacity, 3) low discharge rate effect, 4) high cycle life at deep discharges, 5) long calendar life, 6) high temperature battery (>200° F internal, but 10-15° above ambient) so low ambient temperature operation is not impacted, 7) zero self-discharge, and 8) established recycling infrastructure | 1) Developed for stationary power applications (telecom, grid support, backup, energy management), but not developed yet for mobile applications (battery position must be level for optimum performance) and 2) No data to prove performance claims. |
| Lithium-ion (several chemistries) | Corvus Energy, A123 Systems, Ultralife Corporation, MasterVolt | 1) High energy capacity, 2) high-power density, 3) low discharge rate effect, 4) high cycle life at deep discharges, 5) long calendar life, and 6) very low self-discharge | 1) High-initial cost (esp. for U.S. manufactured cells), 2) poor performance in low ambient temperature operation, and 3) no established reuse/recycling infrastructure |

All of the electric propulsion system manufacturers interviewed during this project stated that the low initial cost of lead-acid batteries does not overcome the battery chemistry's cycle life, calendar life, discharge rate effect, and battery mass issues. None of the electric propulsion providers recommend lead-acid as a battery solution unless the initial system cost was the driving factor.

Only two nickel metal hydride suppliers (Cobasys and Saft) were identified in the industry research. Previous NEW WEST experience with these companies has shown that significant sales volumes on the order of a major automotive manufacturer electric vehicle program are needed to gain access to these batteries. None of the electric propulsion providers provided nickel metal hydride batteries as a battery option. This was due to availability, but primarily for similar reasons presented for lead-acid. The performance (energy density, power density, cycle life, calendar life, self-discharge, etc.) and cost difference of nickel metal hydride compared to lithium-ion did not warrant selecting nickel metal hydride over lithium-ion.

The NYSCC tender application was discussed with General Electric (Schenectady, NY) for use of their high-temperature sodium halide Durathon batteries. The batteries were available at that time for telecom, grid support, backup, and energy management applications, but were not yet available for mobile applications. General Electric's primary concern was related to the battery orientation since it would be moving. Stationary power applications are installed on a rigid level base where this is not a concern. Based on the limited information available on the batteries, they have several features that would make them well-suited to the NYSCC application so warrant investigation once they are available for mobile applications. The batteries have a high specific energy (kWh/kg), but the specific power (kW/kg) is not has high as nickel metal hydride or lithium-ion. For this reason, they are not a good candidate for a power-assist type parallel hybrid-electric with a small battery pack where high power is needed from a small battery pack. The batteries are, however, well-suited to a series hybrid-electric or full-electric powertrain configuration where the battery is larger (which overcomes the lower specific power rating) and supplies the majority, or all, of the motive power. General Electric's initial motive power markets will be full-electric material handling vehicles (e.g., forklifts) and commercial trucks. General Electric claims that the high internal operating temperature (>200 °F) means that the wide temperature range experienced during the NYSCC operating season would not have any impact on the available energy or battery life. The batteries also have a claimed useful life of over 3,500 deep discharge cycles, which would equate to 19 years for the NYSCC Utica Section tender application.

The electric powertrain providers use several manufacturers and chemistries of lithium-ion batteries. As discussed earlier, the initial cost of lithium-ion batteries is higher than lead-acid and nickel metal hydride, but all of the powertrain providers recommended lithium-ion batteries over all other options because they claim the batteries have significantly better performance (energy density, power density, cycle life, calendar life, self-discharge, etc.) which results in the lowest total cost of ownership.

### 6.1.2 Hybrid-Electric System Options

After discussing the application with the battery manufacturers and several powertrain system (e.g., electric motors) providers it became clear that it was necessary that the optimized NYSCC tender powertrain system had to be developed as a system by a powertrain provider company to ensure the system was high-quality, reliable, efficient, and capable of performing its duty in the NYSCC tender. The commercially-available powertrain system options included a range of powertrain architectures and a wide range of electric motor output power from partial-power (on the order of 10 kW [13 bhp]) to full-power capability (>200 kW [268 bhp]).

The available options are summarized below in Table 4. The original intent was for the extensive list of options to be down-selected through a formal process to determine the best candidates for this application. The selection criteria were to include; commercial availability, prior deployments (number and applications), range of product offerings (kW power ratings specific to the meet the duty cycle requirements, along with slightly smaller products for the option of downsizing), and location of manufacturing (with an emphasis on those in New York state).

The original project intent was to engage with third-party marine architects/engineers or other firms to assist in designing the system and specifying the control system. The decision to focus on developed powertrains from experienced suppliers eliminated the need for the control system specification since all commercial hybrid-electric systems have a developed and integrated control system. Discussions with

## Table 4: Hybrid-Electric Powertrain System Options

| Down-selection | Company | System Name | Company Headquarters Country | Configuration | $ | Voltage | Electric Output Power (kW) Peak | Continuous | Batteries | Intended market | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Out of Production | Fischer Panda | Whisperprop | Germany | Series HEV | n/a | 240 | 50 | n/a | Various | | **Out of production, recalled because of poor performance** |
| Power Too Low | Elco Motor Yachts | EP Motor-7000 | Athens, NY | Series HEV or Full-Electric | 13,125 | 108 | **30** | n/a | PbA Li-Ion | Sail boats, catamarans | Primary market is sailboats (38'-56'). Price includes motor, display and motor controls. Batteries, charger, genset, and integration are additional costs. |
| | | EP Motor-10000 | Athens, NY | Series HEV or Full-Electric | 15,750 | 144 | **42** | n/a | PbA Li-Ion | Sail boats, catamarans | Primary market is sailboats (50'-75'). Price includes motor, display and motor controls. Batteries, charger, genset, and integration are additional costs. |
| | MasterVolt | DriveMaster 20 | Netherlands | Full-Electric | n/a | 96 | **20** | n/a | PbA Li-Ion | Sail boats, catamarans | |
| | | HybridMaster 10 | Netherlands | Parallel HEV | n/a | 48 | **10** | n/a | PbA Li-Ion | Sail boats, catamarans | 10 kW electric + up to 150 hp diesel |
| | Propulsion Marine | Electroprop 10 kW | Santa Barbara, CA | Full-electric | 15,000 | 72 | **18** | **10** | PbA | Sail boats, catamarans | |
| | | 20 kW diesel-electric hybrid | Santa Barbara, CA | Series HEV | 46,000 | 72 | **36** | **20** | PbA | Sail boats, catamarans | |
| | Nanni | Nanni Hybrid | France | Parallel HEV | n/a | 48 | **7** | n/a | Various | | Diesel engines from 20 - 350 kW. Honda IMA-like configuration. |
| | Steyr Motors | Steyr Motors Hybrid Drive System | Germany | Parallel HEV | n/a | 48 | **7** | n/a | Various | Recreational to light working boats up to displacement boats and sailboats. | |
| Too Expensive | American Traction System | AC Hybrid | Fort Myers, FL | Series HEV | **$$$** | 320-460 | Up to 300 | n/a | PbA | Ferry, tug and pleasure boats | Customer example system. DC or AC systems. Can handle any application |
| | Ecomarine Propulsion Systems Corp | PowerRing | U.S. | Series HEV | **292,000** | n/a | n/a | 130 | Li-ion | Small to huge | Hybrid system specs shown are for the Tender application. Tender application is below their smallest module size, so is expensive. ***Batteries, charger, genset, and integration are additional costs. |
| | Northern Lights/ BAE Systems | Hybrid Marine | Seattle, WA | Series HEV | **250,000** | ~650 VDC | 200 | 160 | Li-ion | Yachts or commercial boats | |
| | Siemens Marine | EcoProp | Germany | Parallel HEV or Full-Electric | **$$$** | n/a | 135-360 | | Not specified | Yachts or fishing boats | Company said our application was too small and that the system would be much too expensive. |
| Hybrid-Electric Option 1 | Regen Nautic | Series HEV | Fort Lauderdale, F | Series HEV | **155,000** | n/a | 200 | 115 | Li-ion | 40 to 90 foot hull displacement target | Recommended by Mastervolt for the NYSCC dredge tender application. ReGen Nautic uses automotive grade electric drive and control components integrated with their own control software. System specs shown are for the Tender application |

marine electrified powertrain system suppliers revealed that the companies were experienced in specifying the system with proper components, so marine architects were not necessary for this task. The expertise of marine architects will be needed for the system integration design and for acquiring the required U.S. Coast Guard certification.

The first rough cut of the down selection process was straightforward because most of the available systems fell into the following broad groups. A discussion of some systems is shown for some systems where additional detail is needed or if further discussion were held.

### Out of Production

- Fischer Panda Whisperprop – The company stated that all of the units in the field were recalled because of poor performance and sales of additional units was halted.

**Electric Power Too Low** – These systems are either intended to provide only low speed maneuvering power (approximately 7 kW) or are intended for smaller/lighter vessels that require less power than the NYSCC tender application. The continuous electric motor power for the latter subset ranges from 10 kW to 42 kW. The systems from Mastervolt (Netherlands), Propulsion Marine (Santa Barbara, CA), Nanni (France), and Steyr Motors (Germany) all had significantly too little power.

- Elco Motor Yachts (Athens, NY) – The Elco Motor Yachts system was at the lower edge of what could have been useful. Detailed discussions were held with Elco Motor Yachts because the company is located, designs, and builds their equipment in New York. The motors are designed for continuous use, so are a good fit for the tender application. The highest power capacity motor currently available is the EP Motor-7000 which is rated at approximately 35 bhp (26 kW) output power. (A more powerful EP-10000 rated at 50 bhp [37 kW] output power was close to production, but was not available when the analysis was being done.) The tender's current diesel engine output power was verified by data collected in this project to be very close to the rated 175 bhp (130 kW). This would mean that three of the EP-70000 electric motors would be needed to match the diesel engine's peak output power. Other powertrain providers (e.g., Siemens Marine) have connected multiple lower power capacity electric motors to a common driveshaft via a fixed gear reduction combiner box to give higher output capacities. Elco said that they had not done this, but agreed that it would be possible. Two of the EP-1000 motors could possibly be used. Ultimately, since the EP-7000 was the only powertrain available, the decision was made for this project that this was not an ideal approach so was not pursued further.

**Too Expensive** – These systems were very expensive ($250,000 or above), so regardless of the savings will not be able to payback the initial investment. In some cases the manufacturers provided a cost estimate, others simply said that their system was too expensive or oversized for the tender application. American Traction System (Fort Meyers, FL), and Siemens Marine (Germany) were eliminated from the analysis at an early stage because of high cost or no response from the manufacturer, so are not discussed further. Details for the system manufacturers who remained are below.

- EcoMarine Propulsion Systems Corporation – The company's electric motors are scalable and are available in power ratings from less than 1 bhp to 20,000 bhp, so the company can supply a single motor for the tender application. EcoMarine's system is designed as a series hybrid-electric, but could also be full-electric if a generator was not used. The power electronics system uses a modular approach the combines multiple 250 bhp (200 kW) modules via a backplane and rack system to meet the vessel's total power requirement. The same device can be used in many ways such as an inverter (DC – AC conversion), as a rectifier (AC to DC conversion), as a DC-to-DC converter (converts from one DC voltage up/down to another DC voltage), or for power balancing and conditioning. EcoMarine electric drive systems are typically used is for larger vessels with high power requirements. For these larger applications, the fixed costs for the rack and wiring has a smaller impact on the total system price. For a small application like the tender these costs have a bigger impact. The design also requires numerous power electronics devices and racks. The series hybrid-electric system requires four power electronics modules, four racks, and four control modules. EcoMarine developed a rough cost estimate for a system suitable for the tender application of $292,000 including batteries ($80,000) and generator ($27,000). A full-electric system eliminates the generator and one power electronic device (rectifier), one rack, and one control module. EcoMarine did not quote a full-electric system, but NEW WEST estimated it to cost over $240,000, so is still too expensive for the tender application.

- Northern Lights/BAE Systems – Northern-Lights partnered with BAE Systems' HybriDrive division (Endicott, NY), developer and manufacturer of the HybriDrive hybrid powertrain systems that are best known for their series hybrid-electric systems for transit buses. There are more than 4,000 units on the road. The HybriDrive portfolio is broader and also includes parallel hybrid-electric systems for heavy-duty commercial trucks, full-electric systems for transit buses and light rail, and stationary power. The Northern Lights Hybrid Marine system is a series hybrid electric system that uses Northern Lights Lugger diesel engines and the same BAE HybriDrive electric powertrain components and technology used in the on-road systems. The Hybrid Marine system is very capable and can be configured to meet the NYSCC tender application. Unfortunately, the system cost was estimated at $250,000 or more so was taken out of consideration.

**System Option 1** – ReGen Nautic USA (discussed below) was the only electric powertrain provider who was able to provide a system that met the power requirements at a price that was reasonable and had the potential to meet NYSCC's payback requirements.

- ReGen Nautic USA – ReGen Nautic has developed hybrid-electric and full-electric propulsion systems for various marine vessels including yachts, trawlers, and sailboats, mainly for applications over 50 feet. The company uses robustly designed automotive-grade electric drive and control components. This approach eliminates duplicated development effort/cost and also results in lower part costs since the combined component sales volumes are higher. ReGen Nautic designs and produces the unique components needed for system function, including the high-voltage boxes and the software for integration and safety systems that control the system operation. The automation control systems are customized for each vessel design to maximize efficiency. The tender hybrid powertrain system quote was $155,000, so was considerably less expensive than all of the other systems. This cost will make payback based on fuel and maintenance alone difficult, but was closer to what NYSCC could realistically consider deploying in the fleet. ReGen Nautic does not install the system; installation is the fleets' responsibility (either with full-time staff or a third-party installer). ReGen Nautic will assist with the system integration design to determine where the components will be located and how all of the wiring and cabling will be routed. All cables, wires, and components are packaged on shipping pallets along with detailed installation procedures. ReGen Nautic claims that all of the power and signal wire connections are plug-and-play and should be straightforward during installation. The fleet is also responsible for designing and fabricating the mounting racks and brackets for the batteries and for the electric motor. ReGen Nautic requires that the first installation by each fleet or installer does be inspected and verified by a ReGen Nautic engineer (for an additional $15,000) before the vessel can be commissioned. The fee includes one week of onsite support. The engineer will also make the high-voltage cable connections to ensure they are done properly. This factory-certified inspection is only needed for the first installation.

## 6.2 FULL-ELECTRIC VERSUS HYBRID-ELECTRIC POWERTRAINS

The Project Team (NEW WEST, NYSCC, NYSERDA, and NYSDOT) discussed the available hybrid-electric system options and the high cost for systems suitable for the NYSCC tender application. All of the systems, except the ReGen Nautic system, were significantly too expensive. The ReGen Nautic system is much less expensive, but is still too expensive ($155,000) for NYSCC to realistically consider for deployment once the demonstration project is completed using NYSCC funds. Because of these findings, NYSCC made the decision to change the powertrain design focus to a full-electric system instead. The change actually better fits NYSCC’s long-term goal to eliminate diesel fuel use and thus eliminate the cost and variability in cost for their fleet. Moving to a full-electric powertrain reduces the system cost because the generator and the associated mounting and other hardware are not required. Depending on the original hybrid-electric battery capacity, a larger battery pack may be needed to meet the range requirement which would increase the cost. The duty cycle analysis of the collected data and discussions with NYSCC staff showed that approximately 95% of the tender’s typical duty on the Utica Section of the Canal could be met with a full-electric system with a reasonably sized (and thus cost) battery pack. Mr. Gritsavage understands this limitation and stated that the fleet would have to be managed in a slightly different way to ensure that a diesel tender was assigned to the 5% of the duties that the electric boat cannot handle.

Moving to a full-electric system raises the concern that the boat could be left stranded if it did not make it back to dock or another charging location before the battery pack was “empty”. Mr. Gritsavage agreed this was a concern, but would have to be incorporated into how the boats’ duties were scheduled. The option of including an emergency/standby generator in the system was discussed by NYSCC and NEW WEST. This approach would provide a method to charge the battery pack if the boat did not make it back to dock or another charging location. The small emergency generator could also be used to extend the vessel’s range for the small portion of the typical duties that need a little more electric energy than the batteries can provide. The generator would be intended to be used infrequently, so would not be considered a tool for extending the vessel’s operational range. NYSCC was not interested in using an emergency/standby generator because it veers from the goal of all-electric power and also because it adds a management and maintenance requirement for the engine, fuel tank, and the fuel in the tank. Mr. Gritsavage stated that the boat would never be stranded on open waters and that the canal at its widest is only several hundred yards wide. (The electric powertrain control systems generally are configured to discharge the down to 20% state-of-charge [i.e., 20% capacity remaining in the pack] for battery life reasons. The result is the pack would have enough charge to move the boat to the side of the canal to not interfere with Canal traffic and so it could be accessed by shore if necessary.) Several options are available to remedy this issue if/when it occurs. One option is that another tender could be deployed to tow the electric tender back to dock or another charging location. This is not ideal because the rescue tender would increase its diesel fuel use for the trip to meet up with and then to tow the electric tender. Depending on the location of the rescue boat when it was deployed and the location of the electric tender large quantity of fuel could be used, effectively decreasing the electric tender’s payback. Another option would be to send a pickup truck with an emergency generator in the bed to the shoreline nearest to the tender to charge the pack enough to get the boat back to the dock. This option would also use fuel for the rescue truck, but the fuel consumption of a truck is much lower than for a boat, so would impact the fuel use and payback less.

With this revised direction, NEW WEST reconnected with ReGen Nautic to have them revise the system design and quote for a full-electric powertrain. A revised application summary was developed and share with the powertrain developers (Appendix C). NEW WEST also contacted BAE Systems' HybriDrive division (Endicott, NY) directly since earlier discussions with Northern Lights indicated that BAE Systems was interested in the project for business reasons and also because it supports New York state business. BAE Systems was interested in the project and even though HybriDrive has no commercialized full-electric system. BAE stated that the drive and control components and software is used in other applications so can be relatively easily modified for the tender application. Ultimately, BAE did not provide a cost quote and did not reply to numerous attempts to contact the to discuss the system quote. None of the other powertrain provider companies were contacted for a full-electric system quote because it was clear from the earlier discussions that the powertrain architecture change would not dramatically reduce the system prices to a point that would provide an acceptable payback for NYSCC. Only ReGen Nautic provided a quote response for the full-electric system. A system design and cost summary is provided below and in Table 5.

- ReGen Nautic USA –ReGen Nautic revised the original hybrid-electric system design to develop a full-electric system. The generator and related hardware were removed and the battery pack capacity was increased from 53 kWh to 76 kWh. The total hardware costs for this system was quoted to be $106,000. ReGen Nautic also quoted additional battery capacity moving from 76 kWh to 92 kWh for an additional $10,300 if it was needed/requested. The total cost for this system would be $116,300.

**Table 5: Full-Electric Powertrain System Options**

| Down-selection | Company | System Name | Company Headquarters Country | Configuration | $ | Voltage | Electric Output Power (kW) Peak | Electric Output Power (kW) Continuous | Batteries | Intended market | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Full-Electric Option 1 | Regen Nautic | Full-electric | Fort Lauderdale, F | Full-electric | 106,000 | n/a | 200 | 115 | Li-ion | 40 to 90 foot hull displacement target | Recommended by Mastervolt for the NYSCC dredge tender application. ReGen Nautic uses automotive grade electric drive and control components integrated with their own control software. System specs shown are for the Tender application |
| Full-Electric Option 2 | BAE Systems HybriDrive | Full-electric | Endicott, NY | Full-electric | ~100,000 | ~650 VDC | 200 | 160 | Li-ion | Yachts or commercial boats | Not a commercial system, but same as Northern Lights Hybrid w/o the diesel engine |

## 6.3 ELECTRIC POWERTRAIN INTEGRATION DESIGN AND INSTALLATION

The system integration design is handled after the system hardware requirements are determined. Neither ReGen Nautic nor BAE Systems would install the systems. Installation is the fleets' responsibility. ReGen Nautic and BAE Systems will assist with the system integration design to determine where the components will be located and how all of the wiring and cabling will be routed. All cables, wires, and components are packaged on shipping pallets along with detailed installation procedures. The fleet is also responsible for designing and fabricating the mounting racks and brackets for the batteries and for the electric motor. ReGen Nautic claims that all of the connections for their system are plug-and-play and should be straightforward. ReGen Nautic requires that the first installation each fleet or installer does be inspected and verified by a ReGen Nautic engineer (for $15,000 in addition to the powertrain system cost) before being commissioned. The fee includes one week of onsite support. The ReGen Nautic engineer will also make the high-voltage cable connections to ensure they are done properly. This factory-certified inspection is only needed for the first installation done by any new company/installer. A marine architect firm should be involved in the system design and installation to ensure the system is properly integrated and will meet all necessary operational, safety, and U.S. Coast Guard certification requirements.

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# SECTION 7
# POTENTIAL SYSTEM BENEFITS

This section discusses the process used to quantify the electric powertrain's potential system benefits such as fuel consumption, fuel cost, maintenance cost, and emissions reduction, compared to the baseline diesel vessel. A simulation model was developed that incorporated the performance of the baseline diesel and the conceptual electrically-powered vessels. The data recorded by the DAQ system onboard the vessel was post-processed to convert the various sensors' outputs (in the form of frequencies, voltage measurements, and pulse counts) to useable duty cycle data that reflected the vessel's duties and to filter out erroneous data points (e.g., torque spikes, vibrations, and signal noise). The duty cycle data parameters (shaft power, shaft torque, fuel consumption rate, and GPS data) were inputs to the model. The model architecture incorporated component (e.g., electric motor, electric motor controller, and battery pack) efficiencies. The power, torque, and shaft rotational speed duty cycle data were collected directly from the vessel's output shaft. This allowed the propulsion system to be treated as a "black box" to allow various combinations of system components to be modeled. The model initially included an onboard generator, which required runtime logic. As discussed earlier, the decision to focus on full-electric drivetrain meant that this feature was ultimately not used which also simplified the model complexity. The energy modeling method provided flexibility for evaluating propulsion system configurations. A high-level summary of the methodology is shown in Figure 45. While a large portion of the vessel's seasonal operation profile was captured with the installed onboard equipment, every day of operation was not captured because of factors outside of NEW WEST's control (e.g., early season operation before the installation of the DAQ system, vessel mechanical issues that took the boat out of service, and limited access to the vessel during busy dredging operations). To account for the days not monitored, the retrieved data was extrapolated, using weighting factors that were derived through discussions with NYSCC staff and review of the vessel's operational logs to reflect the total annual operation.

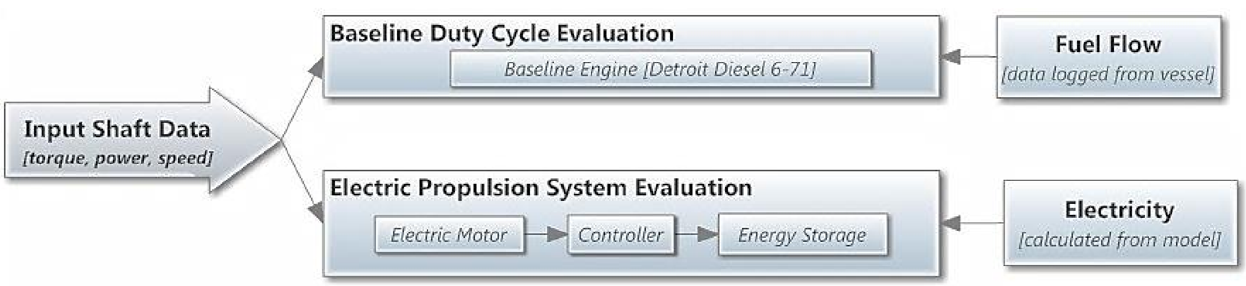



**Figure 45: Propulsion System Energy Modeling**

The instrumentation required to continually monitor vessel exhaust emissions was prohibitively costly and complex so was not included in the project scope. To accurately model the vessel's emissions, U.S. Department of Transportation, Maritime Administration emission factors from a study of similar engines in marine applications were used to develop representative emissions for all engine loads and speeds.[10] The data from these tests, when applied to the instantaneous duty cycle data recorded from the tender,

[10]Thompson, G., et al. Department of Mechanical and Aerospace Engineering, West Virginia University (2002). Evaluation of Exhaust Emissions from Elizabeth River Ferries.

provide an accurate estimation of the emission production rate. These emission rate factors were applied to the collected dataset to develop a comprehensive annual emission profile.

The amount of diesel fuel the electrically-powered vessel eliminates is directly related to the vessel's battery energy storage capacity and the amount of vessel operation time that it can offset. For modeling purposes, it was assumed that the electric vessel's daily operational profile would be modified slightly by NYSCC fleet management to maximize the electric vessel usage and capitalize on all potential charging opportunities while the vessel was not active. The analysis assumed that NYSCC will allocate a diesel-powered tender for the extremely heavy-duty operational days (roughly 5% of work days) to minimize the battery storage capacity/costs. Larger battery capacities would allow for longer operation times between charging and thereby potentially offset more diesel tender operation. However, the significant initial cost associated with increased battery capacity can easily offset the potential savings. To quantify the ideal energy storage capacity to achieve the most economical success of the system, various sized energy storage, including 52, 76, and 92 kWh capacities were evaluated and a comprehensive economic analysis completed. (The capacity values were selected based on available battery capacity levels from ReGen Nautic.) Further daily vessel operation optimization to maximize the available battery capacity per day can be accomplished by NYSCC by scheduling vessel duties that can be completed with ample charging times between. The potential benefits discussed in this section are based on the vessel operational data recorded throughout the 2012 NYSCC operating season for diesel-powered Tender 4. Overall, based on the extrapolated data, the baseline tender would have used 669 gallons of diesel fuel and produced an estimated 11.3 kg of HC, 136 kg of CO, 5,332 kg of $CO_2$, 212 kg of $NO_X$, and 3.3 kg of PM emissions throughout a full year of operation.

## 7.1 ENERGY SAVINGS

The energy savings resulting from the electrified propulsion system are in the form of decreased diesel fuel use, less the electrical energy required to recharge the batteries. The costs and environmental impacts associated with the electricity are significantly lower than the eliminated diesel fuel. The estimated overall energy offsets from a diesel tender retrofit with an electrified propulsion system are shown in Figure 46 and Table 6. This figure shows the expected diesel fuel

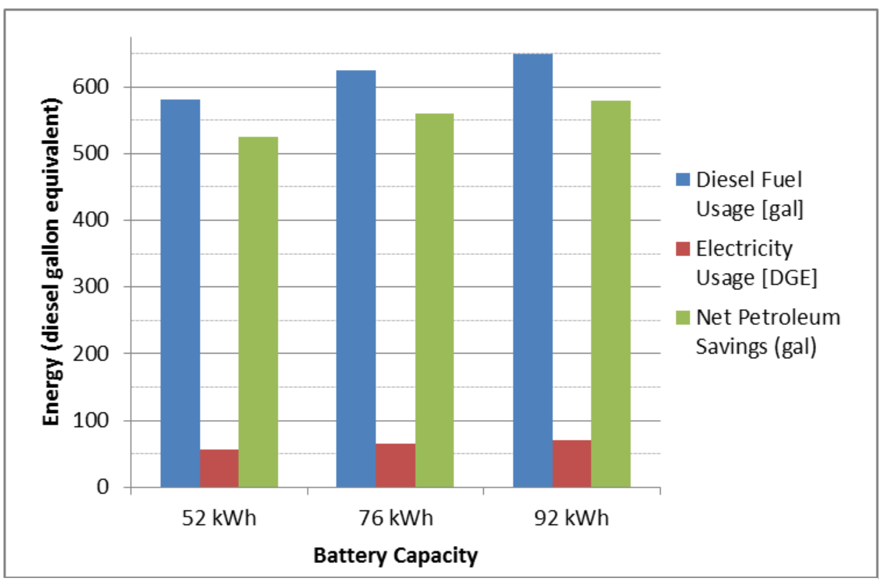



**Figure 46: Electrified Tender Energy Savings**

reductions as well as the required electrical energy (in diesel gallon equivalent [DGE] units).[11] The chart also shows that the additional fuel savings from the larger battery pack capacities (i.e., 76 and 92 kWh) are small. Given the high cost for batteries, this limits the payback potential for higher battery capacities.

**Table 6: Energy Savings Summary**

| Battery Capacity | 52 kWh | 76 kWh | 92 kWh |
|---|---|---|---|
| Fuel Offset (gal) | 582 | 625 | 650 |
| Electricity Usage (DGE) | 57 | 66 | 71 |
| Net Petroleum Savings (DGE) | 525 | 560 | 579 |
| Savings Over Base System (DGE) | n/a | 35 | 54 |
| Savings Over Base System (%) | n/a | 6.6% | 10.2% |

It may also be possible and/or necessary at times to recharge the electrically-powered tender by means of a power generator at times, either remotely (e.g., truck mounted generator) or from floating infrastructure (e.g., dredges, barges, and tugboats). In these circumstances, petroleum fuels would be consumed, but the overall efficiency of the system should remain better than the baseline vessel (dependent on generator used) due to optimized diesel engine loading.

## 7.2 EMISSIONS SAVINGS

The electrified tender's potential emission savings are directly related to the fuel offset benefits and to the clean electrical energy available in New York State. The vessel's current Detroit Diesel 6-71 diesel engine is relatively fuel efficient, however considering the engine's two-stroke design, the lack of an exhaust aftertreatment system, its age, and duty cycle, it emits a significant amount of pollutant emissions. The visible exhaust emissions of the diesel tender are clearly shown by the smoke plume (Figure 47).

**Figure 47: Visible Emissions from Diesel Tender**

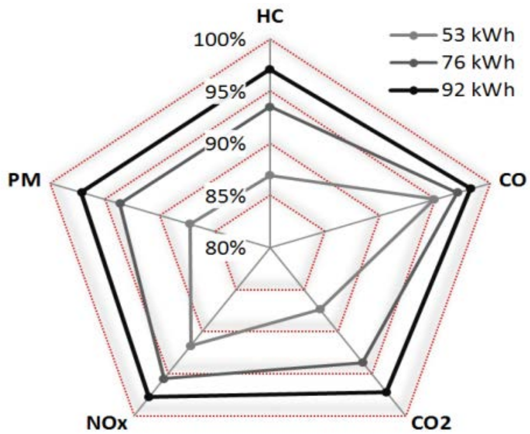
While the emissions produced are generally correlated to the amount of diesel fuel used, the specific emission rates also vary with engine load and speed. To account for all varying and transient emission factors, emission estimates were modeling using second by second data collected throughout the season and then combined to provide a yearly emission offset that could be realized from the electrified vessel. The annual potential emission savings (shown in mass and percent savings) compared to the baseline diesel vessel are shown in Figure 48.

## 7.3 COST SAVINGS

Annual operating cost savings during the operation of the electrified tender would be realized from reductions in both energy costs and vessel maintenance. Electric powertrains only have a few moving parts and are typically very reliable and require little maintenance. Battery packs require little or no

[11] Diesel gallon equivalents calculated with information taken from http://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf

maintenance, but will require replacement(s) during the vessel lifetime which adds cost. The modeling showed that approximately $140 of grid-supplied electricity is able to eliminate over $2,000 of diesel fuel costs per year (at current rates). NYSCC provided diesel fuel cost ($4.00/gal) and electricity cost ($0.06/kWh) data for current costs. Future fuel and electricity cost variations were accounted for by using future fuel cost data taken from the U.S. Energy Information Administration's Annual Energy Outlook to calculate energy cost variability as accurately as possible. Significant yearly cost savings would also be potentially seen from the reduction in vessel maintenance pertaining to its current




| | Battery Capacity | | |
|---|---|---|---|
| | 52 kWh | 76 kWh | 92 kWh |
| ***HC Emissions [kg]*** | 9.8 | 10.5 | 10.9 |
| ***CO Emissions [kg]*** | 129 | 132 | 134 |
| ***$CO_2$ Emissions [kg]*** | 4,658 | 4,994 | 5,180 |
| ***NOx Emissions [kg]*** | 194 | 202 | 207 |
| ***PM Emissions [kg]*** | 2.9 | 3.1 | 3.2 |

**Figure 48: Potential Electrified Vessel Emission Savings**

diesel engine including engine fluids, filters, labor, and misc. components. NYSCC Utica Floating Plant Maintenance staff estimated that each tender requires approximately $2,000 worth of engine maintenance each year (including parts and labor). Table 7 provides a summary of the initial system cost and the estimated annual savings for each battery capacity variant. The higher battery capacity variants are estimated to only save a small amount of fuel and cost above the base (52 kWh) system assuming the electric tender will be used for the light- and medium-duty uses (roughly 95% of tender duties). The higher capacity systems will be able to operate for longer periods to handle some of the heavier duty demands on tenders; however will only incrementally improve the tender's utility to NYSCC.

**Table 7: Summary of System Variant Performance**

| | | | |
|---|---|---|---|
| Battery Pack Capacity (kWh) | 52 kWh | 76 kWh | 92 kWh |
| Incremental System Cost | $50,425 | $64,225 | $73,825 |
| Fuel Offset [gal] | 582 | 625 | 650 |
| Diesel Fuel Cost ($) (@ $4/ gallon) | $2,328 | $2,500 | $2,600 |
| Electrical Energy Use [kWh] | 2,278 | 2,639 | 2,849 |
| Electrical Energy Use [DGE*] | 57 | 66 | 71 |
| Electricity Cost ($) (@ $0.06/ kWh) | $137 | $158 | $171 |
| Annual Energy Savings | $2,191 | $2,342 | $2,429 |
| Maintenance Savings | $2,000 | $2,000 | $2,000 |
| Total Annual Savings | $4,191 | $4,342 | $4,429 |
| Savings Over Base System | n/a | $150 | $238 |

The overall cumulative yearly value of retrofitting a canal vessel with an electrified propulsion system, including systems with 52 kWh, 76 kWh, and 92 kWh battery packs, is shown in Figure 49. This graphic accounts for initial incremental cost of the system and all yearly expenditures and savings. A $2,000 annual maintenance savings (parts and labor) is assumed for the electric system compared to the diesel system. Overall, the system is predicted to provide a payback of the initial investment in 12 years (52 kWh), 14 years (76 kWh), and 16 years (92 kWh). NYSCC repowers tender infrequently. NYSCC currently has tenders with engines that are 30-42 years (1980s-1971) old. Assuming a 35 year useful life between engine repowers, the different system levels will save NYSCC $114,000, $107,000, and $100,000 respectively. These calculations, however, assume the battery pack is not replaced, so are not realistic projections.

Battery replacement is a significant factor that must be included. This is especially true for Li-ion batteries which are currently very expensive. The ReGen Nautic supplied battery pack replacement costs (in 2012) for the different capacity levels are $30,000, $43,200, and $53,600 respectively.[12] The cost of

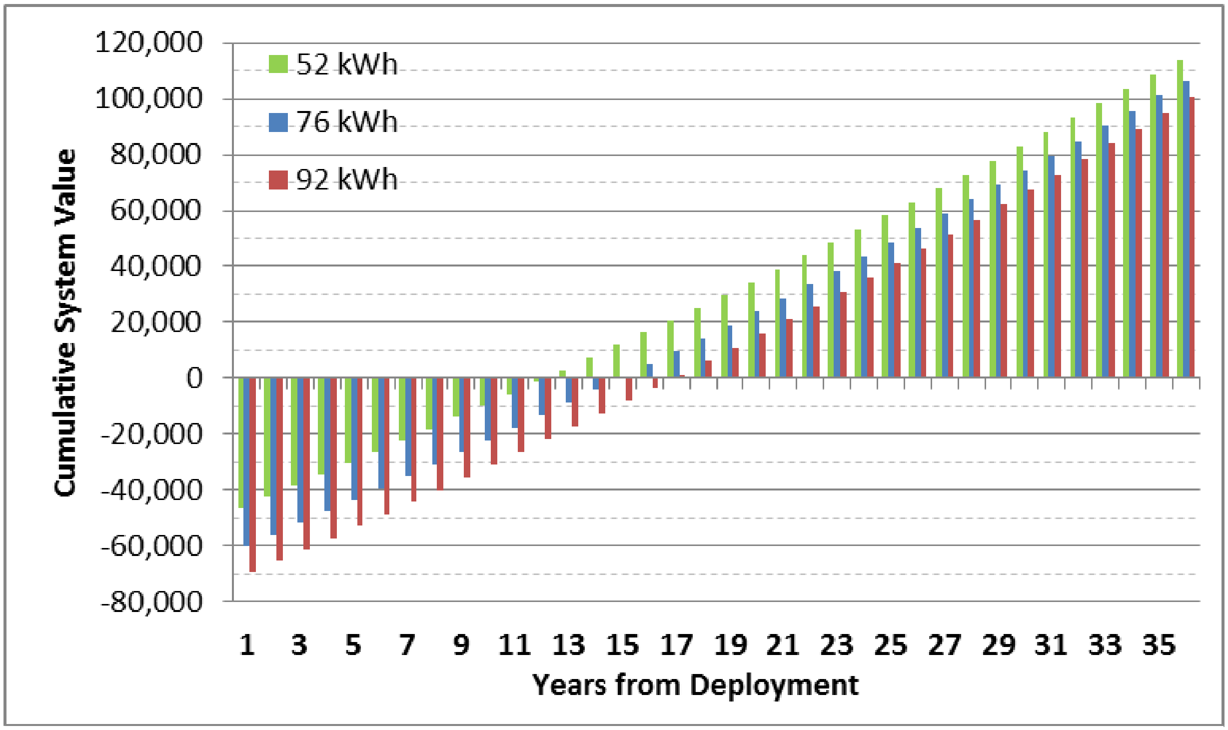



**Figure 49: Yearly Electrified Propulsion System Net Value to Canal (no battery replacement)**

Li-ion batteries (or a suitable replacement) are expected to be much lower when the pack needs to be replaced given the R&D emphasis supporting the plug-in electric vehicle and renewable power industries. A price decrease estimate over time was developed since Li-ion batteries are a relatively new technology and are expected to significantly decrease over time. The estimate assumed a 25% price drop in 15 years, a 40% price drop from original price in 30 years, and a 50% price drop from the original price in 45 years. An exponential curve fit expression was used to interpolate between years.

[12] Costs using ReGen Nautic USA battery pack quote

The U.S. Advanced Battery Consortium set a goal for electric (onroad) vehicle battery useful life at 10 years.[13] The electric tender application has a different operating profile (seven months per year, 4 days per week; 126 days) than an onroad electric vehicle with relatively consistent seven-day per week, 12-month usage (roughly 365 days per year use). This different usage pattern is expected to extend the battery life, but it is still expected to have to be replaced. Two different battery replacement scenarios were developed for 15-year and 10-year battery pack replacements for more realistic payback estimates.

The overall cumulative yearly value for the retrofitted canal vessel with an electrified propulsion system, including systems with 52 kWh, 76 kWh, and 92 kWh battery packs, with a 15-year payback is shown in Figure 50. As with the previous case, the system is predicted to provide a payback of the initial investment in 12 years (52 kWh), 14 years (76 kWh), and 16 years (92 kWh).
After accounting for the battery replacements, the vessel reaches a net positive savings in Year 17 (52

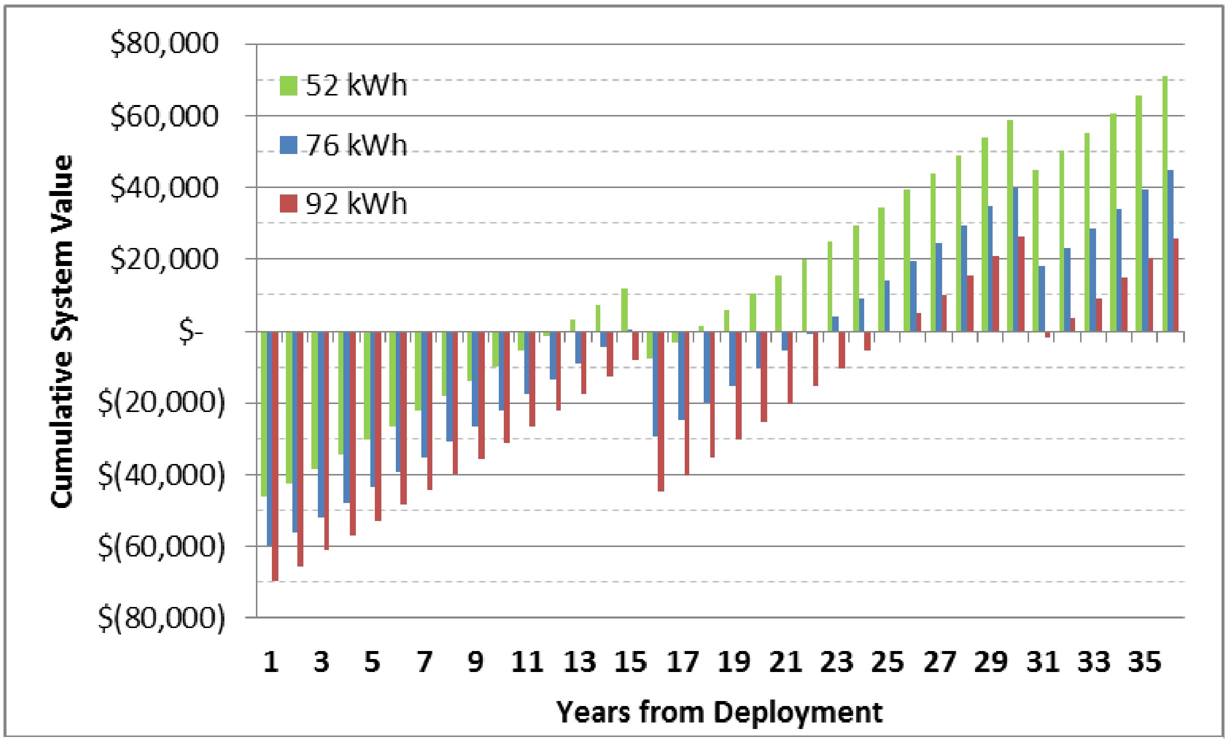



**Figure 50: Cumulative Yearly Electrified Propulsion System Net Value to Canal (15-Year Battery Replacement)**

kWh), Year 22 (76 kWh), and Year 25 (92 kWh) respectively. Over the 35 year useful life between diesel engine repowers of the current baseline boat, the different system levels will save NYSCC $71,000, $45,000, and $26,000 respectively.

The overall cumulative yearly value for the retrofitted canal vessel with an electrified propulsion system, including systems with 52 kWh, 76 kWh, and 92 kWh battery packs, with a 10-year payback is shown in Figure 51. As with the previous case, the system is predicted to provide a payback of the initial

[13] United States Advanced Battery Consortium, LLC, Goals for Advanced Batteries for EVs, http://www.uscar.org/commands/files_download.php?files_id=27, accessed May 30, 2013.

investment in 12 years for 53 kWh, 14 years for 76 kWh, and 16 years for 92 kWh. After accounting for the battery replacements, the vessel reaches a net positive savings in Year 23 (52 kWh), Year 32 (76 kWh), and roughly reaches breakeven (92 kWh) over the engine useful life respectively. Over the 35 year useful life between engine repowers, the different system levels will save NYSCC $45,000, $17,000, and roughly breakeven respectively. The payback and savings are summarized below in Table 8.

**Table 8: Summary of Payback and Savings**

| Battery Pack Capacity (kWh) | 52 kWh | | | 76 kWh | | | 92 kWh | | |
|---|---|---|---|---|---|---|---|---|---|
| Battery Pack replacement Interval | None | 15 year | 10 year | None | 15 year | 10 year | None | 15 year | 10 year |
| Initial Capital Cost Payback (years) | 12 | 12 | 12 | 14 | 14 | 14 | 16 | 16 | 16 |
| Years to Net Positive Cash Flow | 12 | 17 | 23 | 14 | 22 | 32 | 16 | 25 | n/a |
| Total Savings over Diesel Engine Useful Life | $114,000 | $71,000 | $45,000 | $107,000 | $45,000 | $17,000 | $100,000 | $26,000 | $- |

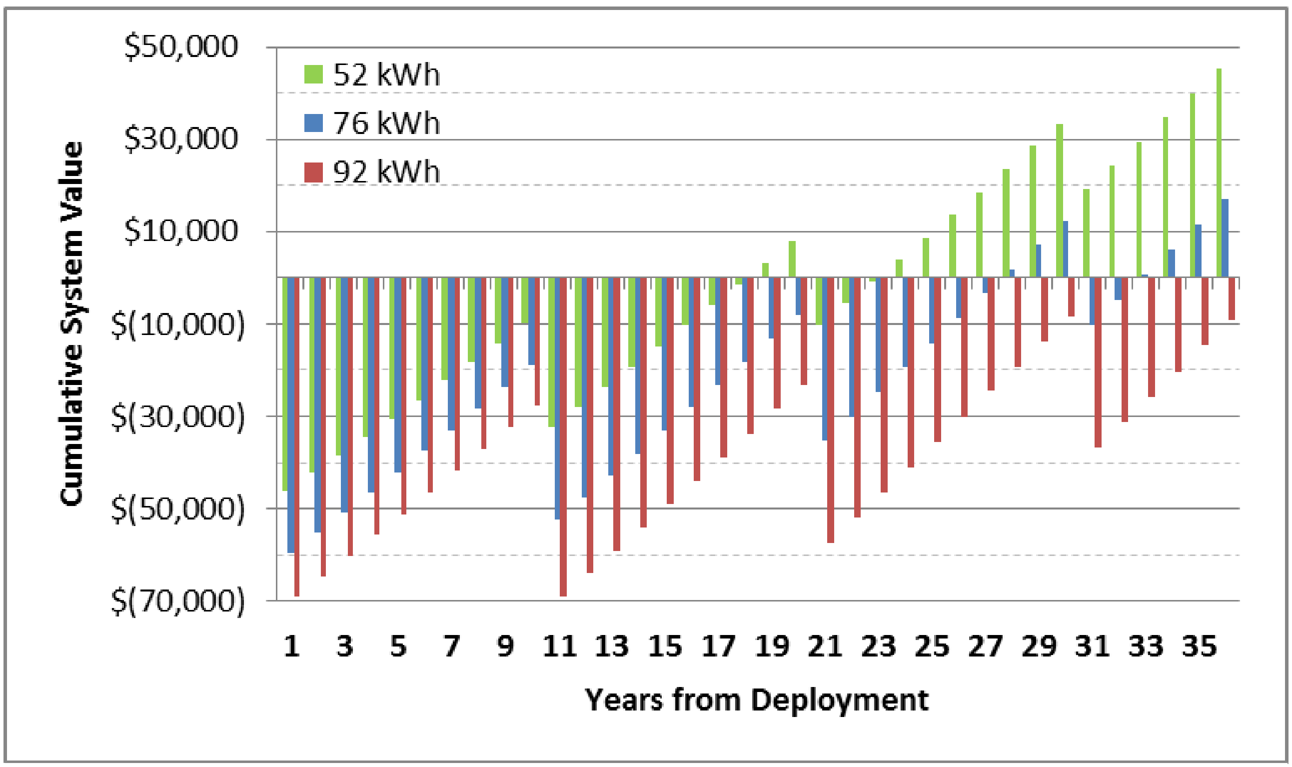



**Figure 51: Yearly Electrified Propulsion System Net Value to Canal (10-year battery replacement)**

## 7.4 OTHER BENEFITS

The economic and energy security benefits of utilizing electricity for propulsion purposes are generally the driving factor behind electrification of any form of transportation; however, other benefits exist which must be taken into account when analyzing any potential application. The electrically-powered tender application has several benefits compared to the current diesel tender that affect canal workers and residents along the canal. The benefits include: reducing the Canal's environmental impact, significantly reducing vessel noise levels (onboard and onshore), improving the Canal's public image, and promoting tourism along the Canal system.

### 7.4.1 Environment and Emissions

There are also other environmental benefits from replacing diesel-powered tenders with electrically-powered vessels. One potential benefits is eliminating diesel fuel spill risks and cleanup costs. While the environmental impact of a fuel or oil spillage/leakage from a single tender is relatively localized and low-volume, they damage the surrounding environment. The crew working onboard the vessel also benefits because they will work in a much cleaner environment and will not be exposed to exhaust fumes and pollutants like in the current diesel propulsion system.

### 7.4.2 Noise

The significantly reduced noise level of an electrically-powered tender does not provide a direct quantifiable economic saving but will be beneficial for NYSCC tender operators and for individuals living, working, or vacationing near the Canal. The tender's Detroit Diesel 6-71 is known for being an extremely loud diesel engine. Sound measurements were recorded for Tender 4 during normal operation on the vessel and along the shore to quantify the current level of noise experienced by the tender's crew and for individuals along the canal. Sound intensity levels onboard the tender under low power cruising conditions is approximately 100.6 dBA inside the vessel's pilothouse and 108.6 dBA on the deck (where a crew member are often positioned while towing equipment). Sound measurements on shore when the tender was cruising were approximately 77.4 dBA. For comparison purposes, the U.S. Department of Labor, Occupational Safety & Health Administration advises no more than an 8-hour exposure to sounds greater than 90 dBA, no more than a 2-hour exposure to sounds above 100 dBA, and no more than a 30 minutes exposure to sounds above 110 dBA noises each day. A figure showing comparisons to well-known sounds are shown in Figure 52 to give the reader a frame of reference for understanding the sound level measurements.[14]

[14] Graphic taken from http://www.soundadvice.info/thewholestory/san1.htm

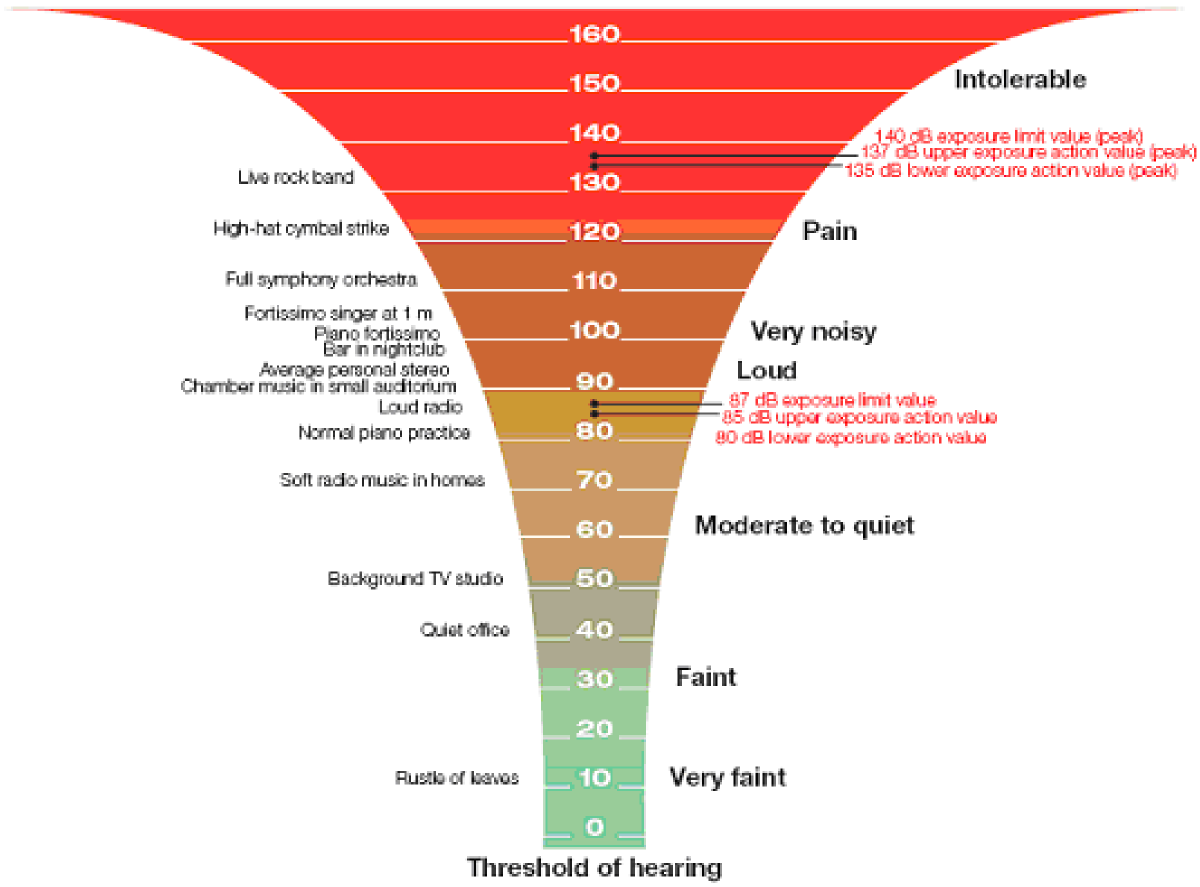



**Figure 52: Common Sounds Noise Levels**

### 7.4.3 Public Image

Adopting electrified propulsion technologies for the vessel fleet will improve NYSCC's public image and bolster the NYSCC Environmental Stewardship Program[15] which currently includes many dredging and Canal practices that minimize damage to the surrounding environment. While many of the issues associated with NYSCC's environmental stewardship activities are targeted toward marine habitats and species preservation, the adoption of this technology will extended their environmental efforts by reducing criteria and GHG emissions.

NYSCC could also use the electrically-powered tender as a flagship demonstration vessel and outreach instrument during press and public events and as an educational tool to promote environmentally sound technology. Events involving NYSCC, including boat parades and other community gatherings would provide an ideal showcase for this technology. Further developments along the Canal, such as the Utica

[15] New York State Canal Corporation Webpage on environmental Stewardship, http://www.canals.ny.gov/community/environmental/, accessed March, 25, 2013.

Harbor development project[16], could also provide a public site for the public to see and interact with this new green technology.

## 7.5 POTENTIAL CHALLENGES

### 7.5.1 Daily Operation

One of the challenges to the economic payback of electrified propulsion system for NYSCC's vessels is the tender's limited daily operating time. The typical daily run time for the current tender is less than two hours a day, which limits the fuel reduction potential offset. (As mentioned earlier, this includes 95% of typical daily operation, but does not include heavy-duty operations and extended towing requirements.) To maximize the annual fuel savings and improve the payback, the electrically-powered tender should be operated as much as possible. This will require a NYSCC Operations to ensure the vessel is deployed every work day for a job it is capable of completing. This will require NYSCC Operations Managers to work with vessel operators to promote understanding and interest in the system and its benefits throughout the vessel crew. This could also mean that the electric tender is deployed to locations where it could charge from shorepower or from mobile equipment generators to increase the daily range. Preliminary interest from the dredging crews, gauged by NEW WEST through informal discussions when onsite and gathering operational information, is extremely high and all parties were motived to utilize this technology. This interest, along with the significantly more favorable operational characteristics (e.g., significantly reduced powertrain noise, vibration, fumes) should prove very successful for the deployment and usage of this technology.

### 7.5.2 Seasonal Operation

The tender's annual operating time is further restricted because of NYSCC's limited operating season for Canal maintenance and dredging activities. The season is limited because of icing on the Canal, so most NYSCC vessels are removed from the water between early-November and mid-April (depending on weather). This results in the vessels only operating six to seven months out of the year which slows the economic payback.

[16] Additional information on the Utica Harbor Development Project can be found at http://www.cityofutica.com/pdf/Utica%20LWAP%20Final%20Report%20December%202011%20with%20maps.pdf

# SECTION 8 RECOMMENDED VESSEL SPECIFICATION

## 8.1 RECOMMENDED PERFORMANCE SPECIFICATIONS

Based on the analysis of the collected duty cycle data, even the lowest battery capacity variant (52 kWh) full-electric system is capable of handling roughly 95% of the tender's typical duties. As expected, the analysis presented above in Section 7showed that this system variant also is the most cost-effective. Since the data collection was limited due to the various issues discussed in Section 3, to ensure that the demonstration boat is not battery capacity limited, it is recommended to move up to the next capacity system (76 kWh). The 76 kWh system is still cost-effective and reaches a net positive value within the vessel's engine repower timeframe. This will increase the demonstration system cost by roughly $14,000. The goal will be to validate that the lower capacity (52 kWh) system would have been sufficient to support the most cost-effective system for future NYSCC deployments.

## 8.2 PHASE II TEAMING RECOMMENDATIONS

NYSCC, NEW WEST, and ReGen Nautic USA developed a NYSERDA PON 2618 (Integrating Mobility Strategies for a Sustainable Multi-Modal Transportation Network) proposal the next step including installing a full-electric powertrain on a NYSCC tender and performing a long-term field performance assessment to validate the system's performance. Proposal discussions were started in August 2012 and the proposal was submitted on October 10, 2012. Only preliminary duty cycle data were available at that time and showed higher daily energy requirements than the final recommendations discussed above that were completed in early 2013. Because of this limited data and uncertainty in the comprehensive accuracy of the collected data, the highest battery capacity pack (92 kWh) was selected to ensure the system had enough battery capacity to meet the tender's duty cycle during the demonstration project. This 92 kWh battery system was roughly $9,600 and $23,400 more than the 76 kWh and 52 kWh variants. One project goal will be to determine the lowest capacity that would be needed to meet NYSCC's duty cycle and to maximize the system's cost-effectiveness for future NYSCC deployments.

NEW WEST was notified on January 30, 2013 that the Phase II project proposal was successful. The project will install a full-electric powertrain on a NYSCC tender and will perform a long-term field performance assessment to validate the system's performance. The electrically-powered vessel's performance, energy consumption, operating costs, and emissions will be determined and compared to the baseline diesel system. The project outcomes will include: 1) an assessment of how well electrically-powered boats, in general, meet NYSCC's performance requirements, 2) how well the particular electric powertrain used in the demonstration performed, and 3) to develop the necessary cost and savings data NYSCC needs to determine the future deployment potential/plan for electrically-powered boats in their fleet. The project is expected to be completed in early 2014.

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# APPENDIX A – LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| bhp | Brake horsepower |
| BSFC | Brake specific fuel consumption |
| Canal | New York State Canal System |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| DAQ | Data acquisition system |
| DFM | Differential fuel flow meter |
| GHG | Greenhouse gas emissions |
| GPS | Global positioning system |
| HC | Hydrocarbon |
| Hz | Hertz, a measurement of frequency per second |
| mph | Miles per hour |
| NEW WEST | New West Technologies, LLC |
| $NO_x$ | Nitrogen oxides |
| NYSERDA | New York State Energy Research and Development Authority |
| NYSCC | New York State Canal Corporation |
| PM | Particulate matter |
| rpm | Revolutions per minute |
| Tender | NYSCC dredge tender vessel |
| VAC | Volts Alternating Current |
| VDC | Volts Direct Current |

# APPENDIX B – HYBRID-ELECTRIC NYSCC TENDER APLICATION SUMMARY

New West Technologies, LLC
Engineering | Technical Services | Management Consulting ■ www.nwttech.com

# New York State Canal Corporation
# Canal Electrification Project

**Contact Information:**

**New West Technologies, LLC**
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**Paul Windover**
Project Engineer
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pwindover@nwttech.com

**Kenneth Rocker**
Project Engineer
(240) 696-6574
krocker@nwttech.com

**Project Summary**

Funded by the New York State Energy Research and Development Authority (NYSERDA) in this Phase I feasibility study, New West is collecting and analyzing operational data from NYS Canal Corporation vessels to determine the potential energy, environmental, and economic gains from installing electric propulsion systems. New West is also performing an evaluation of commercially available systems that meet the required demand of the Canal fleet. Over the next decade, it is highly likely that the Canal Corporation will need to replace many of the vessel engines that are reaching their end of life, while the vessels themselves will likely be around for another half century, the Canal Corporation operates over 70 work vessels on the canal system. The results of this Phase I project will provide the Canal Corporation a decision basis for repowering their vessels with electric propulsions systems that include onboard energy storage and grid recharging capability.

A second project phase is envisioned that would involve the actual repower of a Canal Vessel to electric propulsion with onboard energy storage to demonstrate its performance and benefits. Currently only Phase I is funded, results from Phase I, including system component recommendations, would be used to develop a proposal for Phase II funding. Phase II would also see the introduction of a marine architect to oversee vessel design and construction.

**<u>Details of Target Application</u>**

**Type:** Dredge Tender
**Operation:** Used as a canal work boat to support dredging operations. The tender transports workers and materials from the shore to dredge. It also moves scows, barges, work platforms and occasionally the dredging platform when larger tug is unavailable.

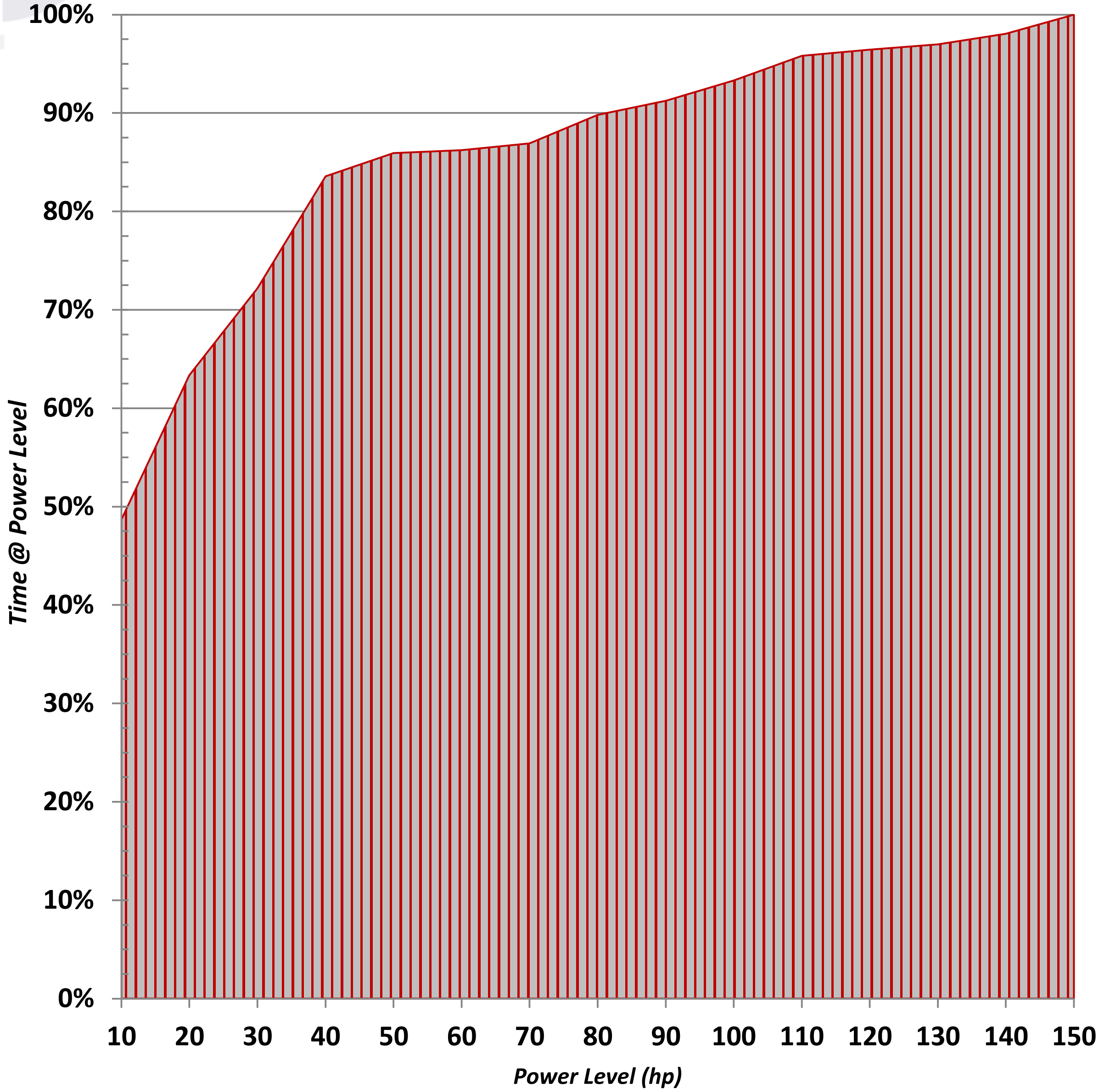
**Overall Length:** 40ft
**Waterline Length:** Unknown
**Beam:** 10ft
**Draft:** 3.5 to 5.8
**Current main engine:** Detroit Diesel 6-71 (N55 Injectors) 175hp
**Fuel Capacity:** 150
**Gearbox:** 2:1 single speed with reverse
**Aux Generator:** None
**Propulsion Type:** Single screw

1 Tender #7


2 Engine room looking up to pilot house

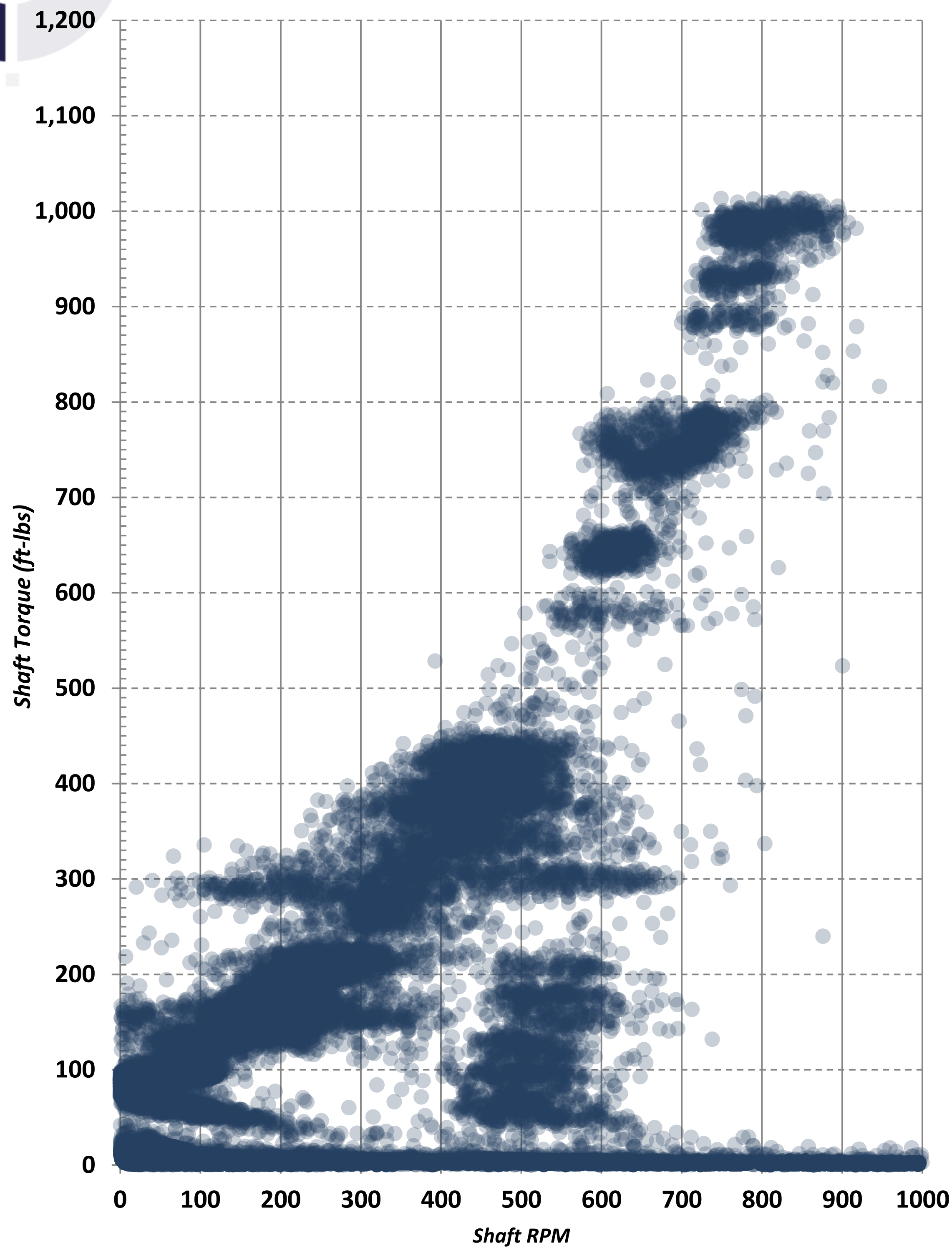

3 Engine room looking aft

**Duty Cycle Percent of Time at (or under) Rated Power Level**




Measured data from on-board data acquisition. Measurement taken post gear box. Represents 5 weeks of continuous monitoring.

Output Shaft Torque vs. Output Shaft RPM (effective propeller torque curve)

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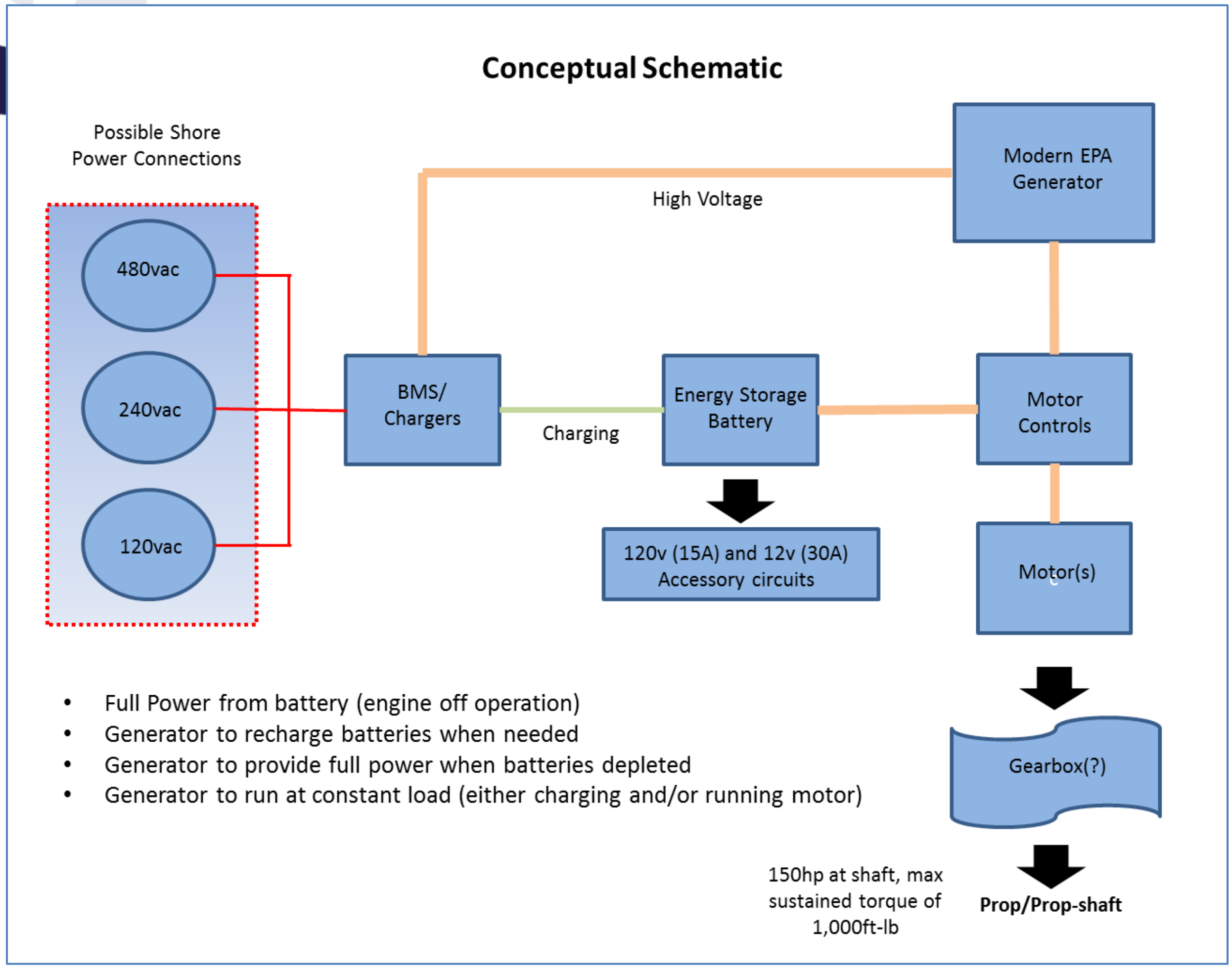


**<u>Information Requested of System Manufacturer</u>**

1. Description and Specifications of Proposed System, potentially including, but not limited to:
    a. Component Efficiency Maps
    b. Power Levels
    c. Charge Rates
2. Diagram/Schematic of Proposed System (above schematic is a rough concept, not final)
3. Identification of in-house components versus sourced components
4. Itemized cost estimation of major components to include
    a. Motor
    b. Energy Storage
    c. Generator
    d. Power Electronics
    e. Control system and HMI
    f. Utility grid interface (charger and battery management system)
5. Identification of options and scalability.
6. Identification of components manufactured in New York State or component manufacturers headquartered in New York State.

# APPENDIX C – FULL-ELECTRIC NYSCC TENDER APLICATION SUMMARY

New West Technologies, LLC
Engineering | Technical Services | Management Consulting ■ www.nwttech.com

# New York State Canal Corporation
# Canal Electrification Project

**Contact Information:**

**New West Technologies, LLC**
4947 Commercial Drive
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(315) 272 – 4574
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**Russ Owens**
Project Manager
(240) 696-6571
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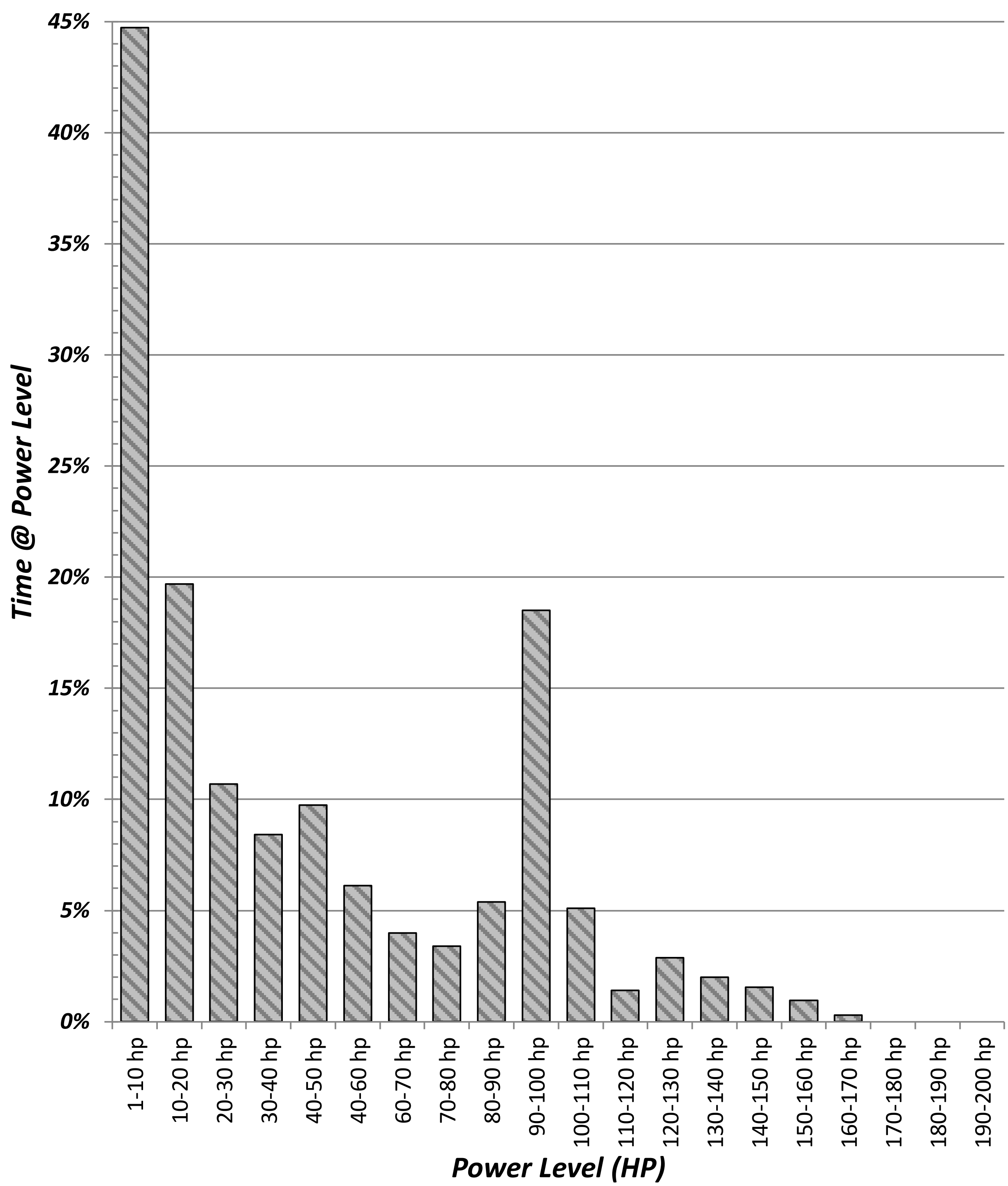
**1 Tender #7**


**2 Engine room looking up to pilot house**


**3 Engine room looking aft**

**Duty Cycle Percent of Time at (or under) Rated Power Level**

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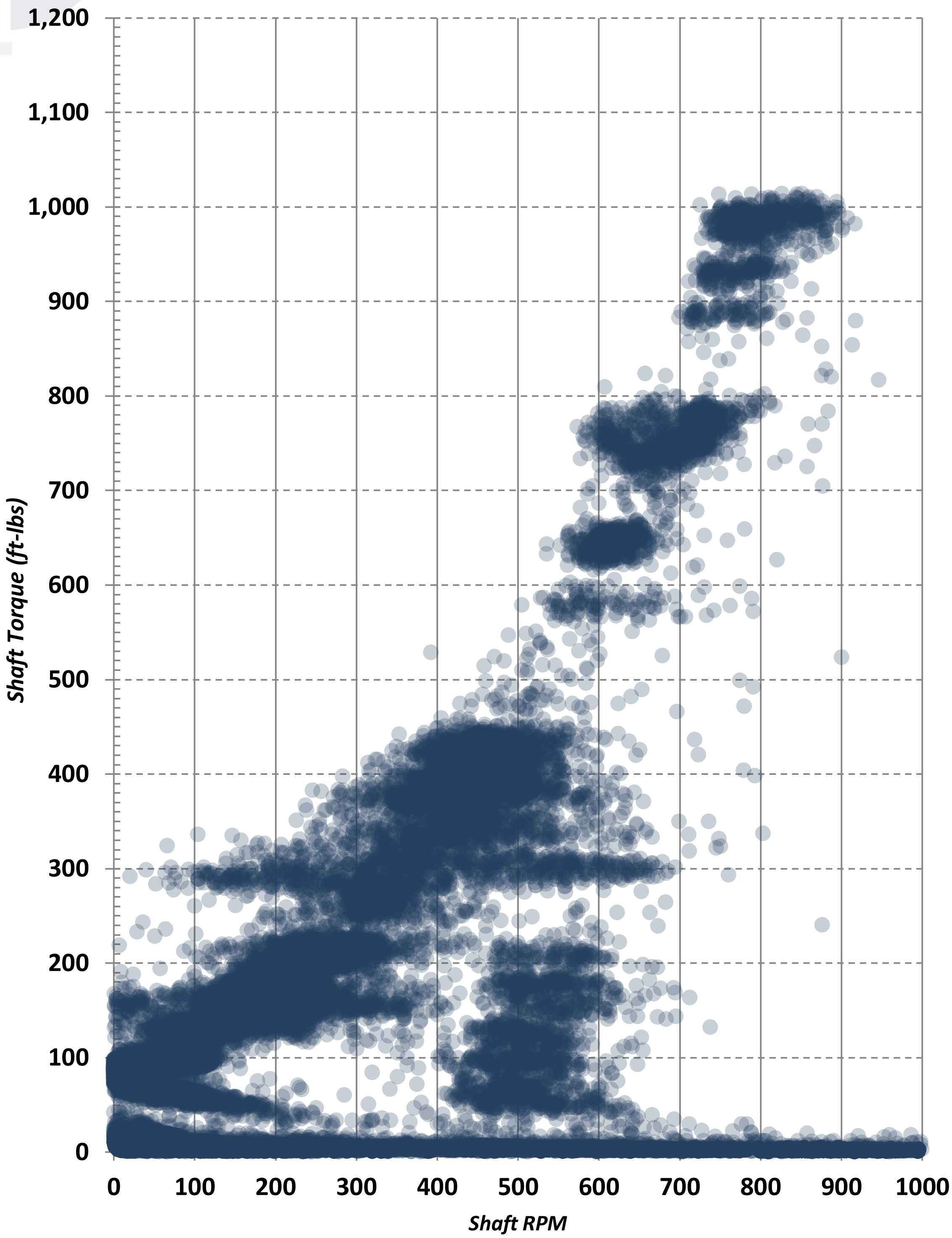
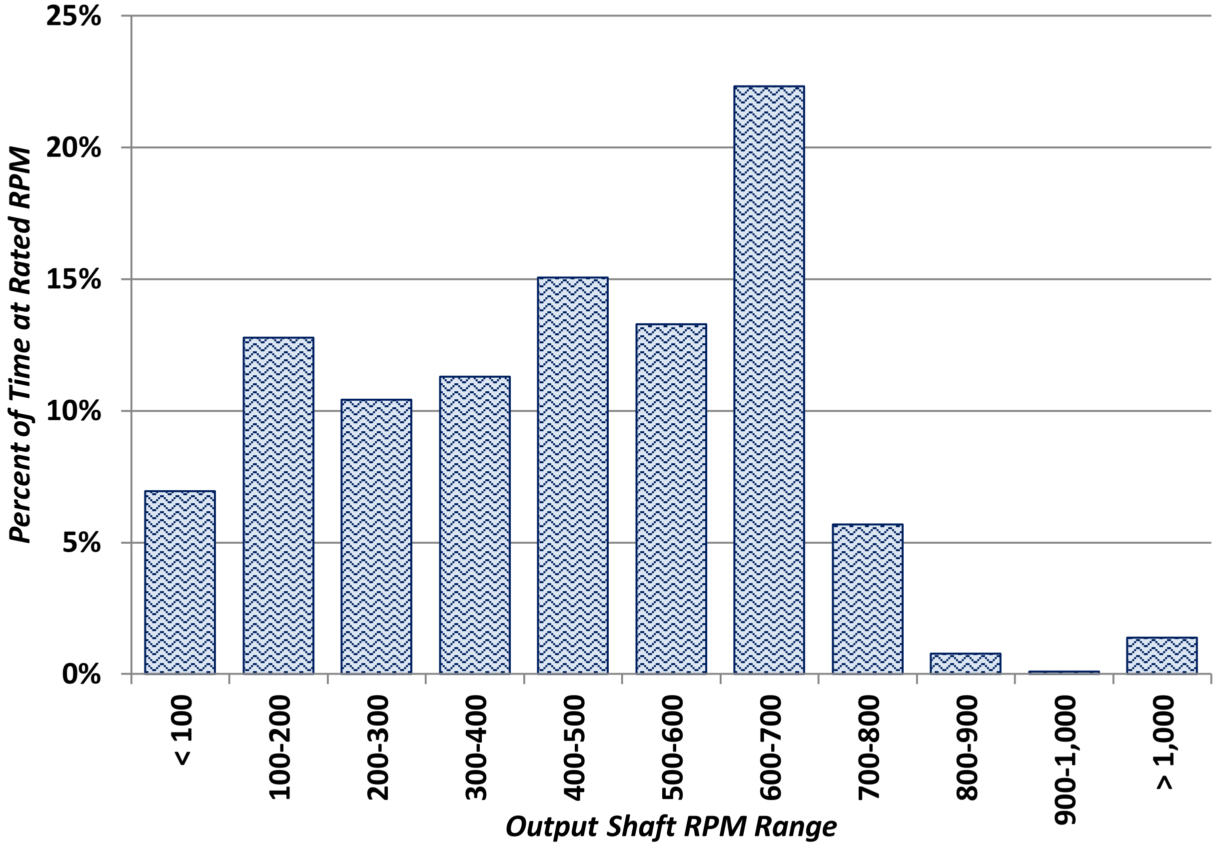



Measured data from on-board data acquisition. Measurement taken post gear box. Represents 5 weeks of continuous monitoring.

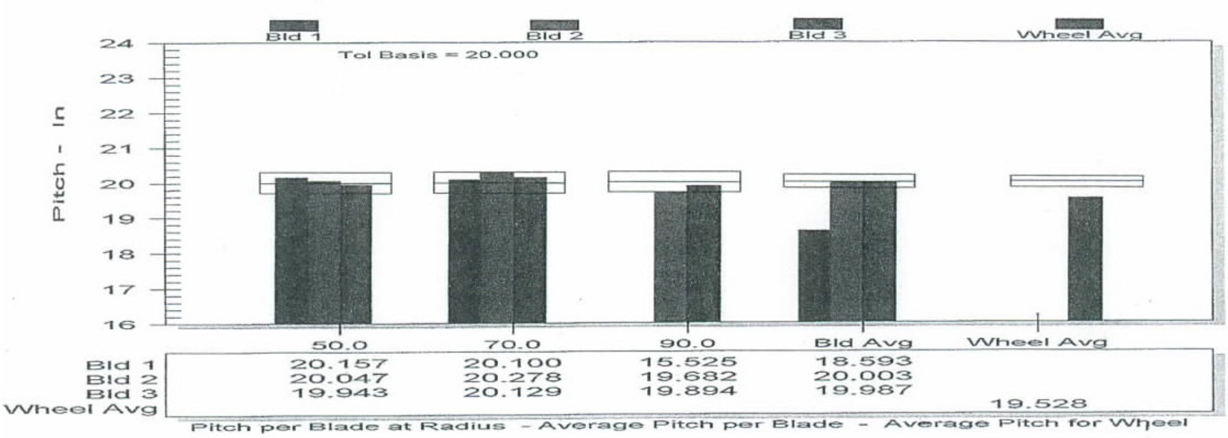
**Output Shaft RPM Range**

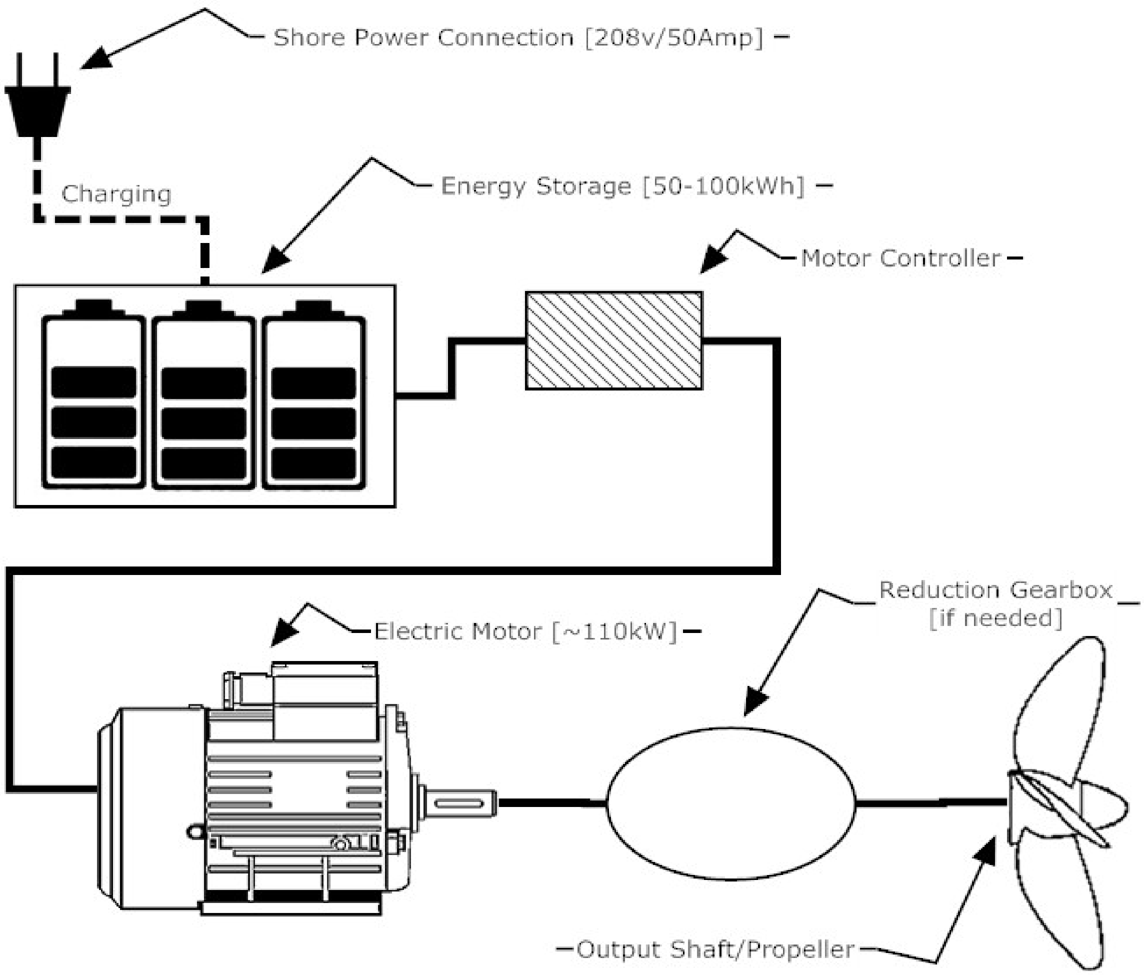



**Propeller Specifications**

Michigan 30 RH 20 MP 4/3/2012

| | | | | | |
|---|---|---|---|---|---|
| Customer | Tender # 4 | Rotation | RH | | |
| Part Number | S782 | Cupping | 0 - .000 | Repair Status | Initial |
| Material | Bronze | Marked Diameter | 30 | Pitch of Wheel | 19.528 |
| Class | I | Marked Pitch | 20 | | |



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